INTERNATIONAL ENERGY AGENCY
Energy conservation in buildings and community systems programme

25th AIVC Conference

Ventilation and Retrofitting

Proceedings

Air Infiltration and Ventilation Centre
Operating Agent and Management
INIVE EEIG
Boulevard Poincaré 79
B-1060 Brussels

INTERNATIONAL ENERGY AGENCY
Energy conservation in buildings and community systems programme

25th AIVC Conference

Ventilation and Retrofitting

Proceedings

This report is part of the work of the IEA Energy Conservation in Buildings & Community Systems Programme – Annex V Air Infiltration and Ventilation Centre

Publication prepared by
Annex V Air Infiltration and Ventilation Centre

Document AIC-PROC-25-2004

ISBN 2-9600355-6-9

Annex V Participating countries:
Belgium, Czech Republic, France, Greece, The Netherlands, Norway and the United States of America.

Preface

International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster co-operation among the twenty-four IEA Participating Countries to increase energy security through energy conservation, development of alternative energy sources and energy research development and demonstration (RD&D).

Energy Conservation in Buildings and Community Systems

The IEA sponsors research and development in a number of areas related to energy. In one of these areas, energy conservation in buildings, the IEA is sponsoring various exercises to predict more accurately the energy use in buildings, including comparison of existing computer programs, building monitoring, comparison of calculation methods as well as air quality and studies of occupancy.

The Executive Committee

Overall control of the programme is maintained by an Executive Committee, which not only monitors existing projects but also identifies new areas where collaborative effort may be beneficial.

To date the following have been initiated by the Executive Committee (completed projects are identified by *):

I	Load Energy Determination of Buildings *
II	Ekistics and Advanced Community Energy Systems *
III	Energy Conservation in Residential Buildings *
IV	Glasgow Commercial Building Monitoring *
V	Air Infiltration and Ventilation Centre
VI	Energy Systems and Design of Communities *
VII	Local Government Energy Planning *
VIII	Inhabitant Behaviour with Regard to Ventilation *
IX	Minimum Ventilation Rates *
X	Building HVAC Systems Simulation *
XI	Energy Auditing *
XII	Windows and Fenestration *
XIII	Energy Management in Hospitals*
XIV	Condensation *
XV	Energy Efficiency in Schools *
XVI	BEMS – 1: Energy Management Procedures *
XVII	BEMS – 2: Evaluation and Emulation Techniques *
XVIII	Demand Controlled Ventilation Systems *
XIX	Low Slope Roof Systems *
XX	Air Flow Patterns within Buildings *
XXI	Thermal Modelling *
XXII	Energy Efficient communities *
XXIII	Multizone Air Flow Modelling (COMIS)*
XXIV	Heat Air and Moisture Transfer in Envelopes *
XXV	Real Time HEVAC Simulation *
XXVI	Energy Efficient Ventilation of Large Enclosures *
XXVII	Evaluation and Demonstration of Residential Ventilation Systems *

XXVIII Low Energy Cooling Systems *
XXIX Daylight in Buildings *
XXX Bringing Simulation to Application *
XXXI Energy Related Environmental Impact of Buildings *
XXXII Integral Building Envelope Performance Assessment *
XXXIII Advanced Local Energy Planning *
XXXIV Computer-aided Evaluation of HVAC Systems Performance *
XXXV Design of Energy Hybrid Ventilation (HYBVENT) *
XXXVI Retrofitting of Educational Buildings *
XXXVII Low Exergy Systems for Heating and Cooling of Buildings
XXXVIII Solar Sustainable Housing
XXXIX High Performance Insulation systems (HiPTI)
XXXX Commissioning Building HVAC Systems for Improved Energy Performance
XXXXI Whole Building Heat, Air and Moisture Response (MOIST-EN)
XXXXII The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (COGEN-SIM)
XXXXIII Testing and Validation of Building Energy Simulation Tools
XXXXIV Integrating Environmentally Responsive Elements in Buildings

Annex V: Air Infiltration and Ventilation Centre

The Air Infiltration and Ventilation Centre was established by the Executive Committee following unanimous agreement that more needed to be understood about the impact of air change on energy use and indoor air quality. The purpose of the Centre is to promote an understanding of the complex behaviour of air flow in buildings and to advance the effective application of associated energy saving measures in both the design of new buildings and the improvement of the existing building stock.

The Participants in this task are Belgium, Czech Republic, France, Greece, Netherlands, Norway, and the United States of America.

25th AIVC Conference
Prague, Czech Republic, 15-17 September 2004

"Ventilation and Retrofitting"

CONTENTS

Session 1

Session 2

Session 3

Session 4

Session 5

Session 6

Session 7

Session 8

Session 9

Session 10

TESTING A METHOD FOR THE EVALUATION OF THE AIRTIGHTNESS OF VENTILATION SYSTEMS IN EXISTING BUILDINGS

P. Barles[1], X. Boulanger[2], S. Buseyne[2]

[1] *Pierre Barles Consultant, BP 4, F-83460, Les Arcs, France*
[2] *ALDES, BP 9707, F-31312, Labège, France*

ABSTRACT

The airtightness of ventilation ductwork is an important element of the global performance of ventilation systems. Nevertheless, it is too often neglected in practice.

Today, the new French Thermal Regulation (RT2000) encourages taking it into account as the energy losses calculation includes an additional part which is directly related to the additional air flow through ductwork leakages.

If we want to improve the results and the practice, we have to take into consideration the whole ventilation installation : the ducts and accessories, of course, but also the connections between ducts and air terminal devices, the connections between ducts and fan units, the characteristics of these fans, CTA, etc. We also have to take into account the reality of the building site.

This paper shows how to implement a methodology for measuring, on site, the global airtightness of ventilation installations. It is based on real applications on commercial and residential buildings, in France. It shows the feasibility of the method and, notably, the difficulties which were encountered for the investigations in multi-family buildings.

Measurements results are given and compared to the standard classes. They show the poor quality of airtightness on the most of installations which were tested. These results are in agreement with previous studies.

In parallel, this work enables to identify some of the causes of the low airtightness of ventilation systems.

KEYWORDS

Ventilation, Ductwork, Airtightness, Measurements, Leakage.

METHODOLOGY

The following methodology is applied, for each operation (after discussion with the owner or building administrator, to explain the goals and to get the permissions):

- Check the available documents which describe the ventilation system: drawings, requirements, components characteristics, …; in order to recognize the installation and select, if necessary – or to simplify -, a part of the ductwork for the measurements;

- Close up the exhaust air terminal devices (exhaust ATD) (exhaust system is the most used in France) : either with adapted cap where possible, or with small balloons equipped with a small rubber tubing which can easily be blocked (this method was specially tested in this study);

- Measure the residual air flows on certain parts of the network, or the global air flow at the fan unit; measure the pressures in different points. Sometimes, the air leakage is calculated by the comparison between the global ventilation air flow at the fan box and the addition of the individual air flows at every exhaust ATD, in normal use. The measurement devices are, mainly : balometer (ex. measuring the air flow at the fan unit exhaust – for small fan boxes) ; hot wire anemometer ; manometer, …;

- Look for the visible leakages if there are (some open connections were found) ; this is made by a detailed inspection of the network, as much as possible, everywhere it is possible; sometimes smoke test can be used;

- Make a precise description of the ventilation ductwork: lengths, diameters, reductions, etc. Available drawings are used ; but if there are not, then a detailed inspection has to be made ; the aim is to get a description of the ductwork as precise as possible;

- Analyse the results: tables, graphs, elementary calculations. Establishing a database on the ventilation ductwork components and their « areas » (for the evaluation of the total ductwork area which can be used in some leakages ratios).

RESULTS

Example of detailed results is shown on a Middle School, and then a summary of the results on four buildings (Middle School, Nursery School, Multi-Family A & B) is presented: tables, ratios, graphs.

Example of detailed results: Middle School building

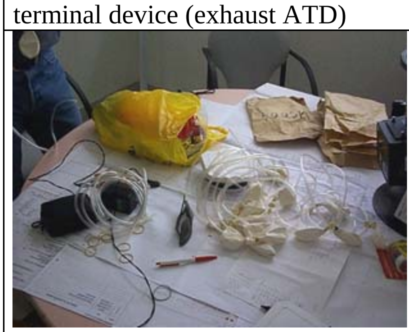
Picture 1: Middle School (year of construction: 1998)

Ventilation system

Simple exhaust ventilation system for classrooms.
The fan unit is on the roof; nominal air flow rate is around 2500 m3/h; it serves seven classrooms and two technical rooms (archives).

List of observations (see the following pictures)

- The inspection took place during holidays (spring) ; because out of this period it would have been difficult to enter the different rooms;
- Detailed drawings of ventilation ductworks were available, on site;
- For sealing the exhaust ATD, small balloons were used, without any difficulty;
- The links between flexible ducts and rigid ones (on the terminal parts of the ductwork) appeared not to be very airtight ; one reason is the lack of specific connection component;
- One open connection duct was found inside a coffered ceiling (125 mm diameter); it was then sealed with a special cap;
- Some connections between exhaust ATD were visibly not airtight at all;
 (these terminal defaults are not taken into account in the global network leakage evaluation, because the small balloons were placed downstream)
- The links between the main ventilation duct and the secondary ducts were airtight, due to the use of tape and mastic (no leakage could be visualised with the smoke test) ; also along the main duct, the connections between duct components (deviations, reductions) were visibly airtight;
- On one part of the network (one classroom, two exhaust ATD) the extracted air flow was really too high and a lot of noise was emitted inside the classroom; it seemed that a terminal regulation component was lacking (for the moment, the situation has been improved by closing an air damper on the roof part of the network; then the air flow and the noise were significantly reduced in the classroom).

		
Picture 2: Removing an exhaust air terminal device (exhaust ATD)	Picture 3: Connection between a flexible duct and a rigid duct	Picture 4: Terminal part for the exhaust ATD connection
		
Picture 5: Preparing the small balloons to close up the exhaust ATD	Picture 6: ”open duct”, which was discovered inside the coffered ceiling	Picture 7: Smoke test for leakages visualization; here, the connection is well mounted and airtight

Detailed results on air flow measurements, ductwork area, and leakages

The ductwork leakage is expressed in m^3/h and also, according to the French regulation, in $10^{-3} m^3/s/m^2$ under 1 Pa. Other ratios are calculated, for example "leakage/total extracted air flow rate".

MIDDLE SCHOOL

NETWORK n°3 | **CLASSROOMS (B1)** (total floor area arround : 516m²)

AIR FLOWS AT EXHAUST ATD		
ATD	**Measured**	**Designed**
(room)	(m3/h)	(m3/h)
Salle 133 b1	96	130
Salle 133 b2	105	130
Salle 133 b3	108	130
Salle 134 b1	110	130
Salle 134 b2	112	130
Salle 134 b3	120	130
Collections 135	74	75
Salle 136 b1	124	130
Salle 136 b2	127	130
Salle 136 b3	131	130
Collections 137	200	45
Salle 138 b1	77	130
Salle 138 b2	124	130
Salle 138 b3	85	130
Salle 140 b1	120	130
Salle 140 b2	203	130
Salle 141 b1	120	130
Salle 141 b2	120	130
Salle 142 b1	249	130
Salle 142 b2	255	130
TOTAL	**2660**	**2460**
Ratio Measur./design.	*8%*	

DUCTING AREA		
Diameter	**Length**	**Area**
(mm)	(m)	(m²)
125	33	12,96
200	14,5	9,11
250	15,5	12,17
315	18	17,81
355	23	25,65
450	1,5	2,12
	Total :	***79,83*** m²

OTHER COMPONENTS AREA — ***Total :*** ***4,63*** m²

TOTAL NETWORK AREA — ***Total :*** ***84,46*** m²

Some characterisitc Ratios	
NETWORK AREA / CONNECTIONS LENGTH	
1,51	m²/ml
NETWORK AREA / TOTAL AIR FLOW RATE	
0,026	m²/m3/h

	AIR FLOW AT FAN UNIT		
	Measured	**Designed**	Δp measured
	(m3/h)	(m3/h)	(Pa)
	3280	2460	300
Ratio Measur./design.	*33%*		

LEAKAGE AIR FLOW

Directly measured at the fan unit, after sealing the exhaust ATD

	515	m3/h	Δp measured
Pressure corrected	**392**	m3/h	(Pa)
Ratio leakage/extract	*12%*		450

Calculated by difference : fan unit air flow / total ATD exhausted

	620	m3/h
Ratio leakage/extract	*19%*	

AVERAGE LEAKAGE		
	506	m3/h
Ratio leakage/extract	***15%***	

Remark : if the initial "free" open duct wouldn't have been discovered and sealed, then the global leakage would have been : 26 %

"LEAKAGE" RESULTS		
RT2000 "Leakage"	**0,0365**	10^-3 m3/s/m² under 1Pa
Leakage/Total extracted Flow	15%	
Leakage/Connections Length	4,3	m3/h/ml under 100 Pa
Leakage/Nb of ATD	12,1	m3/h/ATD under 100 Pa

IDENTIFIED COMPONENTS						Component Area
Type	**nb**	diam.* info	connect. Nb	racc	l mm	(m²)
Exhaust ATD	20	125	1	20	7854	0,00
T315	1	315	3	3	2969	0,32
T355	1	355	3	3	3346	0,36
Cap315	1	315	1	1	990	0,08
Cap355	1	355	1	1	1115	0,10
Connection125	20	125	1	20	7854	0,00
Connection315	1	315	1	1	990	0,00
Elbow90/125	2	125	2	4	1571	0,31
Elbow90/315	1	315	2	2	1979	0,98
Elbow90/355	1	355	2	2	2231	1,07
Damper315	1	315	2	2	1979	0,13
Damper355	2	355	2	4	4461	0,54
Reduction200/125	2	163	2	4	2048	0,06
Reduction250/200	2	225	2	4	2827	0,06
Reduction315/250	2	280	2	4	3519	0,12
Reduction355/315	1	335	2	2	2105	0,05
Reduction450/355	1	403	2	2	2532	0,13
Flexible450	1	450	2	2	2827	0,35
Sound attenuator	1	450	2	2	2827	0,00
total nb of connections	*83*	* for the reduction it is an average value				*total components area (m²)*
total length of connections (m)	*56,0*					*4,63*

Figure 1: Detailed results for the network n°3, in the Middle School

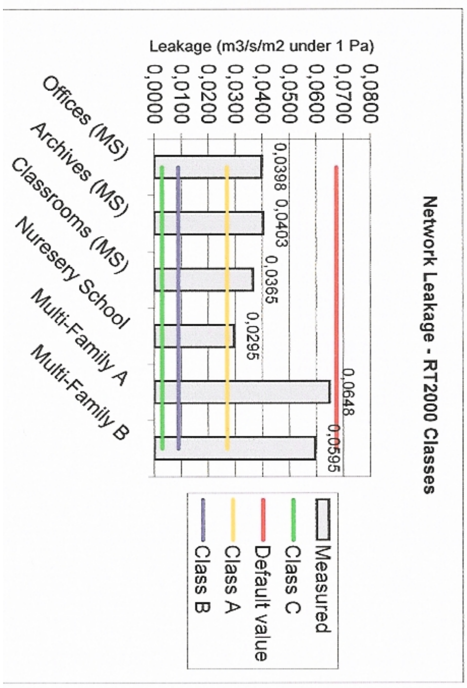
Summary of the results on four buildings and six ventilation networks

Different ratios are presented, and also, on the graphs, the situation of the different systems by comparison with the leakages classes according to the French regulation.

SUMMARY OF NETWORKS RATIOS AND CHARACTERISTICS : Middle School (3), Nursery School (1), Multi-Family A (1), Multi-Family B (1)

	RATIOS					
Network	Leakage/Extracted air flow	RT2000 "Leakage" (m3/s/m2 ss 1Pa)	Leakage/Connect. Length (m3/h/ml ss 100Pa)	Leakage/Nb of ATD (m3/h/bouche ss 100Pa)	Network Area/Connect. Length (m2/ml)	Network Area/Extracted air flow (m2/m3/h)
Offices (MS)	24%	0,0398	5,00	9,50	1,60	0,051
Archives (MS)	18%	0,0403	4,80	15,60	1,52	0,047
Classrooms (MS)	15%	0,0365	4,30	12,10	1,51	0,026
Nuresery School	10%	0,0295	2,20	8,00	0,96	0,045
Multi-Family A	22%	0,0648	4,90	8,90	0,96	0,041
Multi-Family B	18%	0,0595	4,80	7,50	1,01	0,029

	NETWORK					
Characteristic	Offices (MS)	Archives (MS)	Classrooms (MS)	Nuresery School	Multi-Family A	Multi-Family B
Leakage	291	39	506	96	502	175
Network Area	60,4	9,8	84,5	44,7	92,2	25,7
Connections Length	37,8	6,5	56,0	46,6	96,2	25,3



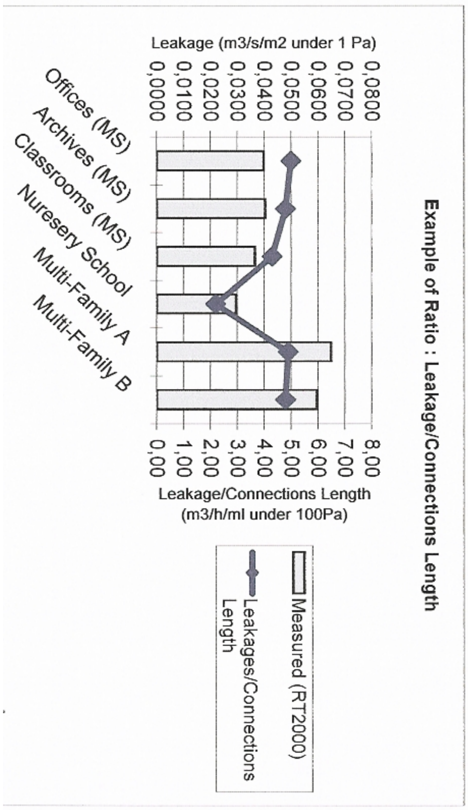


Figure 2: Tables and graphs, showing the leakages and the characteristics of the 6 ventilation networks which were studied: Middle School (3), Nursery School (1), Two Multi-family Buildings (2)

FIRST CONCLUSIONS AND PERSPECTIVES

This first study (four buildings, six ventilation networks) contributed to improve our knowledge and practical experience on the ventilation network airtightness.

None of the tested ventilation ductworks fulfilled the Class A requirements for leakages, according to the new French regulation RT2000. Leakages values were comprised between Class A and the default value (the default value is 2,5 higher than the Class A). For the two multi-family buildings the airtightness of the ventilation system was comparable, and close to the default value, according to RT2000; both cases were significantly worth compared to the others.

It seems that the poor quality of the airtightness of the ventilation system is often due to the terminal parts of the ductwork; further investigations on another multi-family building revealed strong defaults (see picture n°8, below) which led to higher leakages values. Bad airtightness is also due, in some cases, to major errors like an open duct without any ATD (see picture n°6, above); a visual inspection before coffering the ceiling would allow to avoid such a mistake.

Picture 8: (Multi-Family Building) Connecting duct (flexible) with a strong leakage (the ATD has been removed, it was directly – and bad – mounted on the connecting duct)

To analyse the results, a correlation like « leakage/connections length » seems to be interesting to study; but the defaults are not only localized at the connections.

A future commitment on airtight ventilation systems will suppose, in addition with efforts on conception, installation and maintenance, also to schedule and organise the commissioning (in residential buildings, it seems to be difficult because of the very short period between the end of the construction act and the arrival of the owners).

Today, ALDES is developing a new fan unit (with an integrated air flow measurement device) which will allow to measure the ductwork leakage, the apartments leakages, and also to check the nominal ventilation air flow rate.

References

[1] Norme Française X 10-236, Degré d'Etanchéité à l'Air dans les Réseaux de Distribution en Tôle
[2] Dossier Ventilation et Perméabilité, Revue CVC n° 4, avril 1999
[3] European Project SAVE-DUCT Improving Ductwork – A time for Tighter Air Distribution Systems, Final Report CE DG XVII, 1999
[4] Arrêté du 29/11/00 Relatif aux Caractéristiques Thermiques des Bâtiments Nouveaux et des Parties Nouvelles de Bâtiments, JO n°277 du 30/11/2000
[5] CSTB, Méthode de Calcul Th-C, juin 2001
[6] En 12599, Ventilation for Buildings – Test Procedures and Measuring Methods for Handling over Installed Ventilation and Air Conditioning Systems

THE IMPACT OF ENERGY EFFICIENT REFURBISHMENT ON THE AIRTIGHTNESS IN ENGLISH DWELLIGS

Sung H. Hong[1], Ian Ridley[2], Tadj Oreszczyn[3], The *Warm Front* Study Group[4]

[1, 2, 3] Bartlett School of Graduate Studies, Faculty of the Built Environment,
University College London, London, WC1E 6BT, UK
[4]The Centre for Regional, Economic and Social Research, Sheffield Hallam University,
City Campus, Howard Street, Sheffield, S1 1WB, UK
[4]Environmental Epidemiology Unit, London School of Hygiene & Tropical Medicine
Keppel Street, London WC1E 7HT
[4]National Centre for Social Research

ABSTRACT

Fan-pressurisation method was used to test the air infiltration rate of 191 dwellings in England. All tested homes were either pre or post the introduction of energy efficient retrofit measures such as cavity wall insulation, loft insulation, draught stripping and energy efficient heating system. Results show that the average air infiltration rate of the post dwellings is only marginally lower by 4% compared to the pre dwellings. Component infiltration rate based on model prediction indicates the combination of cavity wall insulation, loft insulation and draught stripping potentially reducing infiltration rate by 24%. On the other hand, longitudinal comparison shows a retrofit gas central heating system offsets this effect by contributing 13% increase in infiltration rate.

KEYWORDS

air infiltration, refurbishment, insulation, draught stripping, central heating, English dwelling

INTRODUCTION

As a part of the UK government's commitment to reduce green house gas emissions, measures to improve airtightness in the UK dwellings are being implemented through building regulation and energy efficient refurbishment programs.

Warm Front (WF) is a major energy efficient refurbishment project undertaken primarily to reduce fuel poverty in England by delivering affordable warmth through improved household energy efficiency. The main elements comprising the WF energy efficiency package are cavity wall insulation (CWI), loft insulation (LI), draught stripping (DS) and depending on the householders' qualification, the option of a hot water tank jacket and gas wall convector heaters or a gas central heating system (CH).

In 2001, the "Health Impact Evaluation of Warm Front" study was commissioned to investigate the effect of WF on resident health. Household data from 3099 properties was collected over two successive winters in five urban areas: Birmingham, Liverpool, Manchester, Newcastle and Southampton. A subset of 191 properties was targeted to conduct 221 (78 pre-intervention and 143 post-intervention) air infiltration rate tests. The case study dwellings are classified as pre- or post-intervention depending on the completion status of the WF refurbishment work.

This paper will present the results of the field-measured, whole house, air infiltration rate tests and discuss the effect of different energy efficient refurbishment measures on dwelling infiltration rate. The parameter used to present infiltration rate in this paper is *air permeability* which is used by UK building regulations and expressed in units of $m^3/hr/m^2$ (of exposed building envelope area including the ground floor) at 50 Pascals [2000, CIBSE].

OPPORTUNITIES FOR ACHIEVING AIRTIGHTNESS

Results from past projects indicate that there is a great opportunity of achieving airtightness in UK dwellings by refurbishment work. Studies carried out by Leeds Metropolitan University on a group of 12 properties (Derwentside Project) have shown a 46 to 66% reduction in infiltration rate [1997, BRESCU] while a maximum of 71% reduction was observed in a single case study dwelling following refurbishment measures (York Project) [Lowe, *et al*., 1997]. WF, on the other hand, is expected to have a lesser impact in reducing infiltration rate as a result of fewer delivered airtightness measures as shown in table 1.

TABLE 1
Opportunities of achieving airtightness

Opportunities of Achieving Airtightness	WF	York	Derwentside
Draughtstrip loft hatch and fit securing bolts	X	X	X
Draughtstrip opening windows and external doors	X	X	X
Seal around windows and door frames			X
Seal service holes through timber floors		X	
Seal service penetrations through ceilings			
Seal all remaining plumbing services			
Seal all joints in heating ductwork (where possible)			X
Seal all electric services including faceplates			X
Hardboard across timber floors and seal to skirting		X	
Install cavity wall and loft insulation	X	X	X
Seal air space behind plasterboard dry-lining		X	X
Seal top and bottom of stud partitions			
Add a draught lobby to exterior doors			
Block disused chimney opening			

MEASURING AIR INFILTRATION RATE

Fan pressurisation method was used to measure the whole house air infiltration rate. All open flues and vents were kept open during the test in order to measure airtightness under a normal dwelling condition. Open chimneys were sealed but depending on the circumstance they were left open and only the pressurisation cycle was carried out. The test was accompanied by a thermal imaging camera to record areas of air ingress and missing insulation. The tested dwellings are classified in table 2 which shows that the majority are of masonry construction.

TABLE 2
Case study dwellings (n=191)

age		wall type		building type	
pre-1900	15%	cavity masonry	66%	terraced	57%
1900 – 1950	50%	solid brick	33%	semi-detached	33%
1951 – 1976	32%	timber framed	0.5%	flats	9%
Post 1976	3%	other	0.5%	detached	1%

PRE- AND POST-INTERVENTION AIR INFILTRATION RATE

The comparison of air infiltration rate distribution between the pre- and post-intervention dwellings in figure 1 shows little difference between the two groups with the post- dwellings showing a marginally lower average infiltration rate of $0.7m^3/hr/m^2$ in table 3. One of the main reasons seems to be the fact that the impact of measures which may result in decreased infiltration rate such as CWI and DS is offset by other measures such as the installation of a CH whose effect is shown by the increase in infiltration rate among the CH properties in table 3.

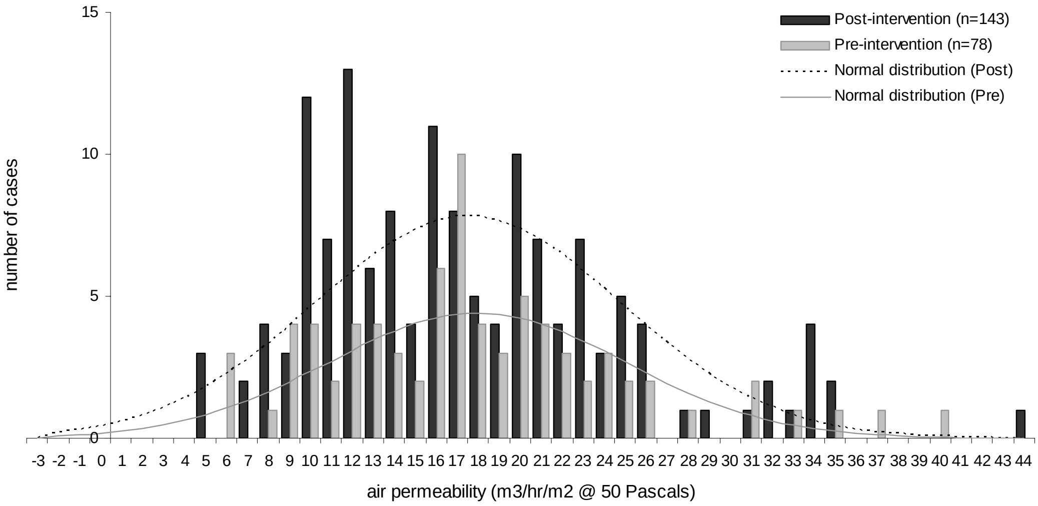


Figure 1: Air infiltration rate distribution for pre- and post-intervention WF dwellings

TABLE 3
Mean and standard deviation of air infiltration rates (n=221)

WF Scheme	Pre-WF ($m^3/hr/m^2$)	Post-WF ($m^3/hr/m^2$)	% Change
All properties	17.7 (s.d. 7.1), n = 78	17.0 (s.d. 7.2), n = 143	-4%
w/o CH	19.1 (s.d. 7.8), n = 22	16.5 (s.d. 7.3), n = 51	-14%
w/ CH	17.1 (s.d. 6.8), n = 56	17.2 (s.d. 7.2), n = 92	+1%

CH: Gas Central Heating System

TABLE 4
Change in air infiltration rate based on longitudinal cases (n=21)

Intervention		Sample Size		Infiltration Rate Change ($m^3/hr/m^2$)		% Change	
CH only	w/ PU	12	4	+1.8	+ 3.0	+13%	+21%
	w/ PA		8		+ 1.1		+9%
CH w/ PU + LI + DS		2		+2.1		+10%	
CH w/ PU +PA + DG		2		-0.3		-3%	
CH w/ PA + CWI		2		-3.5		-27%	
CWI		1		-3.6		-19%	
New Boiler		2		+0.2		+2%	

CH w/ PU: Central heating system with plumbing installed under floor boards
CH w/ PA: Central heating system with plumbing installed above floor boards
LI: Loft insulation; DS: Draught stripping; DG: Double glazing; CWI: Cavity wall insulation

Longitudinal test results from a subset of 21 properties further supports the observation where a decrease in infiltration rate is recorded following CWI and double glazing - not a WF measure - while an increase of 13% is observed following the CH measure alone. This increase is not the result of an additional flue since the flues are of balanced type but from the plumbing work associated with the WF supplied radiators. Table 4 shows a pronounced increase in infiltration rate (21%) among the dwellings whose radiator pipes are installed below the suspended floor boards at ground floor level.

COMPONENT INFILTRATION RATE

Because of the small sample size involved in the longitudinal study and the majority of these properties having received only a CH, a statistical model based on multiple regression is used to estimate the effect of component contribution to infiltration rate based on the 221 measured samples. The model shows that 31% (R^2=0.314) of variability in infiltration rate is explainable by the components listed in figure 2 (P-*value* = 4.9×10^{-12}). The components that most significantly affect (P-*value* < 0.05) infiltration rate are indicated as grey bars.

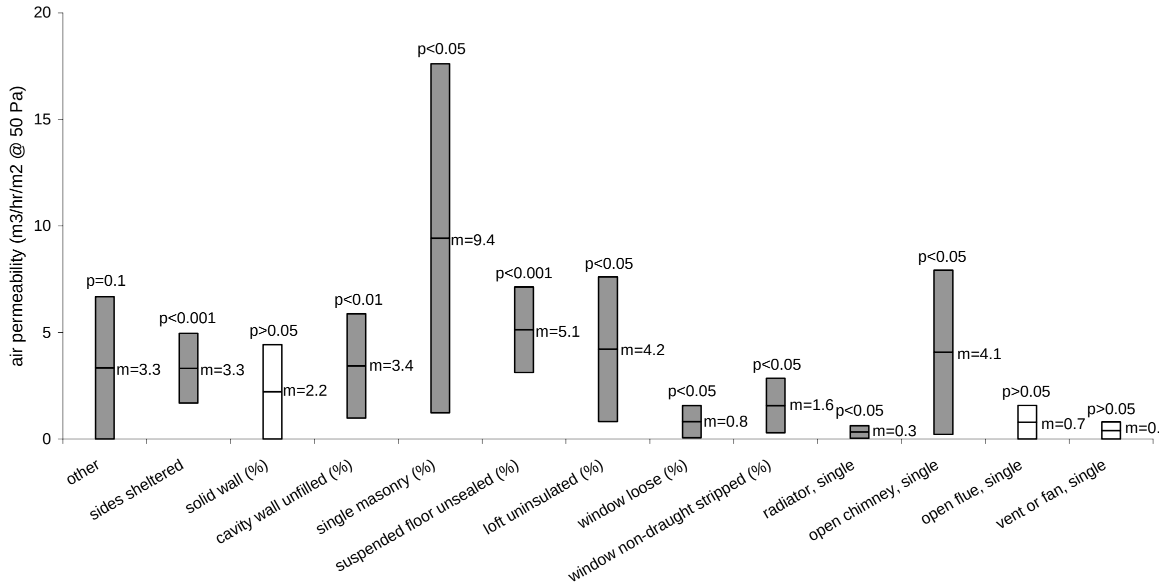


Figure 2: Component infiltration rate at 95% confidence interval range
(m: median; p: P-*value*)

The model indicates that a combination of CWI, LI and DS, which are the primary WF airtightness measures, should achieve a 24% reduction in infiltration rate based on the range median. The reduction will increase to 37% if the suspended floors are sealed and a further 47% if an unwanted chimney is closed.

The largest range is shown by the *single masonry* category which refers to a single withe inner brick wall with an exterior timber tile finish on battens. The wide effective range reflects the difficulty in determining the quality of this wall type where the inner masonry layer is hidden from view. The model shows that the potential impact of this wall type on infiltration rate can be significant while its construction nature does not allow retrofit CWI.

Increase in sheltered sides increases air permeability by $3m^3/hr/m^2$. In other words, a unit wall of a semi-detached house is leakier than a detached house. The reason behind this oddity is due to the way in which the *air permeability* parameter is based on exposed wall surface area while discounting the effects of inter-dwelling air exchange. Building Research Establishment (BRE) study shows inter-dwelling infiltration through walls can contribute from zero to 20% of total infiltration rate [1998, Stephen].

LI can reduce air permeability by 4m^3/hr/m^2. However, post-intervention survey as in figure 3 shows that this potential benefit is frequently lost as a result of missing LI along the ceiling edges near the eaves where retrofit installation is physically difficult to carry out. Without LI over the wall plate, air can travel up the cavity wall space if CWI and closers are missing or behind the drywall finish with poorly sealed surrounds.

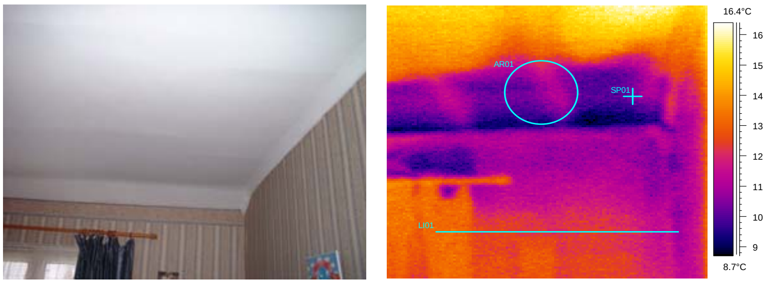


Figure 3: Thermographic image shows missing loft insulation behind the ceiling finish near the eaves

A single retrofit radiator increases air permeability by 0.3m^3/hr/m^2. If the effect of the WF supplied radiators - normally five - is taken into account, the potential increase from a CH can be 1.5m^3/hr/m^2 which is similar to the increase of 1.8m^3/hr/m^2 observed in the longitudinal comparison of table 4.

Minute cracks, unsealed penetrations and other paths that are difficult to classify make up the *other* component which contributes 3m^3/hr/m^2 to infiltration rate. WF measures may have limited effect in reducing this component which possibly reflects the general construction quality of the dwelling and its deterioration through age. A more detailed component classification may reduce the effect of the *other* component while increasing the significance level (R^2 value) of the prediction model.

Poor component classification can be attributed to the low significance level (P-*value* >= 0.05) of the *open flue, single* & *vent or fan, single* components. No detailed survey was made between the flues of open gas fire and those of modern gas fires with grilled front. Similarly, the condition of permanent vents such as air bricks was not surveyed in detail.

COMPARISON OF COMPONENT INFILTRATION RATE DISTRIBUTION

The model prediction is compared in figure 4 with BRE's component infiltration rate which is based on reductive sealing method from 35 UK dwellings [1998, Stephen]. For the comparison, the effect of WF CWI is related to the BRE drywall surrounds sealing because no record was made about the type of internal wall finish in the WF study. The effect of loft hatch is omitted in the WF model because of its poor significance level. The contribution from open chimneys and flues are all omitted because the BRE data excludes their effects. Also, the CH contribution is excluded since its effect on infiltration rate is significant only as a retrofit measure, a condition unique to the WF project.

The comparison of component infiltration rate between the WF and BRE data is not straight forward due to difference in component classification. In the case of the *permanent vents*, the model is predicting the effect from a single vent or fan (1%) whereas the BRE prediction is based on several vents (9%) typically found in UK dwellings. The large difference between the CWI (11%) and the dry wall *surrounds* sealing (2%) and likewise between *loft uninsulated* (14%) and the *loft hatch* (2%) indicates that their effects can't be compared directly. BRE's *remainder* component which makes up 71% of the total infiltration rate can be equated to the model's *solid wall* (7%), *single masonry* (31%), *suspended floor* (17%) and *other* (11%) components which in combination contribute to 66% of the total. The model predicted effect from *no draught stripping* and *window & door loose* which make up 8% of the total is less than BRE predicted16% possibly because the model does not take into account the contribution from well sealed and draught stripped windows and doors.

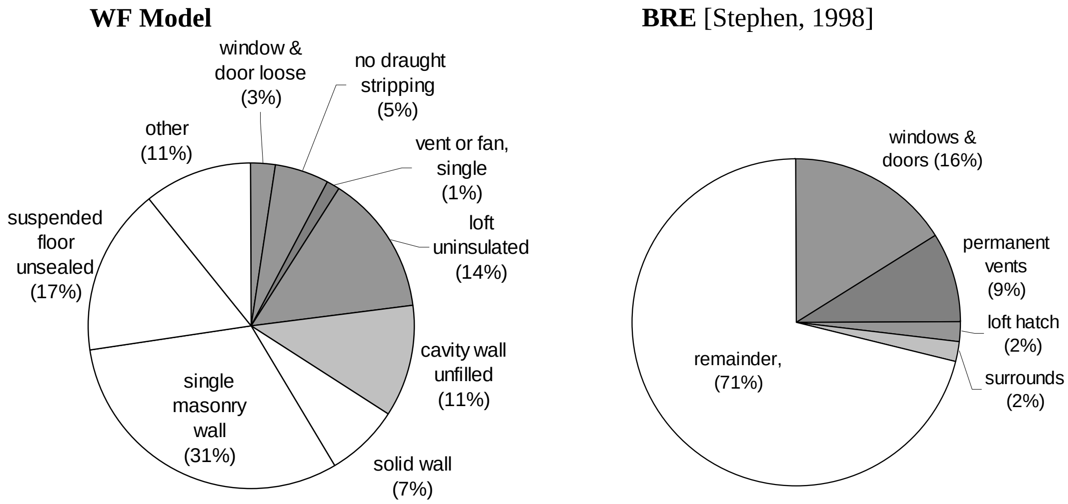


Figure 4: Comparison of component infiltration rate

CONCLUSION

The combination of Warm Front delivered cavity wall insulation, loft insulation and draught stripping can reduce English dwelling air infiltration rate by about 24%. On the other hand, retrofit gas central heating system increases infiltration rate which is particularly sensitive to the way in which the peripheral piping work is installed. To achieve airtightness, the radiator pipes should be installed exposed above the suspended floor, or if installed below the floor, accompanied with a robust sealing procedure around penetrations and along the seams of floorboards temporarily lifted for installation.

ACKNOWLEDGEMENTS

This study was funded by a grant from the Department for Environment, Food and Rural Affairs (DEFRA) and the Welsh Assembly Government. We are grateful to Energy Saving Trust under whose contract the services were carried out and to EAGA Partnership for their support. We are also grateful to the householders for their warm welcome into their homes.

REFERENCE

Lowe, R. J., Johnston, D. and Bell, M. (1997). Airtighntess in UK Dwellings: A Review of Some Recent Measurements. In Proc. Second International Conference on Building and the Environment, June 1997, Paris, 389-396.

Stephen, R. K. (1998). *Airtightness in UK dwellings: BRE's test results and their significance*, Building Research Establishment, Garston, U.K.

(2002). *Conservation of fuel and power in dwellings*, Building Regulations Approved Document L1, The Stationery Office, London, U.K.

(1997). *Improving airtightness in existing homes*, Good Practice Guide 224, BRECSU, Building Research Establishment, Garston, U.K.

(2000). *Testing buildings for air leakage*, CIBSE TM23: 2000, The Chartered Institution of Building Services Engineers, London, U.K.

MEASUREMENT OF BUILDING LEAKAGE BY UNSTEADY PRESSURISATION

E. W. Cooper[1] and D. W. Etheridge[2]

School of the Built Environment, University of Nottingham,
Nottingham, NG7 2RD, UK
[1] *+44 (0) 115 951 3028 email:- laxewc@nottingham.ac.uk*
[2] *+44 (0) 115 951 3171 email:- david.etheridge@nottingham.ac.uk*
Fax +44 (0) 115 951 3159

ABSTRACT

The paper describes the development of unsteady pulse pressurisation techniques for measuring the leakage of buildings. The original version of the technique (the UP technique) has been investigated experimentally and theoretically in a single cell test space. The initial results are very promising, with a good degree of repeatability and similar sensitivity to changes in leakage levels as the conventional steady (DC) technique. An interesting outcome of these early tests was the observation that quasi-steady flow could be established in a short time. This has led to a second version of the technique (the QP technique) and evidence is provided which indicates that this version could offer greater accuracy than the UP and DC techniques.

KEYWORDS

Leakage, infiltration, buildings, unsteady, quasi-steady, pressurisation,

INTRODUCTION

The importance of adventitious leakage has long been known, but it has recently been highlighted in the UK by amendments to Part L2 of the Building Regulations, see DTLR (2002), which require that the air leakage of large buildings be measured on completion, and that it should comply with set levels. The legislation may eventually be applied to virtually all buildings, including dwellings. Currently adventitious leakage is measured by subjecting the building to a known steady flow and measuring the resulting pressure difference. This is the well-known steady leakage technique, often called the DC technique. Although well-established, the technique is not perfect, particularly for large buildings.

In an earlier paper by Carey and Etheridge (2001) it was concluded that a novel form of pulse pressurisation technique allied to a mathematical model of unsteady ventilation offers a way of determining the adventitious leakage of large buildings that would be difficult or impossible with the conventional DC technique. Since that time more precise equipment and instrumentation have been developed and tests have been carried out that demonstrate the promising nature of the technique. During these studies it became apparent that there is another way in which the pulse technique and the mathematical model could be used. This followed from the observation that quasi-steady flow is established quickly after the start of the pulse.

This paper is therefore concerned with two techniques and to distinguish them the first is called the unsteady pulse (UP) technique and the second is called the quasi-steady pulse (QP) technique. Both techniques use the same equipment and mathematical model; they differ only in the way in which the results are analysed.

EXPERIMENTAL EQUIPMENT AND PROCEDURE

The basic technique is to subject the building to a rapid and known change of volume and to record the pressure response with time. For small buildings a single pulse unit is used. For large buildings a number of identical units would be distributed around the building and fired simultaneously. In principle there is no limit to the size of building that can be tested. One simply increases the number of units. This is potentially a major advantage of the technique. Another major advantage is that testing time is reduced. With the pulse technique there is no need to penetrate the envelope and the test itself takes only a few seconds. The pulse unit is simple, relatively inexpensive and can easily be reproduced for multiple applications.

The basic pulse generation equipment consists of a piston that slides along a fixed shaft in a cylinder. The piston is displaced by injecting air into the cylinder from one or two compressors with solenoid valves operated by a time sequencer. A displacement transducer is used to measure the instantaneous position of the piston.

THEORETICAL MODEL AND ANALYSIS

It is the theoretical model that relates the measured pressure pulse to the leakage characteristics of the envelope. The model is described in Carey and Etheridge (2001) and only an outline is given here. This is followed by an explanation of how the model is used specifically for the two techniques.

The basic concept can be seen by considering Figure 1, which shows a single cell of volume, V, with a single opening and a piston. A displacement of the piston, δV, leads to a piston volume flow rate, q_p, and a flow rate through the opening, q. There will be a corresponding change in the internal pressure, P_i, relative to the external pressure, P_e.

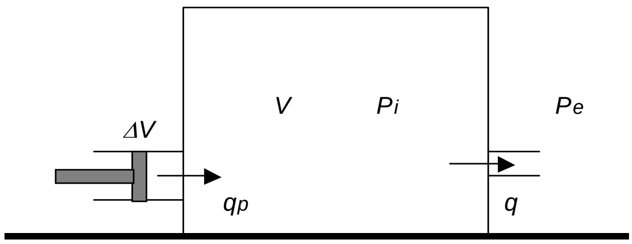


Figure 1: Cell with single opening acted on by a piston.

The theoretical approach is known as the quasi-steady temporal inertia model (QT model). It solves a set of simultaneous first order differential equations, namely the continuity equation for the enclosed space and integral momentum equations for the openings in the envelope.

The continuity equation includes the effect of compressibility of the air in the space and takes the form

$$\frac{1}{\rho_i} V \frac{d\rho_i}{dt} = q_p\{t\} + q\{t\} \qquad (1)$$

Isentropic expansion of the air is assumed, to provide the relation between density and internal pressure.

The momentum equation takes the form

$$\Delta p\{t\} = \frac{\rho B}{2}\left(\frac{q}{A}\right)^2 + \frac{\mu CL}{2d^2}\left(\frac{q}{A}\right) + \rho \frac{dq/A}{dt}\left(L + 1.67d\right) \qquad (2)$$

Where Δp denotes the pressure difference across the opening. The third term on the right-hand side accounts for the inertia of the air that flows through the opening i.e. the air at the inlet and outlet and the air contained within the opening itself.

The Unsteady Pulse (UP) Technique

For the UP procedure, the leakage characteristic of the complete envelope is represented by a single opening, with a leakage Q_{50} and a shape parameter a/b^2. The equation for the flow through the opening is taken to be the quadratic form.

The adventitious leakage of the building is obtained by determining the value of Q_{50} (with a specified value of a/b^2) that best matches the predicted pressure response to the measured pressure response. The value specified for a/b^2 will generally be the value that lies midway in the range of values encountered in buildings. For the investigations described below, the values of Q_{50} and a/b^2 were obtained from a DC test. For the basic data analysis the program in essence determines the difference between the pressure at the peak of the pulse and at reference points before and after the pulse. This value is referred to as ΔP_{max}.

The Quasi-Steady Pulse (QP) Technique

For quasi-steady flow to occur, the inertia term in Eqn. 2, i.e. the third term on the right-hand side, needs to be small compared to the other terms. When quasi-steady flow occurs, the relationship between the instantaneous values of $q\{t\}$ and $\Delta p\{t\}$ is the same as that for steady flow i.e. a plot of $q\{t\}$ against $\Delta p\{t\}$ will lie on the steady flow characteristic. To determine $q\{t\}$ from the measurements it is necessary to take account of the change of internal pressure by using the continuity equation (Eqn. 1).

When the steady flow leakage characteristic is known, from a DC test, it is relatively easy to check the existence of quasi-steady flow. However, in a real situation one would not have the DC curve and it would not be obvious whether quasi-steady conditions had been reached. This is where the theoretical model is used in the QP technique. It is simply used to determine at what time the inertia term in Eqn. 2 becomes negligible. In principle, the QP method is more accurate than the UP technique, because assumptions about a/b^2 and the depth L of the openings do not have a direct effect on the results.

EXPERIMENTAL RESULTS

All experimental investigations so far have been in a single cell test room of volume 406 m^3.

The first measurement to be done was a conventional DC test to ascertain Q_{50} for the room and thereby the air permeability. This was done using the British Gas leakage tester, which offers relatively high accuracy by virtue of the fact that is makes use of an averaging flow meter (Wilson flow grid) in a long duct (see Section 10.2 of Etheridge and Sandberg (1996)). Q_{50} was found to be 2294 m^3/h, which corresponds to a value for the air permeability that is slightly less than the requirements of the new Building Regulations of 10 $m^3/(h.m^2)$, so the room is a suitable test case.

The Unsteady Pulse (UP) Technique

The first investigation concerned the repeatability of the UP technique. Measurements were carried out on different days and with the piston in different locations and facing different directions. The deviation of ΔP_{max} remained less than +/- 5 %, with an average value of approximately 9 Pa. The results of some of these early tests, conducted at different times, are shown in Figure 2. The left-hand plot shows the actual recorded pressure responses, which start from different base levels. It is the change in pressure that is relevant, so the right-hand plot shows the collapse of the data when the base levels are shifted. The pulse start times are slightly offset for clarity.

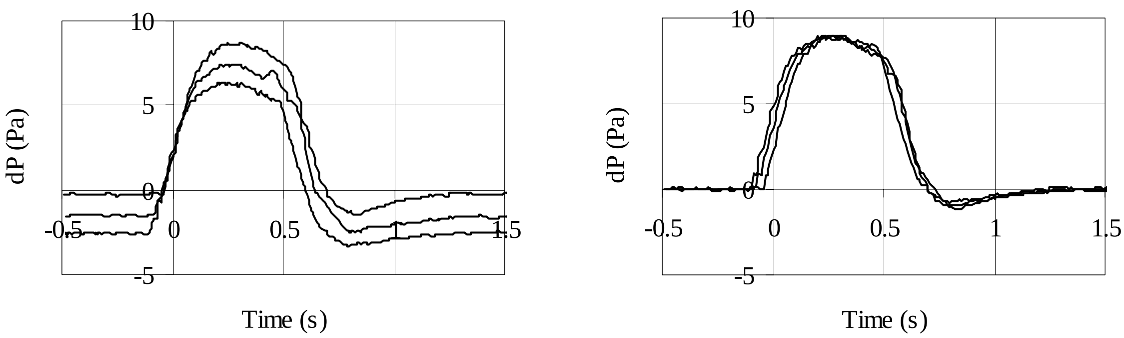


Figure 2: Early experimental results showing repeatability before and after shifting base levels.

An investigation into the sensitivity of the UP and DC techniques to changes in leakage levels was carried out by using both techniques before and after sealing an opening in the test room envelope.

TABLE 1
Sensitivity to changes in leakage levels.

	DC measurement Q_{50} (m^3/s)	Experimental UP ΔP_{max} (Pa)	Theoretical UP ΔP_{max} (Pa)
Before sealing opening	0.64	8.492	8.322
After sealing opening	0.58	9.3272	9.088
Percentage change	-9.38 %	9.84 %	9.21 %

The percentage changes can be seen in Table 1. The Q_{50} and experimental ΔP_{max} percentage changes were of similar magnitude, suggesting that the pulse test is at least as sensitive to changes in leakage as the steady test. Importantly the experimental UP and theoretically predicted ΔP_{max} were within less than 1% of each other. This suggests that the model is a good predictor of what can be expected in practice.

Figure 3 shows the experimental and theoretical pressure pulses for an unsteady pressurisation test after the opening was sealed. It can be seen that the model provides a reasonably close fit with the experimental pulse.

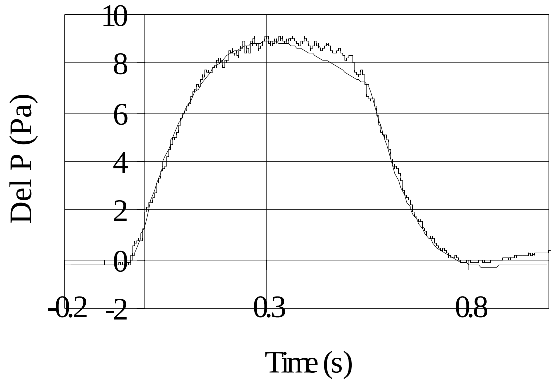


Figure 3: Comparison of experimental (jagged) and theoretical (smooth) pressure pulses.

The Quasi-Steady Pulse (QP) Technique

In Figure 3, it is seen that there is a region between the peak pressure and the start of the rapid fall in pressure where the pressure reduces relatively slowly with time. This is where the flow could be behaving in a quasi-steady manner. When the steady flow leakage characteristic is known, it is relatively easy to check the existence of quasi-steady flow. Figure 4 shows results plotted in this way (only data recorded in the region of interest is plotted), with the arrow showing the direction of increasing time. The DC curve is extrapolated from measured data and may itself be subject to error. Comparison with the DC curve indicates that the results are tending towards a quasi-steady condition, but it seems that condition is not quite reached. The total piston travel time is about 0.7 s for the QP test.

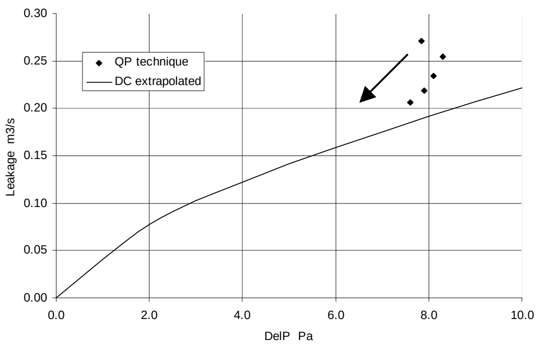


Figure 4: Checking for quasi-steady flow (with short pulse time).

In view of this, a further test was carried with a longer pulse time. The corresponding results are shown in Figure 5. Here it can be seen that quasi-steady conditions appear to have been reached, with good agreement with the DC curve.

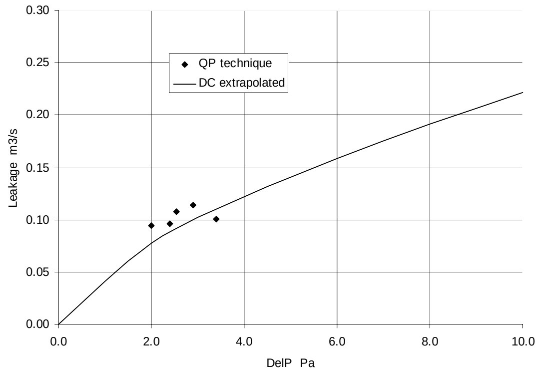


Figure 5: Checking for quasi-steady flow (with long pulse time).

CONCLUSIONS

Two techniques based on an unsteady pulse pressurisation method, for measuring the leakage of building envelopes, have been investigated. Both techniques have potential advantages over the conventional steady (DC) pressurisation technique. The key advantages are that there is no need to penetrate the building envelope, the testing is rapid, results are obtained at pressures normally encountered in ventilation and there is no limit to the size of building that can be tested.

The unsteady pulse (UP) technique has been shown to work well in a single cell test space. Experiments have shown that it is repeatable and is as sensitive to leakage changes as the steady (DC) technique.

The quasi-steady pulse (QP) technique has been shown experimentally to be viable and theoretical investigations indicate that it offers greater accuracy than both the UP and DC techniques.

Further work is concentrating on the use of multiple pulse units for large buildings and on a full theoretical investigation of uncertainties under real operating conditions.

ACKNOWLEDGEMENTS

The Engineering and Physical Science Research Council (EPSRC) and AirFlow Developments Ltd fund the work described in this report. Their support is gratefully acknowledged.

REFERENCES

1. DTLR, 2002. The Building Regulations 2000: Approved Document Part L2 Conservation of fuel and power in buildings other than dwellings, 2002 Edition. The Stationary Office.
2. Carey PS and Etheridge DW, 2001. Leakage measurements using unsteady techniques with particular reference to large buildings. *Building Serv. Eng. Res. Tech.* 22, 2 (2001) pp. 69-82
3. Etheridge, D. W. and Sandberg, M. (1996). *Building Ventilation: Theory and Measurement*, John Wiley & Sons, Chichester, UK, 720pp. ISBN 0 471 96087 X

SOLAR CHIMNEYS FOR RESIDENTIAL VENTILATION

Pavel Charvat, Miroslav Jicha and Josef Stetina

Department of Thermodynamics and Environmental Engineering
Faculty of Mechanical Engineering
Brno University of Technology
Technicka 2, 616 69 Brno, Czech Republic

ABSTRACT

An increasing impact of ventilation and air-conditioning to the total energy consumption of buildings has drawn attention to natural ventilation and passive cooling. The very common way of natural ventilation in residential buildings is passive stack ventilation. The passive stack ventilation relies on the stack effect created by the temperature difference between air temperature inside and outside a building. A solar chimney represents an option how to improve the performance of passive stack ventilation on hot sunny days, when there is a small difference between indoor and outdoor air temperature. The full-scale solar chimneys have been built and tested at the Department of Thermodynamics and Environmental Engineering at the Brno University of Technology. The main goal of the experiments is to investigate performance of solar chimneys under the climatic conditions of the Czech Republic. Two different constructions of a solar chimney have been tested; a light weight construction and the construction with thermal mass.

KEYWORDS

solar chimney, residential ventilation, passive cooling

PRINCIPLE OF SOLAR CHIMNEY VENTILATION

A solar chimney is a natural-draft device that uses solar radiation to move air upward, thus converting solar energy (heat) into kinetic energy (motion) of air. At constant pressure air density decreases with increasing temperature. It means that air with higher temperature than ambient air is driven upwards by the buoyancy force. A solar chimney exploits this physical phenomenon and uses solar energy to heat air up.

Since air is a transparent fluid (radiation-transmitting), it cannot be directly heated by solar radiation. Therefore, a solar chimney has to contain a solar absorber; a surface made of a material which absorbs solar radiation, and which allows solar heat to be transferred to the air by means of convection. The most common configurations of solar chimneys are those utilizing the “greenhouse” effect - air cavities with a transparent material (glass) on one side of the cavity and a solar absorber on the other side. These solar chimneys are very similar to solar air collectors.

Solar chimneys can be employed in many areas, e.g. ventilation, power generation or food drying. The principle of solar chimney ventilation is shown in Fig. 1. As can be seen in Fig. 1, solar chimney ventilation is a kind of stack ventilation. Exhaust air is heated up in a solar chimney by solar radiation, and buoyancy force, which is a driving force in this case, increases. Unlike passive stack ventilation (relaying on the indoor-outdoor temperature difference), the solar chimney ventilation works also when outdoor temperature is the same or higher than indoor air temperature. There are many possible configurations of a solar chimney. A solar chimney can be design either as an integral part of a building or as a device used with a ventilation system.

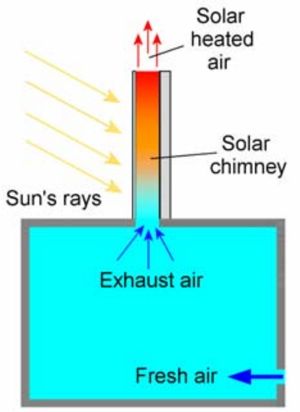


Fig. 1 The principle of solar chimney ventilation

Solar chimneys can also be used for night ventilation/cooling, but in this case they have to contain a heat storage mass. Several studies have been carried out with the aim to investigate the performance of solar chimneys in last several years. Some of these studies, however, were aimed at the utilization of solar chimneys for power generation.

EXPERIMENTAL SOLAR CHIMNEYS

The full-scale solar chimneys have been built and tested at the Department of Thermodynamics and Environmental Engineering at the Brno University of Technology. The main goal of the experiments is to investigate the performance of solar chimneys under the climatic conditions of the Czech Republic.

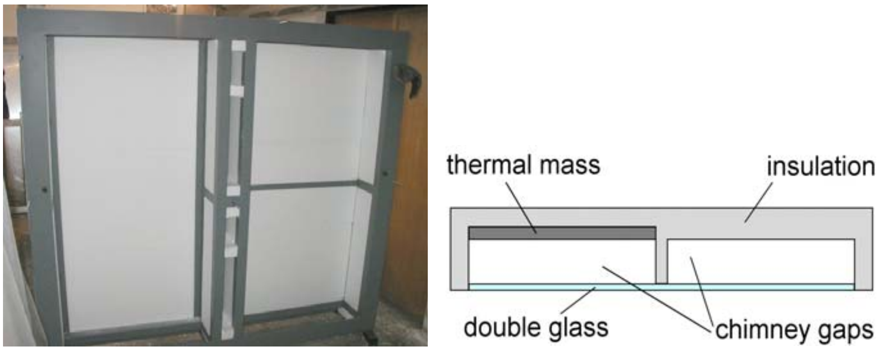


Fig. 2 Metal-frame construction of the chimneys.

The experimental solar chimneys are designed as an insulated metal frame construction. Two different versions of a solar chimney have been built; a light weight construction and a construction with thermal mass. Both chimneys are connected in parallel, as can be seen in Fig. 2. The thermal mass is made of 50 mm thick concrete layer.

The dimensions of the chimney gaps in the glazed part of the chimneys are: width 750 mm, height 1500 mm and depth 200 mm. A double pane glass was applied for the transparent parts of the chimneys. The glazed parts of the chimneys are inclined 30 degrees from the vertical to increase a heat gain in summer. The glazed parts are openable in order to allow cleaning and installation of measurements. The experimental solar chimneys have been located on the platform over the roof of the department's laboratory (Fig. 3). The chimneys are oriented to due south. The 5 m long vertical ducts are connected to the chimneys at the bottom, and the 1.5 m long rectangular ducts (of the same shape as chimney gaps) extend the chimneys at the top.

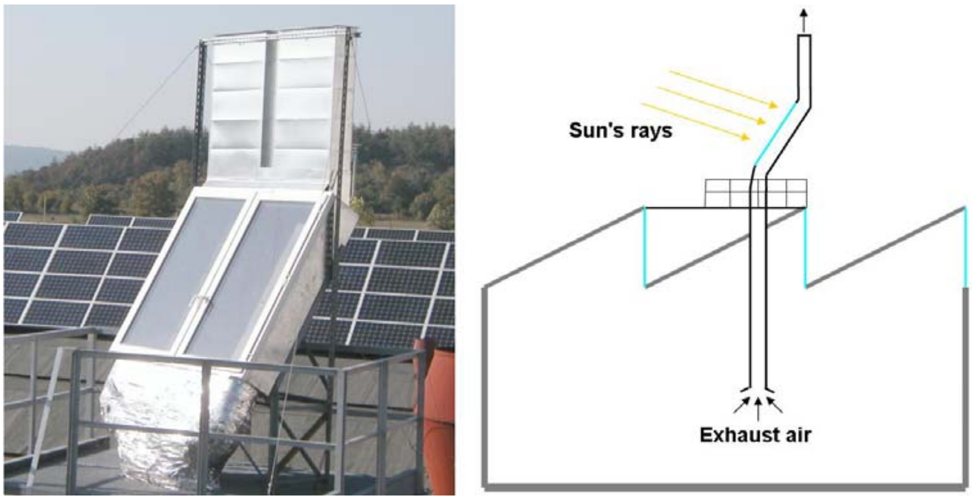


Fig. 3 Experimental solar chimneys

A PC based data acquisition system was used for monitoring of the performance of the solar chimneys. The main difficulty of the monitoring represented measurements of air flow rates through the chimneys. A tracer gas technique was employed for this purpose in the studies performed in Portugal, *Afonso at al (2000)*. A tracer gas was released at a constant rate in test chambers beneath the chimneys, and the air flow rate was obtained from the concentration of the tracer gas. This technique is a little bit complicated for the measurements lasting several months, and so the calorimetric principle flow meters have been installed in the ducts.

RESULTS OF EXPERIMENTS

The long-term monitoring of the performance of solar chimneys began in early March 2003. As expected the air flow through the chimneys in cold seasons is predominantly caused by the temperature difference between the indoors and the outdoors. The cold seasons (late fall, winter, and early spring) are not very interesting from the point of view of utilization of solar chimneys, because passive stack created by the indoor-outdoor temperature difference is usually sufficient for ventilation purposes. Moreover, passive cooling (or cooling in general) is not demanded in these seasons. The main assets of solar chimney ventilation, in moderate climates, can be found during the warm season.

The idea of having two geometrically identical chimneys allows comparative tests to be carried out. It means that the performance of one version of the solar chimney can be compared to the performance of the other version under the same weather conditions. In one of these tests the temperature of the chimney surface (solar absorber) was investigated. The solar absorber of the light-weight chimney is made of black-painted sheet metal; the absorber of the chimney with thermal mass is made of black-painted concrete. The experiments were performed at the zero air flow rate (the vertical ducts were closed at the bottom). The reason for closing the ducts was to achieve the same conditions in both chimneys.

Fig. 4 shows the absorber temperatures recorded on a summer day. As can be seen, the temperature of the metal sheet (light-weight chimney) follows very quickly changes in the solar radiation intensity. The highest temperature during the day exceeded 80 C. In case of the solar chimney with thermal mass fluctuations of the surface temperature are dampened by heat storage mass. The highest temperature during the day was lower than in case of the light way chimney (just over 60 C). The temperature of the absorber in case of light-weight chimney dropped to the outdoor air temperature immediately after sunset, while the temperature of the thermal mass remained higher than outdoor air temperature all night. The chimneys were not closed at the top during this experiment. Therefore, some air exchange between the chimney cavities and the outdoor environment was possible. The absorber temperatures would probably be higher, if the chimneys were also closed at the top.

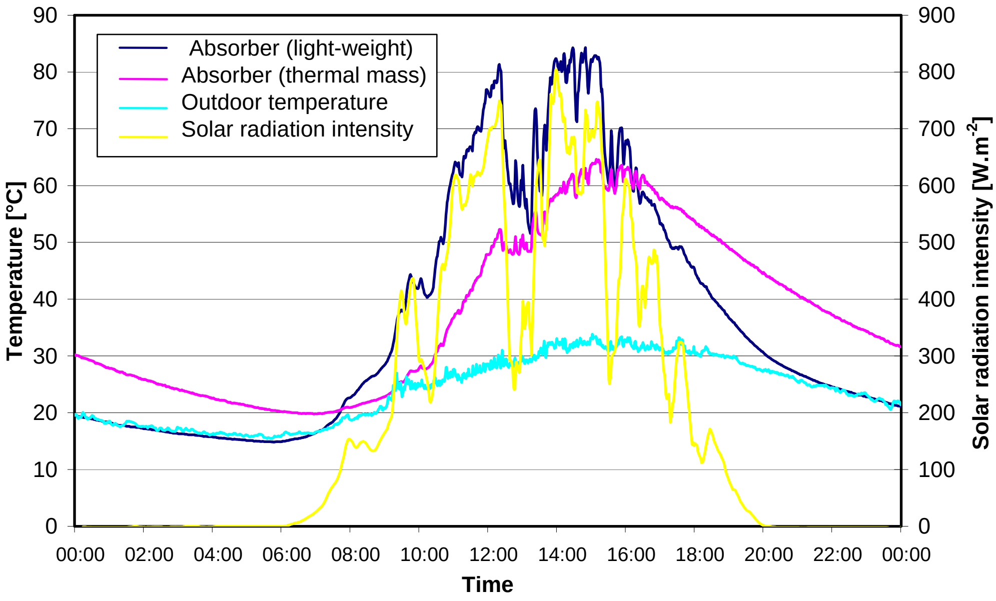


Fig. 4 Temperature of solar absorbers

If a solar chimney with thermal mass is to be used for night cooling, then it is beneficial to keep it closed during the day. In such situation solar heat is stored in the storage mass during day, and after sunset, when the chimney opens, the stored heat can be released to the passing air. The heat storage capacity of the experimental chimney is not very high. The thermal mass is around 120 kg of concrete, which gives the thermal capacity approximately 120 kJ/K .

The most interesting, from the point of view of utilization of solar chimneys, is a comparison of the solar chimney performance to the performance of a normal chimney. With two identical chimneys it is possible to investigate how the solar chimney stands in such comparison. For this purpose the glazed part of the chimney with thermal mass was covered with insulation, and so it worked as a normal chimney (stack). The thermal mass was not taken out of the chimney, but the influence of the thermal mass in such experiment was supposed to be small.

Fig. 5 shows the air flow rates through the chimneys on a sunny summer day - July 20, 2003. It was a day with very clear sky. As can be seen the curve of solar radiation intensity is very smooth. Such weather is ideal for the investigation of the solar chimney performance, because there are no fluctuations of the air flow rate caused by the sudden changes in solar radiation intensity (when a cloud passes over the sun). As can be seen in Fig. 5 the air flow rate during the day was lower than air flow rate at night. It means that the impact of the solar radiation to the performance of the solar chimney was, in current configuration, lower than the impact of the difference between indoor and outdoor temperature at night.

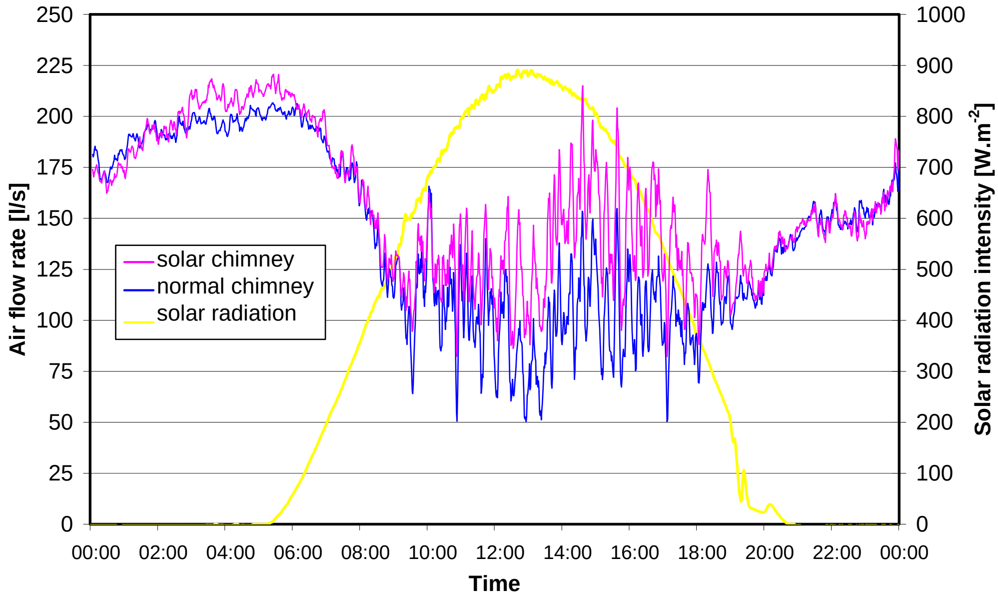


Fig. 5 Air flow rates through the chimneys

The air flow rate trough the solar chimney, between 8 A.M. and 6 P.M., was in average about 20% percent higher than air flow rate through the normal chimney. The air flow rates plotted together with the indoor-outdoor temperature difference (for July 20, 2003) are shown in Fig. 6. As can be seen the air flow rate through the normal chimney did not drop to zero even when the outdoor air temperature was lower than the indoor air temperature. This can only be explained by the influence of wind, because buoyancy force in this situation could not drive air from the lab trough the chimney. Huge fluctuations of the air flow rate during the day support the idea of significant impact of wind to the chimney performance.

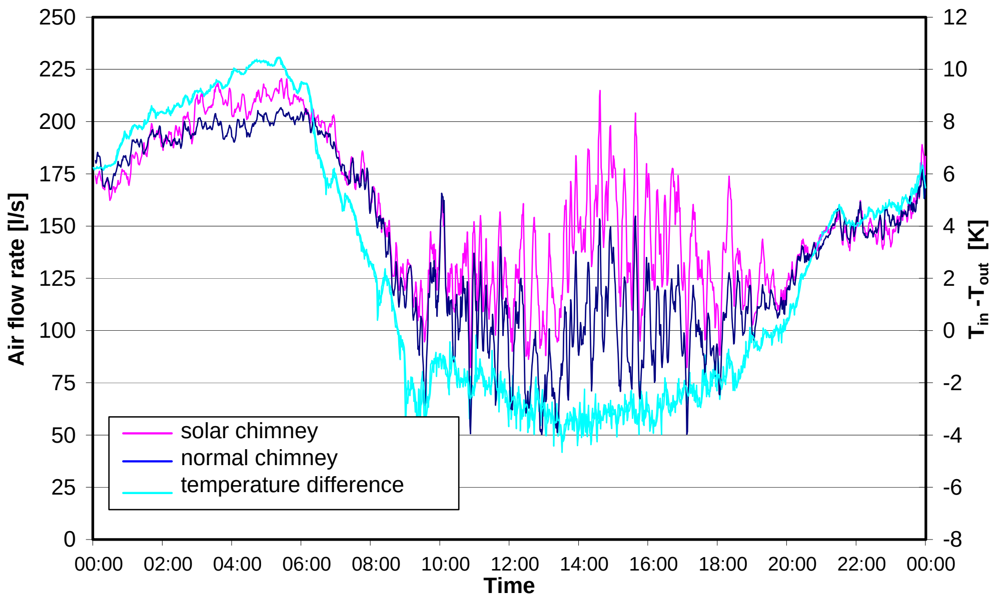


Fig. 6 Air flow rates and indoor-outdoor temperature difference

FUTURE PERSPECTIVE

The experiences acquired with the experimental solar chimneys were utilized in design of solar chimneys for an experimental house with hybrid ventilation, which was built in the university campus (Fig. 7). The experimental house is a two-storey building of the size of a single family house. The solar chimneys, which are a part of the hybrid ventilation system installed in the house, will be used for passive cooling. The solar chimneys are positioned over the stairway in the house. The stairway connects both floors, and so no ductwork is needed with such a position of the chimneys. The experimental house provides more realistic conditions for the investigation of the solar chimney performance than the experimental facility on the roof of the lab.

Fig. 7 Experimental house with hybrid ventilation

Even though the principle of solar chimney ventilation has been known for centuries, there is a possibility to employ modern technologies in the solar chimney design. One option is to replace glass with semi-transparent photovoltaic, which could power a DC fan. Such combination would represent a fan assisted natural ventilation system, which could operate without an access to the power grid. The photovoltaic panels, in this case, could also feed a control system, including motorized dampers.

Acknowledgements

The financial support from the project GA 101/04/P033 granted by the Czech Grant Agency and the Research plan MSM 262100001 granted by Czech Ministry of Education is gratefully acknowledged.

References

Afonso, C. and Oliveira, A. (2000). Solar chimneys: simulation and experiment. *Energy and Buildings*, 32, 71-79.

Halldorsson, J. and Byrjalsen, Ch. (2001). Experimental and theoretical studies of a solar chimney with uniform wall heat flux. MSc. thesis, Aalborg University, Denmark.

da Silva, J.J.C. Silva, A.M. and Fernandes, E.O. (2001). Passive cooling in livestock buildings. Building Simulation, Rio de Janeiro, Brazil.

Spencer, S. Chen, Z.D. Li, Y. and Haghighat, F. (2000). Experimental investigation of a solar chimney natural ventilation system. Roomvent 2000, Reading, UK.

Optimization of Hybrid Air-conditioning System with Natural Ventilation by GA and CFD

Shinsuke Kato [1], Jeong Hoe Lee [2]

[1] Institute of Industrial Science, The University of Tokyo
Cw403 4-6-1 Komaba Meguro-ku, Tokyo, Japan
[2] Department of Architecture, Graduate School of Engineering, The University of Tokyo,
Cw403, 4-6-1 Komaba, Meguro-ku, Tokyo, Japan

ABSTRACT

This study aims at the development of an optimal design tool using a genetic algorithm (GA) and computational fluid dynamics (CFD). To represent a realistic building environment, random variables (fluctuating outdoor conditions), passive control variables (model variables) and active control variables (HVAC system) were set up. A combination of designs are determined based on the relationship between the fluctuating outdoor conditions and the HVAC system in the optimization inquiry. Building environment design should consider this relationship of active and passive control because the HVAC system works until the indoor climate reaches the target indoor climate when outdoor conditions are changing.

Keywords

Optimization, Genetic Algorithm (GA), Computational Fluid Dynamics (CFD)
Passive and active control elements, Random variables, Feed-back loop

1 Introduction

This study aims at the development of an optimal design tool using GA and CFD [2], [3], [4] for hybrid air-conditioning [1]. As elements to be considered in the design, there are the outdoor condisions, passive control elements for natural wind forced ventilation (such as the form of the inside and outside of the building), and active control elements of the indoor environment (such as HVAC system). Outdoor conditions are a fluctuating factor, and active control elements of the indoor climate (such as HVAC system) which are changing the output (boundary conditions of HVAC) in order to maintain the indoor climate at the target level for fluctuating outdoor conditions. This research treats the outside conditions as random variables, and examins the design variables selected by GA and actively changes the indoor situation corresponding to the outdoor conditions with a feed-back loop from the outputs of HVAC system control to the input boundary conditions of the CFD. This optimization method means that the feed-back loop of sensor and outputs of HVAC works until indoor climate is at the target level after GA has selected passive elements (design variables). The whole process of optimization consists of a two-step process to reduce the calculation load for finding the optimal solution. This study carried out a simple analysis using a coarse mesh considering the calculation load in the first step. In the second step, a detailed CFD analysis using a fine mesh was performed on the cases ranked top selected in the first step.

2 Optimization method Using GA and CFD

2.1 The optimization method

1. Setting up passive control elements for natural ventilation (design variables), active control elements (such as HVAC system), random variables (here mainly climatic conditions), restricting conditions and the objective function.

2. Design variables are selected by an optimization technique, and random variables are seleceded by a sampling technique.
3. CFD analysis is performed on the selected design variables and the selected random variables.
4. Active control elements are changed by the CFD feed-back loop, and the indoor climate is analyzed until it reaches the target value.
5. Restricting conditions and the objective function are evaluated.
6. Repeat loops 2-5 and the cases selected from the top rank which show a high value for the objective function in the first step.
7. In the second step, a detailed CFD analysis is performed on the selected cases.

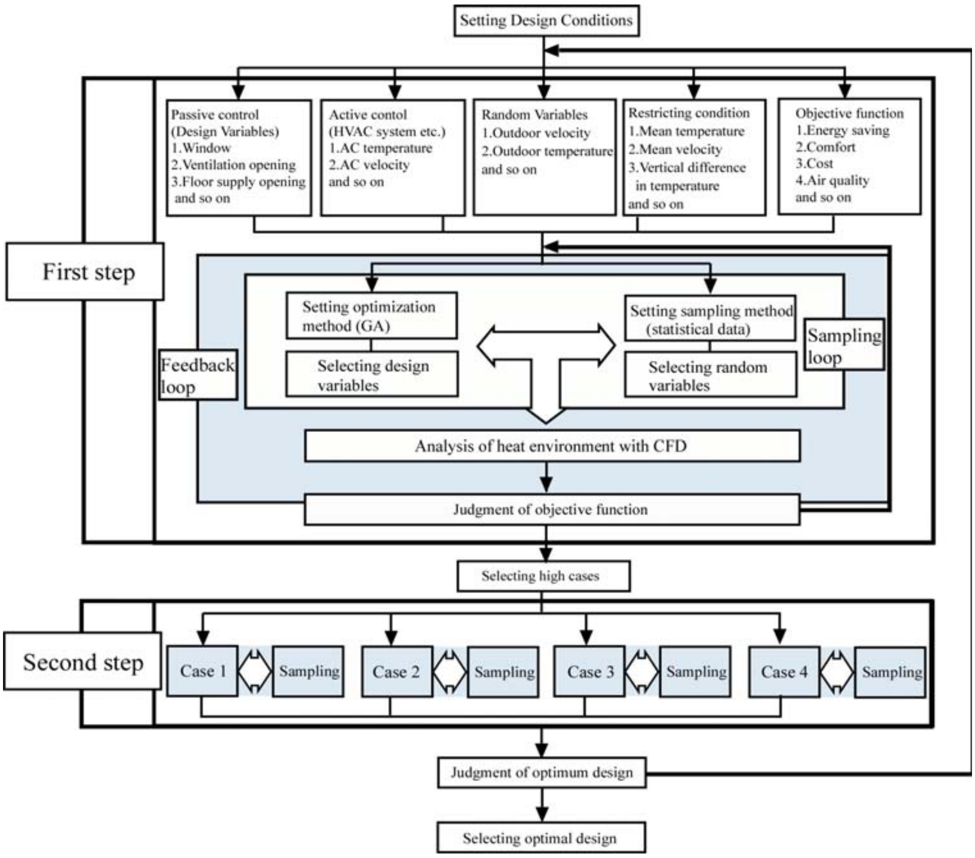


Fig. 1 The optimization procedure

3 Optimization Design Case Study

Assuming that the outdoor temperature is the changing factor, optimization is performed on a hybrid air-conditioning system [1] with natural ventilation in the mid-term.

3.1 Basic Model

The basic model for this study is shown in Figure 2 and Table 1. The width of the calculation area is set at half of the 3.6 m office module (1.8 m), considering of the symmetrical configuration. Hybrid air-conditioning is modeled as the outdoor air flows into the room from the upper opening of the window (0.5×1.8 m; Fig. 2, left), and is expelled through the opening at the other side (0.5×1.8 m; Fig. 2, right), while the HVAC is still operating. And the floor supply openings (0.1×0.2m) are set up. An I-shaped partition and a desk are installed. Personal computers and a human model are installed to represent the source of internal heat generation. In this study, The HVAC system in the room is assumed to be operating and the output of the HVAC is controlled by the CFD feed-back loop.

3.2 Design variables

Design variables for this study are shown in Figure 3. In this study, three design pattern elements are examined for the hybrid air-conditioning system with natural ventilation. These are the locations of the floor supply openings (6 patterns), the styles of the natural ventilation supply openings (5×5=25 patterns, there are two design variables which are width and height of the natural ventilation) and the styles of the window (5×(2×12-1)=115 patterns, there are three design variables which are the width and height of the window and the window start line which are 0.8 m and 2.0 m). The total number of design patterns is 17250.

3.3 Random variables

This study considers only the outdoor temperature which is based on the weather data of the Japan Meteorological Agency from May to June. The wind induced ventilation rate is assumed to be constant with the device of constant volume. The data for the random variables are selected by taking one hour intervals from 8:00 to 18:00. The moment design method was used for selecting random variables according to the average changes in the distribution and standard deviation of the outdoor conditions in this study, and on the assumption of instantaneous diffusion conditions without considering the influence of thermal storage in the building structure. The probability of a random variable is used as a weighting factor, which is multiplied by the objective function. The statistical value of the objective function is calculated with changing outdoor conditions taken into account. In this study, only the range ±2σ (95.4% of the entire ranges) is based on the mean value (M) of the outdoor temperature. The sampling interval and random variables are shown in Table 2.

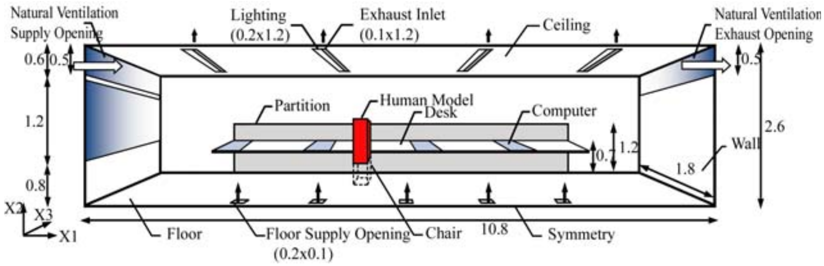


Fig. 2 Basic model (Units:m)

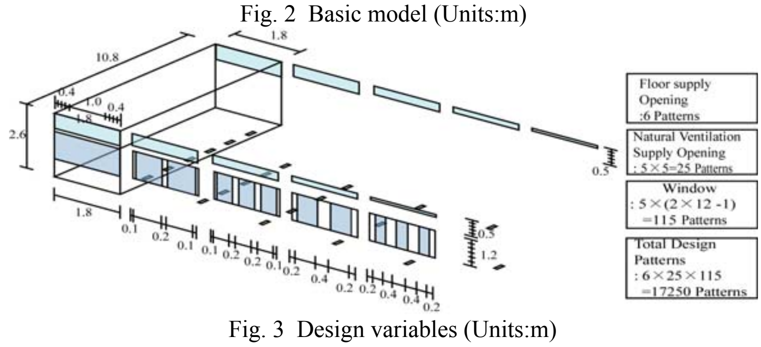


Fig. 3 Design variables (Units:m)

Table 1 Heat sources (Basic model)

Heat sources	Solar Heat (Window)	Lighting (4 Units)	Computer (4 Units)	Human model (One body)	floor four human bodies	Total
Quantity of heat	$100W/m^2$	400W	800W	55W	220W	1700W
・Floor area of 19.4 m^2 produces 88 W/m^2 of sensible heat ・Human model is a cube of dimensions 0.45m×0.33m×0.88m						

Table 2 Random variables

Sampling interval	Probability	Random variable (ºC)
-2σ — -σ	0.136	20.95 (M−1.5σ)
-σ — M	0.341	21.94 (M−0.5σ)
M — σ	0.341	22.93 (M+0.5σ)
σ — 2σ	0.136	23.92 (M+1.5σ)
Mean value(M) = 22.43 ºC, Distribution (σ^2) =0.977 ºC, Standard deviation (σ) = 0.99 ºC		

4 Setting the Optimal Design

4.1 Objective function

The single objective function is the amount of energy-input to the HVAC system. The objective function is as follows:

$$E(kW) = Cp \times \rho \times \Delta T \times Q \qquad (1)$$

Cp: Constant-pressure ratio heat of air [J/kg·K], ρ: Density of air [kg/m^3]
ΔT: Difference in temperature on outflow and inflow temperature of HVAC system [K]
Q: The amount of wind on inflow of HAVC system [m^3/s]
The optimal evaluation is achieved when the amount of energy-input in equation (1) reaches a minimum.

4.2 Restricting conditions

The restricting conditions set for the indoor environmental design in this study are as follows:
·The target temperature is 26.0ºC (±0.2ºC)in the task region.
·The size of window is over than 2.8m^2 a seventh of floor area.
·The average wind velocity is below 0.5 m/s in the task region.
·The limit wind velocity is below 2.0m/s on floor supply opening.
·The vertical difference in temperature is below 3.0ºC in the task region.
Here, the task region is X_1=0.9-10.8 m, X_2=0.0-1.5 m, and X_3=0.0-1.8 m. The number of air changes per hour for the natural ventilation is fixed at 10 times, and the floor supply openings are fixed at 19 ºC.

4.3 GA and CFD analysis conditions

A multi-island genetic algorithm [4] is used in the first step for optimization. The detailed setup is shown in Table 4 and the boundary conditions of the CFD are shown in Table 5. The flow field is analyzed with three-dimensional CFD based on a standard k-ε model.

Table 4 Setting the multi– island GA

Size of Sub-Population	10
Number of Islands	4
Number of Generations	10
Rate of Crossover	0.8
Rate of Mutation	0.1
Rate of Migration	0.5
Interval of Migration	3
Total	400 (10×4×10) × 4 (Sampling)=1600

Table 5 Boundary conditions for the CFD simulation

INLET	$K_{in} = 3/2\ (U_{in} \times 0.05)^2$, $\varepsilon_{in} = C_\mu^{3/4} \times k_{in}^{3/2} / l_{in}$ l_{in} = One seventh of the opening width U_{in}: Velocity of inflow (m/s), C_μ= 0.09
OUTLET	U_{out}: Mass balanced, Tout, kout , ε_{out} : Free slip
Wall,human model	Generalized log-law (Wall Function), Free slip at symmetric plane. Heat flux of human body and floor is fixed.
Turbulence model	High reynolds number k-ε model
Difference scheme	First-order upwind difference
Mesh	1st step 55(X_1)×25(X_2)×16(X_3)= 22000 2st step 78(X_1)×35(X_2)×22(X_3)= 72000
k : kinetic energy of inflow [m^2/s^2], ε: kinetic energy dissipation rate [m^2/s^3], in: inlet out: outlet , T: temperature [K], U: velocity of inflow [m/s], l: specific length scale [m]	

4.4 Feed-back loop

The HVAC system is set so that a sensor is in agreement with the target temperature until the indoor temperature reaches 24 ºC (Heating) and 26 ºC (Cooling) in the hybrid air-conditioning model room with the feed-back loop of CFD. It is set so that the AC supply temperature is 19 ºC for cooling and 26 ºC for heating. The amount of supply air is controlled.

4.4.1 The convergence evaluation standard of the feed-back loop

a) Cooling : The mean temperature in the task region is 26 ºC (The accuracy is less than ±0.2 ºC).
b) Heating : The mean temperature in the task region is 24 ºC (The accuracy is less than ±0.2 ºC).
c) None HVAC system: The amount of HVAC supply air is 0 ($Q<0.001 m^3/s$). When the mean temperature is 24ºC-26ºC in the task region with the amount of supply air which is 0.001 m^3/s.

4.4.2 The standard for changing the HVAC setting between cooling and heating in the feed-back loop

a) Changing from cooling to heating: Even if the amount of supply air (Cooling) is set to 0 ($Q< 0.001 m^3/s$), when the mean temperature of a task region is less than 24ºC.
b) Changing from heating to cooling: Even if the amount of supply air (Heating) is set to 0 ($Q< 0.001 m^3/s$), when the mean temperature in the task region is more than 26 ºC.

4.4.3 The detailed feed-back loop

$Q_{NEW} = Q_{OLD} + \Delta Q$

$\Delta Q = [(T_{TASK} - T_{TAGET}) \times V_{TASK}]/[(T_{TASK} - T_{SUPPLY}) \times t(s)]$

Q_{NEW} = The modified amount of wind [m^3/s]. Q_{OLD} = The amount of wind before modifying[m^3/s].
ΔQ=The up and down amount of wind [m^3/s]. T_{TASK} = The mean temperature of task region [ºC].
T_{TAGET} = The target temperature of the HVAC system[ºC]. V_{TASK} = The volume of task region[m^3].
t = The relaxation time [s].

5 Simulation Result

5.1 GA and CFD analysis conditions

The results of the optimal design in the first step by multi-island GA and CFD are shown in Figure 4. The top three cases are selected in the first step for a detailed CFD analysis using a

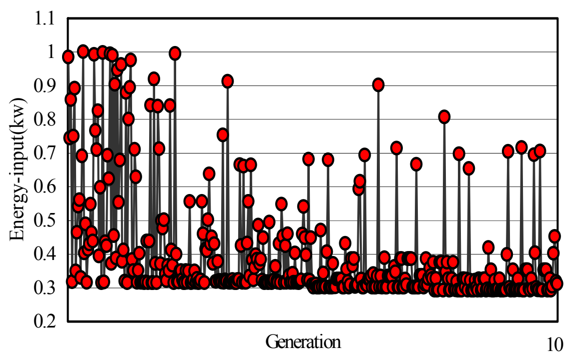


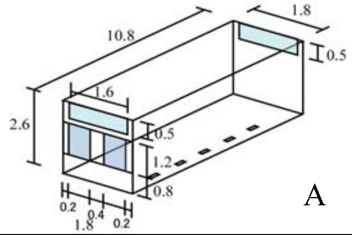
Fig. 4 Curve of GA inquiry

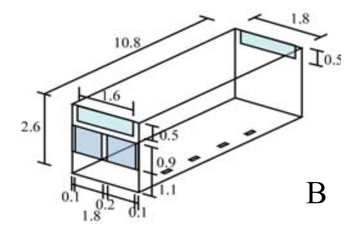
fine mesh in the second step.

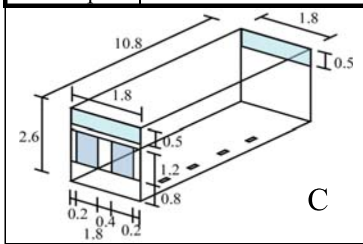
5.2 The design selected in the first and second step

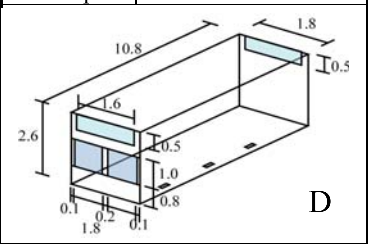
The design selected in the first step is shown in Table 6. The simulation result shows that the objective function is low when a larger natural ventilation opening is selected. It is assumed that the amount of sensible heat removal increases when the natural ventilation opening becomes larger. The floor supply openings are selected according to the relationship between the natural ventilation opening and the window. When the natural ventilation opening becomes small, there is a tendency for the number of floor supply openings to increase. And the amount of energy-input increases when the outside temperature becomes high. In this study, Case A where the purpose function is the highest in step 2 search serves as the optimal design. The CFD analysis results of Case A are shown from figures 5 to 8.

Table 6 Cases selected in the first step (Unit:kw)









A		B	
1Step	0.290	1Step	0.290
2Step	0.300	2Step	0.301
C		D	
1Step	0.291	1Step	0.292
2Step	0.301	2Step	0.302

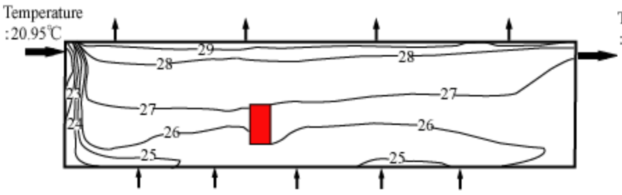


Fig.5 Temperature field (Section,Outdoor:20.95ºC)

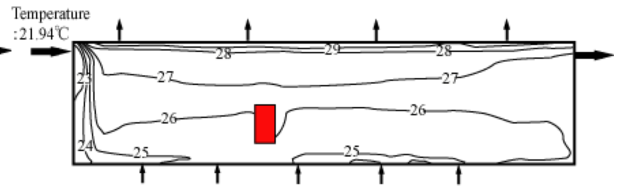


Fig.6 Temperature field (Section,Outdoor:21.94ºC)

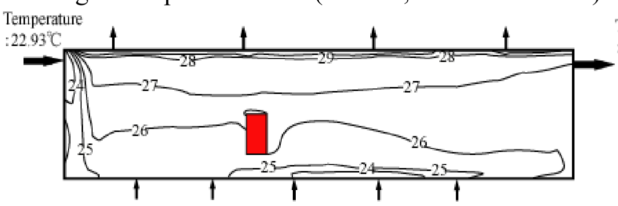


Fig.7 Temperature field (Section,Outdoor:22.93ºC)

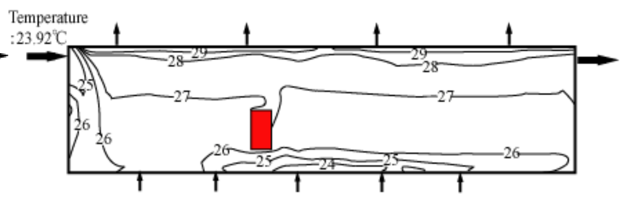


Fig.8 Temperature field (Section,Outdoor:23.92ºC)

6 Conclusions

A hybrid air-conditioning system with natural ventilation in the mid-term was investigated as an example of the optimal design.

The optimal inquiry based on fluctuating factor outdoor conditions as the random variables, the building form as the passive control, and an HVAC system as the active control was performed, and its validity was demonstrated.

A two-step inquiry using a genetic algorithm showed that it was possible to produce an optimal design with a reduction in the calculation time.

The energy-saving effect of the hybrid air-conditioning system using natural ventilation in the mid-term was clarified.

References

[1] Chang H, Kato S and Chikamoto T. Effects of outdoor air conditions on hybrid air conditioning based on task/ambient strategy with natural and mechanical ventilation in office buildings. Building and Environment, Volume 39, Issue 2,pp. 153-164, 2004.2.

[2] Murakami S, Kato S and Kim T. Coupled simulation of convicton, radiation, and HVAC control for attaining a given PMV value. Building and Environment, Volume 36, Issue 7, pp. 701-709, 2001.8.

[3]Sasaki D, Obayashi S, Sawada K. and Himeno R. Navier-Stokes Optimization of Supersonic Wings with Four Design Objectives Using Evolutionary Algorithm. AIAA-2001-2531, June 2001.

[4] Tongchim S and Chongstitvatana P. Parallel genetic algorithm with parameter adaptation. Information Processing Letters, Volume 82, Issue 1, pp. 47-54, 2002.4

NATVENT BUILDINGS VERSUS HVAC BUILDINGS - A NEW DUTCH THERMAL COMFORT GUIDELINE

A.K. Raue[1], A.C. Boerstra[2], A.C. van der Linden[3] and S.R. Kurvers[4]

[1] *Raue IEQ, Rotterdam, the Netherlands. raue@dds.nl*
[2] *BBA Indoor Environmental Consultancy, Rotterdam, the Netherlands*
[3] *Delft University of Technology, Department of Architecture, Delft, the Netherlands*
[4] *High Performance Buildings, Gouda, the Netherlands*

ABSTRACT

A new thermal comfort guideline for moderate environments has been developed: the ATG guideline. The underlying method distinguishes between 'type Alpha' versus 'type Beta' buildings to provide for different adaptation effects. Type Alpha indicates buildings with a major occupant influence on the indoor environment, as characteristic for buildings with natural ventilation. Type Beta instead stands for a centrally controlled indoor environment, such as in most buildings with sealed facades and full HVAC.

The ATG method has some major improvements over the former, PMV based, method:

1 Higher temperatures are accepted in type Alpha buildings during warm periods, putting less demand on mechanical cooling. As a result, improved energy efficiency is expected.
2 As thermal demands in type Alpha buildings are less stringent, it is easier to make naturally ventilated buildings meet the criteria than before. This improves chances for retrofitting older buildings and for the application of advanced natural or hybrid ventilation in new buildings. Demands for type Beta buildings remain practically as before.
3 The new criterion is easy to communicate. Thermal comfort as building performance is now expressed as *Class A*, *B*, or *C*, in accordance to international standards like CR1752.
4 In contrast to the old guideline, the predicted performance can now be tested with field measurements. This means that the performance that was agreed upon in the pre design phase can be assessed during occupation. This makes performance contracting possible.

The ATG guideline has been published in March 2004 and it is expected to become the official guideline for government commissions in the Netherlands.

KEYWORDS

Adaptation, thermal comfort, ATG, guideline, Alpha, Beta

INTRODUCTION

Over the last 10 years natvent and hybvent have regained popularity in Dutch building practice. The existing Dutch thermal comfort guideline, based on the PMV model, has proven less suitable for such 'low tech' environments: the occupants of such buildings seem to expect a less stringent temperature than the existing guideline prescribed. Meanwhile there is a rising attention for performance based design, requiring performance criteria that can be tested after construction. These developments were the basis for developing a new thermal comfort guideline. The new guideline was to be used for design and field assessment of buildings with extensive climate control systems as well as buildings with simple systems, such as natural ventilation. Furthermore the new guideline was to improve communication about thermal comfort to the building principal, usually a layman on this subject.

METHODS

A thorough literature review of field studies and laboratory studies (ISSO, 2002) was carried out to investigate developments after the release of the former thermal comfort guideline. Also national and international comfort guidelines and standards were evaluated, including unpublished draft versions of international standards (e.g. draft ASHRAE standard 55 and draft EN-ISO 55). Further analysis of the ASHRAE RP-884 database was carried out. A workshop (de Wit, 1999) was held to gather comments of professionals who use the existing guidelines in practice. Field research (Raue, 2001) was done to test some findings in the Dutch situation. At several phases the researchers consulted Richard de Dear, whose findings (de Dear and Brager, 2001) formed a major contribution to the new guideline.

RESULTS

The new Dutch thermal comfort method is called the ATG method, ATG being an acronym for *Adaptieve Temperatuur Grenswaarden*. It is meant for moderate indoor environments, with the main emphasis on office buildings (metabolism 1,2 - 1,4 met; clothing in the 0,5 - 1,0 clo range). In less moderate circumstances, a PMV based method is likely to be more accurate. For an extensive explanation of the rationale behind the proposal we refer to Van der Linden et al, 2004. The quantitative data that the comfort limits are based upon, are derived from de Dear & Brager (2001). The thermal comfort model that was used is based on the "adaptation hypothesis" of thermal perception developed by Auliciems et al (1981).

The ATG guideline is based upon a *neutral temperature* that changes every day, as the occupants' expectation and clothing change with the weather. The ATG neutral temperature is calculated from the daily maximum and minimum outside temperatures over 4 days. The difference between the actual operative temperature and ATG neutral temperature defines the buildings' performance. Buildings of the Alpha type allow for a higher neutral temperature in the summer. The calculation of the ATG neutral temperature, performance classification and the Alpha type are explained in further detail below:

Neutral Temperature

The neutral temperature is most straightforward in Type Beta buildings. It is defined as:

$$T_{neutral,\ Beta} = 21{,}45\ ^{\circ}C + 0{,}11 \bullet T_{e,ref}$$

$T_{neutral}$ represents an *operative temperature*, which is roughly the average of the air temperature and radiant temperature in a room.

Reference Temperature: $T_{e,ref}$

Analysis of field studies (e.g. Morgan & de Dear, 2003; Oseland & Humphreys, 1994) showed that the amount of clothing people wear inside correlates strongly with the Running Mean Outside Temperature, which is a 'synthetic' outside temperature that integrates over the day of exposure and a couple of days before. It was assumed that in general the time-dimension of thermal adaptation is of the same order as the time-dimension of clothing adaptation. For practical reasons a numerical simplification of the RMOT is introduced, called $T_{e,ref}$. In formula:

$$T_{e,ref} = \frac{1 \cdot T_{out,\ today} + 0{,}8 \cdot T_{out,\ yesterday} + 0{,}4 \cdot T_{out,\ 2\ days\ ago} + 0{,}2 \cdot T_{out,\ 3\ days\ ago}}{2{,}4}$$

When estimating the 'outdoor temperature' on a certain day (today, yesterday etc.) one should calculate the average from the maximum and minimum outdoor temperature of that day. These data can be collected from local weather stations or mass media.

Classification

In accordance to international standards such as CR1752, performance is expressed in four classes in which Class A stands for a particularly good indoor environment, Class B for good common practice and Class C for lowest desirable performance. Class D is actually a rest category for environments where even class C criteria are not met. The ATG performance classes are defined as *bandwidths* around the neutral temperature:

Class $A_{,Beta}$ = 90% acceptability = $T_{neutral,Beta} \pm 1{,}25$ K.
Class $B_{,Beta}$ = 80% acceptability = $T_{neutral,Beta} \pm 2{,}0$ K.
Class $C_{,Beta}$ = 65% acceptability = $T_{neutral,Beta} \pm 2{,}5$ K.

If these bandwidths are exceeded at any moment during occupation hours of the building (so not at night, in weekends or holidays!), the building falls into the next class. For instance: if the Class A limits are exceeded during only a couple of hours per year, the buildings' performance is class B or lower.

Expressed graphically, the classification bandwidths of Type Beta relate to $T_{e,ref}$ as follows:

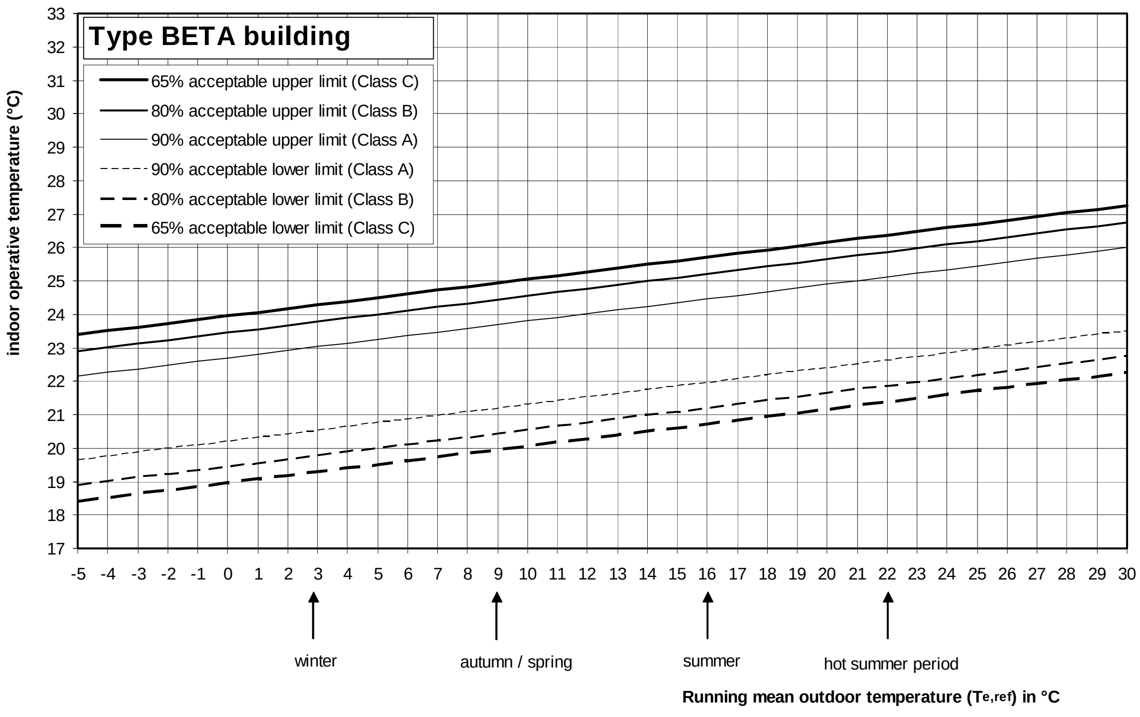


Figure 1: upper comfort limits for the operative indoor temperature (based on the results of de Dear & Brager, 2001) for type Beta spaces in relation to outdoor temperature $T_{e,ref}$.

Type Alpha

Many studies, for instance Oseland & Humphreys (1994), de Dear & Brager (2001) and Humphreys et al (2001), suggest that in buildings with operable windows less stringent criteria should be used than in buildings with centrally controlled climate systems and closed facades due to the 'adaptation factor'. In the ATG method, these distinctive building/climate types are referred to as type Alpha and type Beta.

In the paragraphs above, the method for the type Beta was described. The method for type Alpha is similar, except for that in warm periods ($T_{e,ref}$ > 10°C) $T_{neutral}$ regression is steeper and the upper bandwidths are bigger:

$$T_{neutral,\ Alpha} = 17{,}8\ ºC + 0{,}31 \bullet T_{e,ref}$$

The upper temperature limits for type Alpha buildings, when $T_{e,ref}$ > 10°C, are:

Class A $_{Alpha}$ = 90% acceptability = $T_{neutral,\ Alpha}$ + 2,5 K.
Class B $_{Alpha}$ = 80% acceptability = $T_{neutral,\ Alpha}$ + 3,5 K.
Class C $_{Alpha}$ = 65% acceptability = $T_{neutral,\ Alpha}$ + 4,2 K.

On days when $T_{e,ref}$ is 10°C or lower, the neutral temperature and bandwidths are similar to those of type Beta.

Graphically, the classification bandwidths of type Alpha relate to $T_{e,ref}$ as follows:

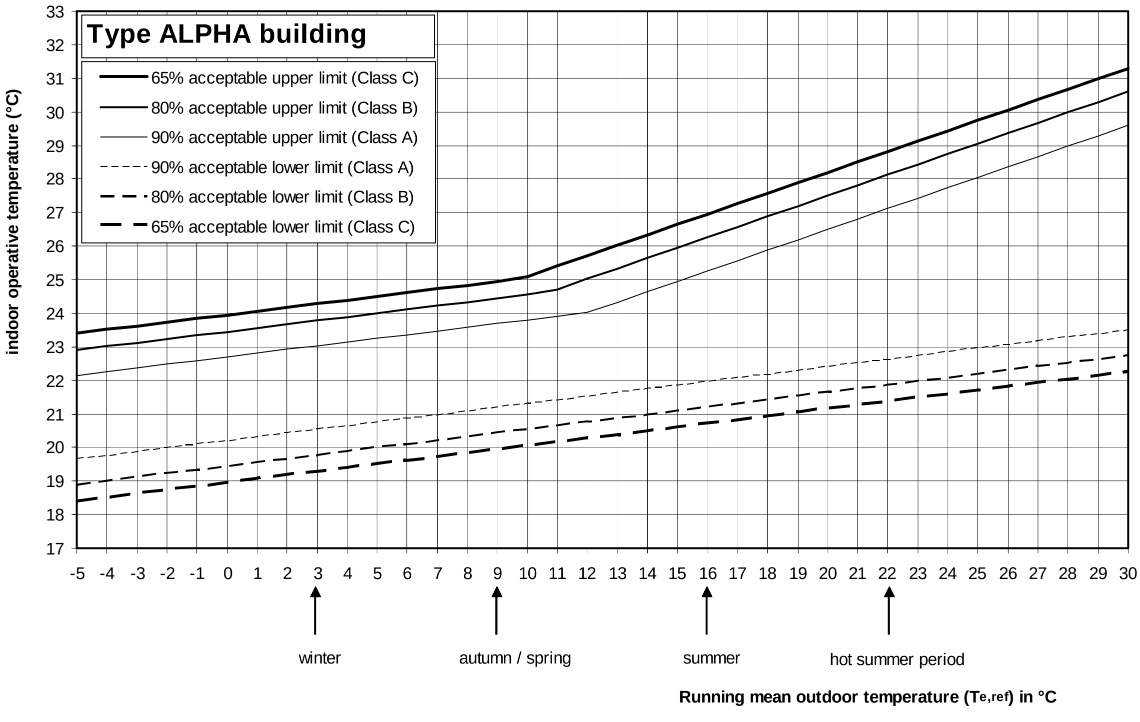


Figure 2: Upper comfort limits for the operative indoor temperature (based on the results of de Dear & Brager, 2001) for type Alpha spaces in relation to outdoor temperature $T_{e,ref}$.

It is possible to have both type Alpha and Beta spaces in one building, dependent on the characteristics of each space. The distinction between type Alpha and Beta is basically to be made upon the degree in which the occupant can actually control his thermal environment, combined with expectation (to put it simple: an occupant expects and so accepts higher temperatures in a building with no air conditioning). It is very complicated to fully model all factors that influence perceived control and expectation. Figure 3 shows a simplified model:

1. Does the façade have operable windows?
YES ↓ NO → type Beta

2. Can the occupants adjust their clothing to weather conditions (no dress code)?
YES ↓ NO → type Beta

3. Is there at least 1 operable window per 2 occupants, that they can actually use?
NO ↓ YES → type Alpha

4. Does the space have mechanical cooling?
YES ↓ NO → type Beta

5 Does the cooling system have at least 1 temperature control per 2 occupants?
YES → type Alpha NO → type Beta

Figure 3: Flowchart for the determination of the building/context type. Type Alpha refers to a building that allows for a high degree of occupant control, Beta to a rather centrally controlled context.

Example

Figure 4 is an example of measurements evaluation in a type Alpha room in an office building. The top- and bottom temperature limits differ per day, as they depend on the daily average outside temperature. In this example the temperature as measured stays within the 80% bandwidth. Therefore, this example shows 'class B thermal performance'.

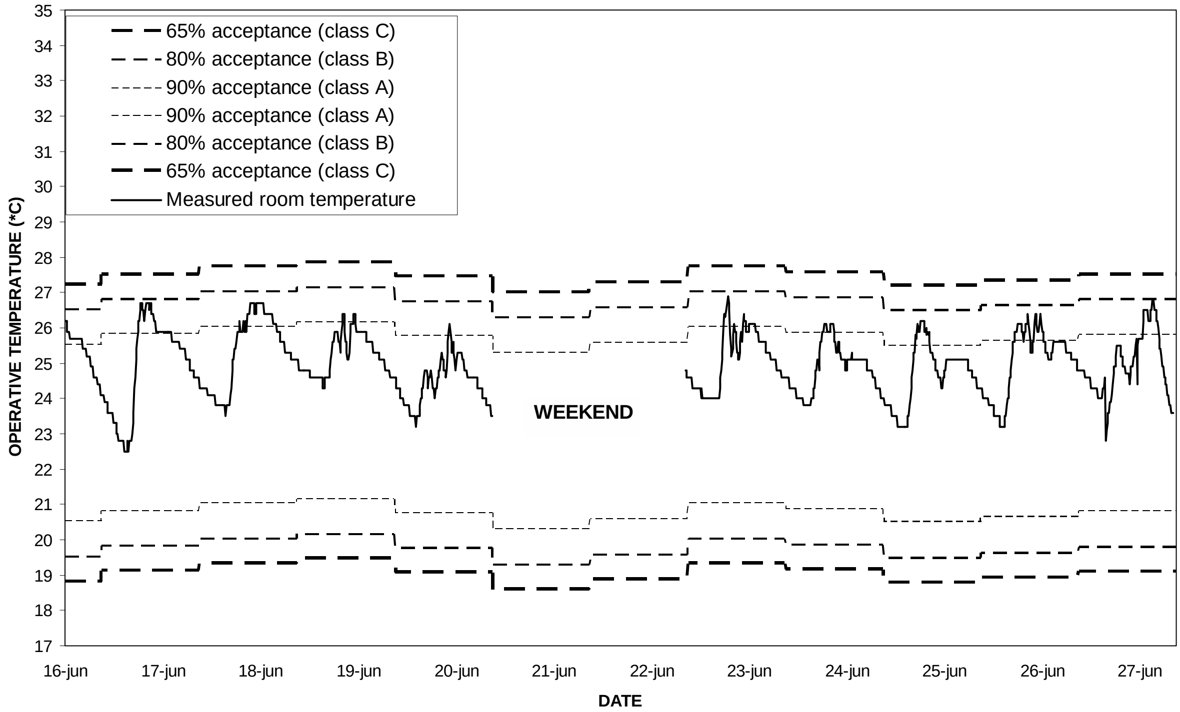


Figure 4: example of measurements evaluation in one room in a type Alpha office building.

CONCLUSIONS AND IMPLICATIONS

With the ATG method thermal comfort performance of buildings can be assessed and communicated.

- It can be used in buildings with sealed facades, full HVAC systems and little occupant influence on the environment, referred to as type Beta. For type Beta, results are quite similar to when the PMV model is applied.
- In contrast to many other methods, it is also validated for environments with simple climate systems and a relatively high grade of occupant control (type Alpha), for instance:
  - Evaluation of older buildings
  - Retrofit situations
  - Buildings with natural ventilation.
- The method can be used for design evaluation: assessment of temperature simulation results, based on building geometry and a standard climate year.
- The method can be used for the indicative assessment of momentary temperatures in a building, comparing the temperature as measured to the classification bands on that day.
- The method can also be used for long term assessment of thermal performance of a building, in cold as well as in warm periods.

The method will be evaluated in practice during the next 2 years in order to further improve its implications.

ACKNOWLEDGEMENTS

This paper is based on a study that was coordinated by ISSO, the Dutch institution for the Study and Research in the field of Building Services. The study was funded by the Dutch organization on Energy and Environment (NOVEM) and the Government Buildings Agency of the Netherlands (Rijksgebouwendienst). The authors also thank Richard de Dear, Bjarne Olesen and Joe Leijten for their general support and comments.

REFERENCES

Auliciems A. (1981). Towards a Psycho-Physiological Model of Thermal Perception. *International Journal of Biometeorology*, vol. **25**, pp 109 - 122.

de Dear R. and Brager, G. (2001). The adaptive model of thermal comfort and energy conservation in the built environment. *International Journal of Biometeorology*, **45:2**, pp 100-108.

Humphreys, M.A. et al ed. (2001). *Moving Thermal Comfort Standards into the 21st Century*. Proceedings conference 5th – 8th april 2001. Windsor, UK: Loughborough University.

ISSO-report 58.1, *Thermische behaaglijkheid als gebouwprestatie – literatuuronderzoek naar recente wetenschappelijke ontwikkelingen.* Rotterdam, 2002.

Linden, A.C. van der, Boerstra, A.C., Kurvers, S.R., Raue, A.K., Arets, M.J.P. (2004). *Thermische behaaglijkheid – Eisen voor de binnentemperatuur in gebouwen.* ISSO publication 74. Rotterdam: ISSO.

Morgan, C. and de Dear, R. (2003). Weather, clothing and thermal adaptation to indoor climate. *Climate Research*, **24:3**; pp 267-284.

Oseland, N.A. and Humphreys, M.A. (ed). (1994). *Thermal comfort: past, present and future.* Proceedings of a conference at the Building Research Establishment. Garston, UK: BRE.

Raue A.K., Arets, M.J.P., Bont, W.A., Notenboom, A.M.J., van der Linden, A.C. (2001). *Thermische behaaglijkheid als gebouwprestatie - Veldonderzoek naar de thermische behaaglijkheid in twee natuurlijk geventileerde gebouwen in de zomerperiode.* ISSO report.

Wit M.S. de, van der Linden, A.C and Raue, A.K. (1999). *Evaluatie van prestatie-indicatoren voor thermische behaaglijkheid in gebouwen.* Report, Delft University of Technology.

AIR LEAKINESS OF NON-STANDARD HOUSING: IMPACT OF UPGRADING MEASURES

S. Sharples[1] and C. Goodacre[2]

[1] Sheffield Hallam University, Centre for the Built Environment, Unit 9 Science Park, Howard Street, Sheffield S1 1WB, UK
[2] Sheffield City Council, P.O. Box 1918, Sheffield S1 2XX, UK

ABSTRACT

Sheffield City Council in the UK identified some dwellings of non-standard construction that needed to be refurbished. The refurbishment mainly involved applying insulation and rendering to the exterior surfaces of external walls and replacing old windows. The main aims of the refurbishment for the Council were to improve the condition and appearance of the dwellings and reduce conductive heat loss through the fabric. Although no specific measures were taken to improve the air tightness of the houses it was thought to be interesting to see if an improvement in air tightness could be achieved as a by-product of the general refurbishment. This study performed a series of blower door air tightness tests on three dwellings, each of different non-standard construction, before and after refurbishment. The three houses displayed a wide range of air leakiness values prior to refurbishment. The worst house had nearly twice the leakage of the best house and all the houses were above the recommended good practice air tightness value for UK housing. After refurbishment the leakiness of each house had been reduced, although the improvements were of not of equal magnitude. Two of the three houses did meet the good practice air tightness as an additional benefit of the general refurbishment.

KEYWORDS

Air tightness, energy, housing, refurbishment

INTRODUCTION

Adequate ventilation is obviously required in buildings to provide fresh air for respiration and to dilute and remove pollutants and combustion by-products. However, excessive ventilation can results in thermal discomfort (particularly draughts) and excessive energy consumption. Although UK thermal building regulations for housing have required progressively higher levels of insulation to reduce fabric energy losses there has not been an equivalent requirement for air tightness. Indeed, there is still no regulatory maximum air leakiness target for new or refurbished UK housing. A recent survey of the air tightness of UK dwellings by the Building Research Establishment (Stephen, 1998; Stephen, 2000) concluded that UK dwellings were leakier than in many other countries and that there was significant room for improvement in the air tightness of the UK housing stock. This improvement is particularly important for existing older housing since they are likely to be quite leaky, quite poorly insulated and to represent the vast majority of the housing stock (given the low rate of new house construction in the UK). Local authorities in the UK often have estates of houses that need refurbishment to improve the condition, appearance and thermal performance. This refurbishment will often involve increasing fabric insulation levels and replacing old single glazed windows. However, it is not usually the case that specific steps are taken to reduce the air leakiness of the properties (for example, sealing around service ducts and at constructional joins such as where walls meet floors and ceilings). Sheffield City Council had identified a number of houses that it wished to refurbish, but no actual target to reduce air leakiness was required as part of the project brief. This study sort to investigate what improvements in air tightness resulted as a by-product of this general programme of refurbishment.

THE HOUSES TESTED IN THE STUDY

The houses chosen for refurbishment by Sheffield City Council were all of non-standard construction (in terms of the combinations of materials used). General pre-refurbishment construction details are given in Table 1 while Table 2 describes the general refurbishment actions.

TABLE 1
Existing construction / materials data for the tested houses

House No.	Pre-Refurbishment Details	Before	After
House A	Ground floor: brick cavity wall 220mm thick. First floor: plasterboard interior on wooden studs with 25mm thick horizontal timber boards. Solid concrete floor. Envelope area: 205.25 m^2 Volume: 225.79 m^3		
House B	External walls of 250mm no-fines concrete, rendered externally and plastered internally. Solid load bearing panels (150mm thick) with infill of 180mm thick breeze block, plastered internally. Solid concrete floor. Envelope area: 190.97 m^2 Volume: 210.95 m^3		
House C	External walls of pre-cast concrete load bearing panels (150mm thick) with infill of 180mm thick breeze block, plastered internally. First floor wall is tiles fixed to battens with 25mm insulation board, 100 x 50 softwood frame with 12.5mm plasterboard. Solid concrete floor. Envelope area: 196.38 m^2 Volume: 220.15 m^3		

TABLE 2

Refurbishment construction / materials data for the tested houses

House No.	Post-Refurbishment Construction Details
House A	External timber cladding removed to allow voids between studs to be filled with 75mm insulation board, recover with vapour barrier and new timber cladding. Existing timber window replaced with upvc double glazed windows with Pilkington low E glass. Replacement of front and rear doors with upvc and fibreglass high performance doors.
House B	50mm insulation boards fixed to the external elevations and covered with a Permarock render system, all windows replaced with upvc double glazed windows as above, Renewal of soffit, fascia and rainwater system.
House C	1st floor tiles removed and 50mm insulation boards fixed to the external elevations and covered with a Permarock render system, all windows replaced with upvc double glazed windows as above, renewal of soffit, fascia and rainwater system.

METHODOLOGY

The air leakiness characteristics of each property were established using the blower door technique described in the Chartered Institution of Building Services Engineers publication TM23 (CIBSE, 2000) and prEN 13829 (2000). Two panels in to which calibrated fans were placed replaced an external door. All internal doors were opened and all purpose-made openings (trickle vents, flues, air bricks etc.) were sealed. The fans were used to depressurise the house to create indoor-outdoor pressure differences from approximately 25 to 55 Pascal (in approximately 6 equal steps) . The airflow through the fan, Q, at each pressure differential, ΔP, was determined and a graph of Q versus ΔP was plotted to show the air leakage characteristic curve for each dwelling. The data were fitted to a power law equation

$$Q = C\,(\Delta P)^n \qquad (1)$$

where Q is the measured air volume flow rate in (m^3h^{-1}); C and n relate to the specific building under test and ΔP is the internal/external pressure difference (Pascal). Work by Walker et al (1998) has tested the validity of using this power law equation for low pressure envelope leakage testing. Figure 1 shows an internal and external view of the blower door in place.

Figure 1: Internal and external view of blower door

RESULTS

i) Air tightness results before refurbishment

Figure 2 show the Q-ΔP curves for the three houses before refurbishment.

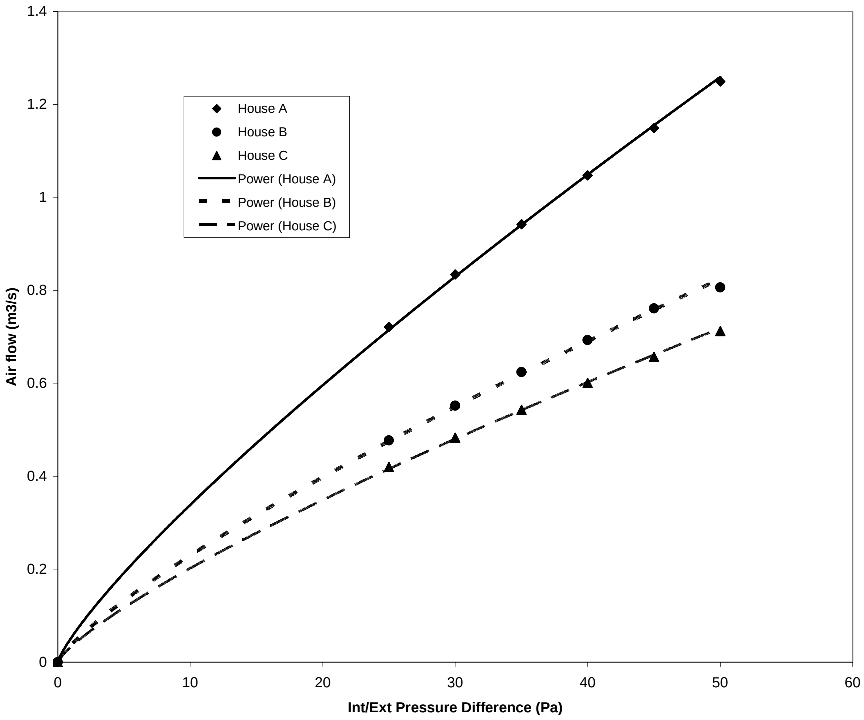


Figure 2: Q-ΔP curves for the three houses before any refurbishment

There are several ways of expressing air leakiness to give a value that can be used to compare the performance of different buildings. Air permeability is defined as the air leakage rate (m^3/hour) at an indoor-outdoor pressure difference of 50 Pascal, Q_{50}, divided by the total building envelope surface area (including the ground floor area) S. In the UK a naturally ventilated dwelling built to a 'good practice' standard would be expected to have a Q_{50}/S value of 10.0 $m^3/h/m^2$ at 50 Pa and a 'best practice' standard would be expected to have a Q_{50}/S value of 5.0 $m^3/h/m^2$. An air leakage test does not explicitly give a value for the air infiltration rate of a dwelling. However, from a large number of measurements on dwellings it has been possible to develop a 'rule of thumb' that the air infiltration rate per hour (ACH) is approximately $1/20^{th}$ of the Q_{50} air flow divided by the volume of the house. Table 3 shows a comparison of the air permeability values for the three houses before refurbishment and estimated ACH values based on the $1/20^{th}$ rule.

TABLE 3
Air permeability values of houses before refurbishment

House	**Q_{50}/S measured ($m^3/h/m^2$)**	**Q_{50}/S good practice ($m^3/h/m^2$)**	**Air Infiltration Rate (ACH)**
House A	21.9	10.0	0.99
House B	15.2	10.0	0.69
House C	13.1	10.0	0.58

It is apparent from Table 3 that, prior to refurbishment all of the houses were a long way from even the 'good practice' value and that there was a large range of leakiness values between the three houses.

ii) Air tightness results after refurbishment

Figure 3 show the Q-ΔP curves for the three houses after refurbishment.

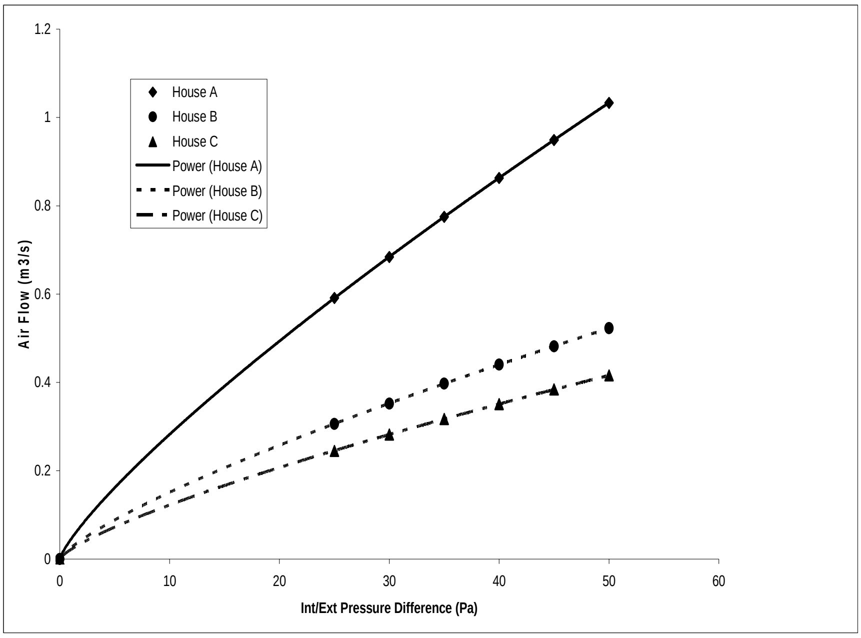


Figure 3: Q-ΔP curves for the three houses after refurbishment

The before and after refurbishment air permeabilities and air changes per hour are shown in Table 4.

TABLE 4
Air permeability values of houses after refurbishment

House	**Q_{50}/S before ($m^3/h/m^2$)**	**Q_{50}/S after ($m^3/h/m^2$)**	**% change**	**ACH before**	**ACH after**	**% change**
House A	21.9	18.1	21 %	0.99	0.82	21 %
House B	15.2	9.9	54 %	0.69	0.45	53 %
House C	13.1	7.6	72 %	0.58	0.34	71 %

DISCUSSION

Table 4 demonstrates that the general refurbishment of all three of the houses did produce, as an added benefit, an improved level of air tightness. However, the improvements were not uniform; the leakiest house before refurbishment, House A, was still the leakiest after refurbishment and was still a long way from meeting the recommended UK ‘good practice’ air permeability for dwellings of 10 $m^3/h/m^2$. The other two house did meet the value after refurbishment. The non standard construction details of House A were still contributing to a high leakiness and the general refurbishment had produced a moderate improvement. The timber boards on the front of House A were replaced after refurbishment and these remained as a potential leakage path. It would be necessary to apply specialist sealing techniques to significantly improve House A's performance. Houses B and C experienced relatively much bigger improvements in air tightness after general refurbishment. House B had solid concrete panels and it might be expected that the applied insulated and rendered panels would not have a big effect. It is probable that the installation of new double glazing in House B and the covering of some old gas fire flue outlets by the rendered panels were the biggest cause for the observed improvement. The hung tiles on the first floor of House C were replaced by insulated and rendered panels. This, together with the new glazing, probably accounts for the very large observed improvement in the air tightness of House C.

The residents of the three houses were all asked for their opinion on the thermal performance / thermal comfort after refurbishment. They all felt that there was a significant and noticeable improvement in terms of reduced need for heating to obtain comfort.

The largest survey of air tightness of UK dwellings, carried out by the Building Research Establishment (Stephen, 1998) examined 471 properties of various ages. The BRE survey found the mean air permeability to be 11.5 $m^3/h/m^2$. Comparison with the values in Table 4 for the three houses from this study indicate that prior to refurbishment all the houses had above UK average leakiness but that after refurbishment only House A was still above the national average.

CONCLUSION

Sheffield City Council undertook to improve the appearance and insulation levels of some unusually constructed dwellings. The cost of refurbishment was high (typically €30,000 per dwelling) because of the non-standard constructional details that had to be worked around. However, this study has shown that as well as reducing fabric heat losses the refurbishment has had the added benefit of reducing ventilation energy losses due to the unplanned improvement in air tightness.

REFERENCES

CIBSE (2000). *Testing buildings for air leakage,* Chartered Institution of Building Services Engineers Technical Memorandum TM23

prEN 13829 (2000) *Thermal performance of buildings - determination of air permeability of buildings - fan pressurisation method* (ISO 9972:1996, modified), European Committee for Standardisation, Brussels

Stephen, R. (1998). *Airtightness in UK dwellings: BRE test results and their significance,* Building Research Establishment Information Report BR 359

Stephen, R. (2000). *Airtightness in UK dwellings,* Building Research Establishment Information Paper IP 1/00

Walker, I.S., Wilson, D.J. and Sherman, M.H. (1998). A comparison of the power law to quadratic formulations for air infiltration calculations. *Energy and Buildings* **27**, 293-299

VENTILATION RETROFITTING OF PUBLIC OFFICE BUILDINGS IN GREECE

Chris J. Koinakis

Laboratory of Building and Construction Physics, Dept. of Civil Engineering, Aristotle University, 54006 Thessaloniki & Social Insurance Institute, Greece, e-mail: chrisko@civil.auth.gr

ABSTRACT

This paper presents aspects of an office renovation project of the Social Insurance Institute (SII), the largest Social Security Organization in Greece. The project refers to small and larger SII office buildings, including various stages of intervention, ranging from the construction of new buildings, to renovation of existing buildings. Construction and electro-mechanical studies for each building were carried out in order to implement the appropriate and feasible actions. Mechanical ventilation was implemented in all spaces, including forced air circulation through wall or ceiling-mounted air ducts and hybrid ventilation. Energy saving strategies were also implemented including shading, solar-absorbent glazing, night ventilation, energy efficient lamps and BMS controlled A/C system. Two case-studies of buildings in the area of Northern Greece are briefly presented. Thermal comfort conditions and energy consumptions are examined for various retrofitting scenarios and results are discussed.

KEYWORDS

Ventilation retrofitting, energy consumption, thermal comfort sense, office buildings.

1. INTRODUCTION

This paper presents aspects of an office renovation project of the Social Insurance Institute (SII), the largest Social Security Organization in Greece. It covers 5,530,000 workers and employees and provides 830,000 pensioners with retirement pensions. This project refers to the renovation of more than 200 SII office buildings throughout Greece, including various stages of intervention. Renovations include complete resettlement of the internal spaces, of counters and furniture of specific types and integrated cable network; they also include linking on-line all desk and back-office positions country-wide. Complete structural and electro-mechanical studies for each building were carried out. The initial budget of the project is 15.000.000 €, not including the construction of new building complexes. The project is mainly funded by the European Union [1], [2].

Within the frame-work of this project, mechanical ventilation of all spaces is implemented, including forced air-circulation, through wall or ceiling-mounted air ducts in each floor independent, and also hybrid ventilation. Two case-studies, are briefly presented, in the cities of Kozani and Ptolemaida in Northern Greece, each one for a specific building. Various HVAC equipment was selected, taking into account the building characteristics and local demands. Both buildings are heated by the tele-heating network of the Kozani prefecture where most of the thermo-electric factories of the Greek Public Electricity Company are established.

1.1. Building characteristics

The building in the first case study is a 5-storey office building with a shopping arcade on the ground floor, located in the center of the city of Kozani, a major town in northern Greece. The 1st to 4th floors are for office use and the basement is used for parking and storing purposes. The building is newly constructed (after 2002) and was built as a commercial building for stores and offices. The retrofitting project began at the concrete frame construction stage. A typical plan view is presented in Fig. 1. A central atrium creates a west and an east wing. The building has a total area of 2.072 m, has extended glazed facades and is constructed according to the Greek Thermal regulation code and the respective HVAC Greek regulations and technical guidelines.

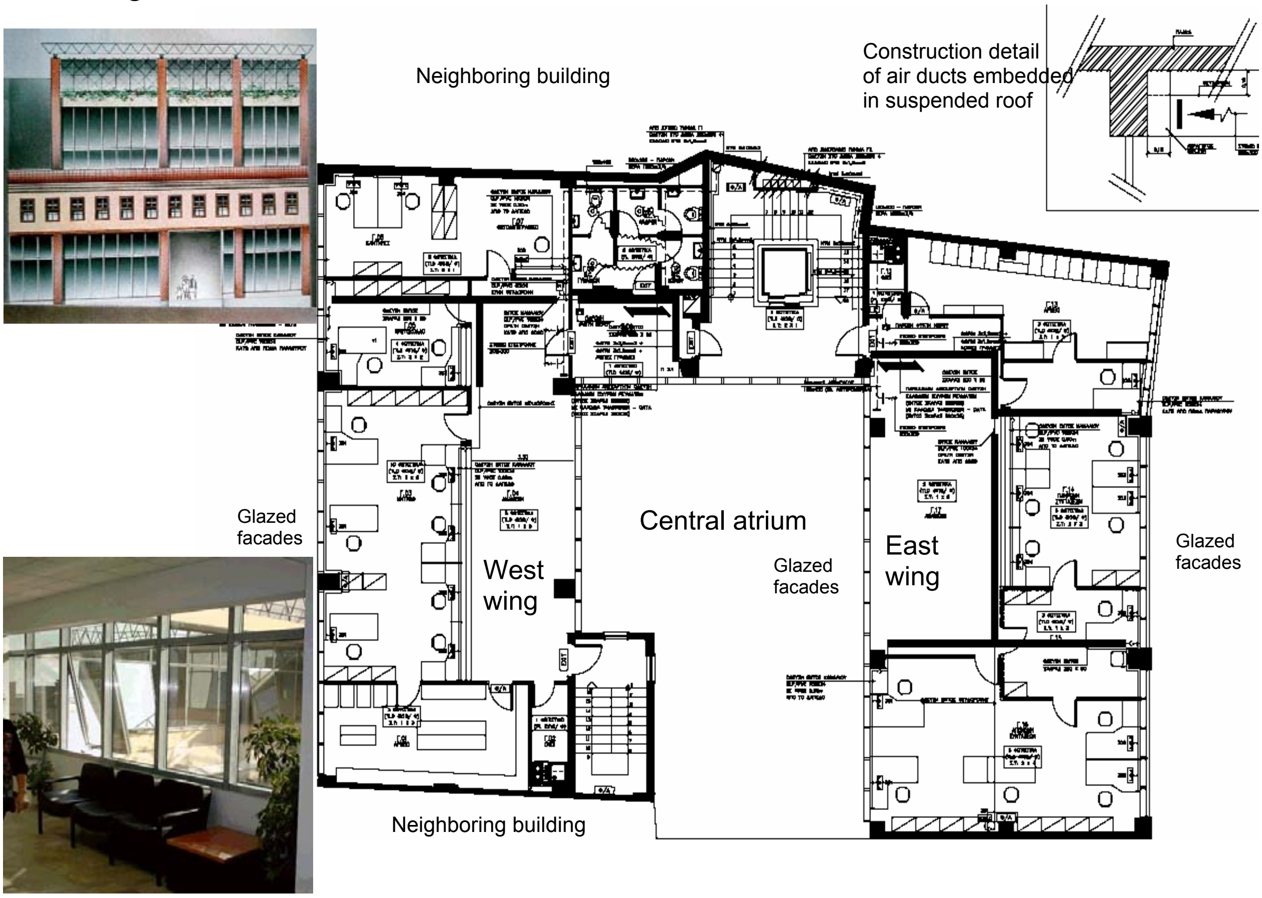


Fig. 1. Above: plan view of a typical floor of the first case study building. Left: views of the building.

The building in the second case study is a 4-storey former apartment house building constructed at late 60's in Ptolemaida a medium-sized town of the northern Greece. Two of the floors were completely reconstructed in order to be used as offices. A new staircase and a new elevator were constructed among others and the HVAC installations were completely re-designed. The building has a northern and an eastern façade and is placed in dense urban environment. A plan view is presented in fig. 2. The surrounding surfaces were reconstructed and solar-absorbent glazing and venetian blinds were used. All the reconstructed elements were insulated.

2. VENTILATION RETROFITTING

Different heating, cooling and ventilation retrofitting strategies were implemented in the two buildings, due to the different configuration, building type and size characteristics.

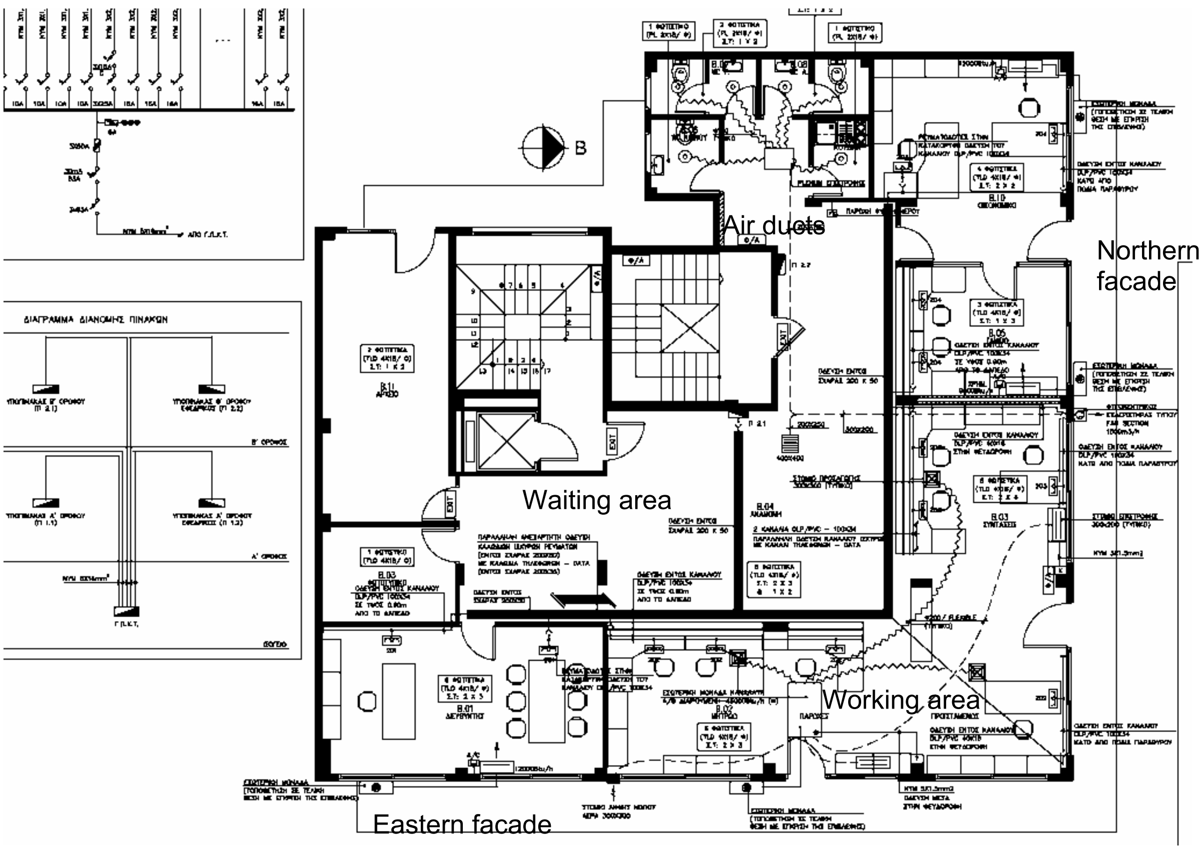


Fig. 2. Plan view of a typical floor of the second case study building.

2.1 First case study

The office building at Kozani has a central heating-cooling installation with a boiler-room at the basement and an external cooling unit on the roof. The central heating installation includes a heat exchange system to cover the thermal demands of the building, supplying the fan coil units of the building with hot water, through a twin-tube system. The heat exchange system is supplied (primary circuit) by the tele-heating network of the thermo-electric factories in the Kozani area and supplies the fan coil units (secondary circuit) with hot water. In the event of supply debility of the tele-heating network an oil boiler and oil tanks could be installed.

For the cooling demands of the building a central cooling system was installed on the roof, including a 500.000 Btu/h air-cooler, the necessary pump equipment and network for the supply of cooled water to the fan coil units of the building. There is no provision for pre-conditioned air and the mechanical ventilation system is designed separately.
In the office building at Kozani, two individual mechanical ventilation systems were installed, one for each wing of the building. There is a separate ventilator unit for each floor of each wing totaling 8 units for the 1st to 4th floors, plus one unit for the separate department of IT services (computer room) and one unit for the basement. The air is removed using plenum and flexible air ducts in the W.C. areas of each wing, which end up at inlets which are placed in the public waiting areas of each level and are covered with grids.

Each unit includes a centrifugal fan (fan section) and the air is carried outdoors, through return outlets and galvanized iron-plated air ducts. The units are placed on the roof of the building near the staircase and ducts are embedded inside the suspended roof. The air enters due to sub-pressure from the external openings of the glazed facades, which are especially designed for this purpose (inclined lintel windows or common, inclined windows). This solution was selected because of the lack of a pre-conditioned air HVAC system in the building. According to the technical guide-lines of the Technical Chamber of Greece (TOTEE 2425/86, tabl. 2.4 & 2.5) [3], there should be air rejection at the rate of at least 25%. The total re-circulated air supply should be at least 6 air changes per hour which is acceptable for office spaces and public waiting rooms. In the examined case, 8 air changes per hour were implemented, taking into account that glazed partitions are used to separate the above-mentioned spaces. Thermal comfort sense in office spaces was carefully estimated by interviewing the staff and by carrying out temperature and air velocity measurements according to the Fanger thermal comfort sense diagrams (Fig 3). The total re-circulated air supply per wing and floor is 3500 m^3/h and the minimum rejected air rate is 875 m^3/h. In order to select the proper ventilation unit characteristics, ventilation efficiency tests are performed for each area, according to the area population, taking into account the peak demands per floor and wing, which is 44 m^2 of the public waiting area and 12 working places. The ventilation demand per person is 30 m^3/h in total, 25% of which (7,5 m^3/h) is fresh air. The peak demands are calculated for 12 working places plus a customer per place, and for the crowded waiting area of 44 m^2, (1 person/1.1 m^2), reaching a total of 64 persons. The lowest total air supply demand is therefore 1920 m^3/h of re-circulated air and 540 m3/h of fresh air. To fulfill the demand of both tests it is necessary to achieve 900 m^3/h minimum rejected air supply. The selected ventilation units are of 1000 m^3/h middle supply and 1500 m^3/h maximum supply.

2.2 Second case study

The office building at Ptolemaida has a central heating installation with boiler room at the basement, including a heat exchange system supplying hot water to ordinary radiators of the building. The heat exchange system is supplied by the tele-heating network of the thermo-electric factories in the wider Kozani area and supplies the radiators with hot water.
The cooling installation in the second case study differs to that in the first case study. Both floors of the office building are air conditioned, implementing two system types. Wall split units are installed for isolated offices and air duct units are installed in unified working places and public waiting areas on both floors. Two 76.000 Btu/h A/C air duct units were selected for each floor and three wall split units from 9.000 to 12.000 Btu/h were selected for the isolated offices. The split units can also be used for heating.

Mechanical ventilation was installed individually on both floors for forced air removal. The air is removed from the areas near the W.C. on each floor, implementing plenum and flexible air ducts and a central air inlet in the public waiting area, for air removal. All ventilation units are placed inside the suspended roof area, including a centrifugal ventilator in a sound-absorbent box (fan section). The air is removed outdoors through air outlets and ducts. The fresh air enters the working spaces through the inlets of the air duct units and through the external openings due to sub pressure. The mechanical ventilation demands are 6 air changes per hour, including 25% of fresh air, according to the technical guidance mentioned before [3]. The total air supply is therefore 3600 m3/h, per floor and the minimum demand of the rejected air is 900 m^3/h. For the selection of the proper ventilation unit, ventilation efficiency tests were performed, taking into account the population of each area.

The peak demands were calculated for 12 working places plus a customer per place and a crowded waiting area of 58 m^2, (1 person/1.1 m^2), reaching a total of 77 persons. The lowest total air supply demand is therefore 2300 m^3/h of re-circulated air and 575 m3/h of fresh air. To fulfill the demand of both tests it is necessary to achieve 900 m^3/h minimum rejected air supply per floor (3600 m^3/h of re-circulation for 6 ach). The selected ventilation units are of 1000 m^3/h middle supply and 1500 m3/h maximum supply.

The energy simulations and the HVAC systems study were performed implementing appropriate software packages (Suncode, EnergyPlus and 3M). Measurements were performed implementing temperate and humidity sensors and a hot-wire anemometer was used for wind speed measurements.

3. THERMAL COMFORT ASSESSMENT

Thermal comfort measurements implementing air and surface temperature measurements, wind velocity and relative humidity measurements, were carried out in both buildings after the completion of ventilation retrofitting,. Winter measurements were carried out during January and summer measurements during July and August. The results are presented in the Fanger diagrams in Fig. 3. The retrofitting of the HVAC systems resulted in a significant improvement of thermal comfort sense with an average of more than 91% satisfaction in all cases. The measurements agreed with the interview questionnaire of the personnel and the public. Some particular problems had to be confronted in-situ, especially the adjustment of the mechanical ventilation outlets near the counters and the relative position of the counter glass partitions and the air outlets. Different diffusion grids were selected and in some cases a re-settlement of the furniture was carried out in order to eliminate local air-draught problems. These problems proved critical for the health of the personnel sometimes resulting serious shoulder and neck problems.

Relative humidity was kept within acceptable values (mean values 49% and 42% in winter and summer respectively in both buildings). Sporadic summer measurements in the crowded waiting areas revealed values above 87% when mechanical ventilation was not operating. Indoor temperatures were kept within tolerable limits. During the summer period the ventilation units were often used in maximum supply (1500 m^3/h in both case studies) resulting in increased air velocity values of more than 50% compared to the respective winter values, reaching 0.24 m/s mean value in highly ventilated waiting areas. Some peak values exceeded 0.65 m/s and efforts were made to confine these to non working or waiting areas. The air change values were increased from 6 ach to more than 8 ach in the summer period. This strategy combines the benefits of roof ventilators and offers the possibility of implementing night-time purge ventilation.

The surface temperatures of the floor and the surrounding walls were kept within the tolerable area in the Fanger diagrams (fig. 3) in most cases due to insulation improvement measures in the floor areas. The different types of office buildings in the examined cased studies, requested different renovation strategies.

4. ENERGY CONSUMPTION FOR RETROFITTING SCENARIOS

The specific annual energy consumption for both case studies is presented in Fig. 5. Heating, cooling, ventilation, lighting, electric appliances etc, are calculated implementing energy simulations for four retrofitting scenarios. “Initial condition” refers to the conditions before the building retrofitting (“old” building) and before the office renovation project. “Present working condition without retrofitting” refers to the implementation of the office renovation project in the “old” building, without intervention on the building envelope or on HVAC equipment. “Present working condition with retrofitting” refers to the conditions after the building retrofitting and the office renovation project, which is the existing condition. “Potential for further improvement” refers to retrofitting measures that was not implemented because of technical and economical reasons or to measures for future implementation.

The heating and cooling set points where 20 °C and 25°C respectively, based on the real working conditions according to the measurements. All the ventilation retrofitting measures as described in the 2nd paragraph were taken into account and the end-users real behavior was simulated. The distribution of ventilation losses for different air supply modes of mechanical ventilation is presented in Fig. 5. The implemented mechanical ventilation schedule was based on the recording of the end-user's behavior. The mechanical ventilation operates for approximately 1.5 hours in winter (at the lower mode) and for approximately 3.5 in summer (at the middle and higher modes). The summer night ventilation taken into account separately.

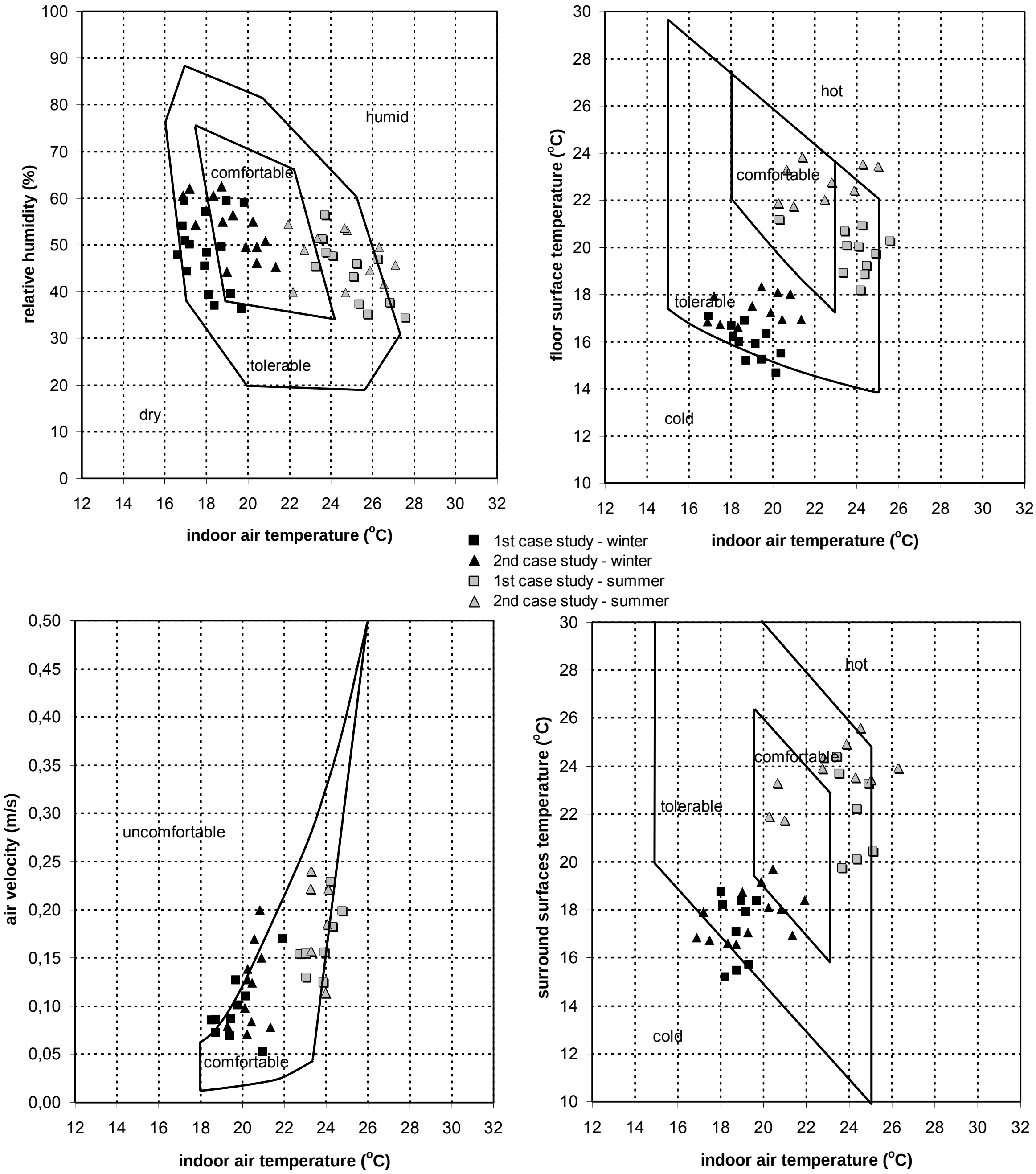
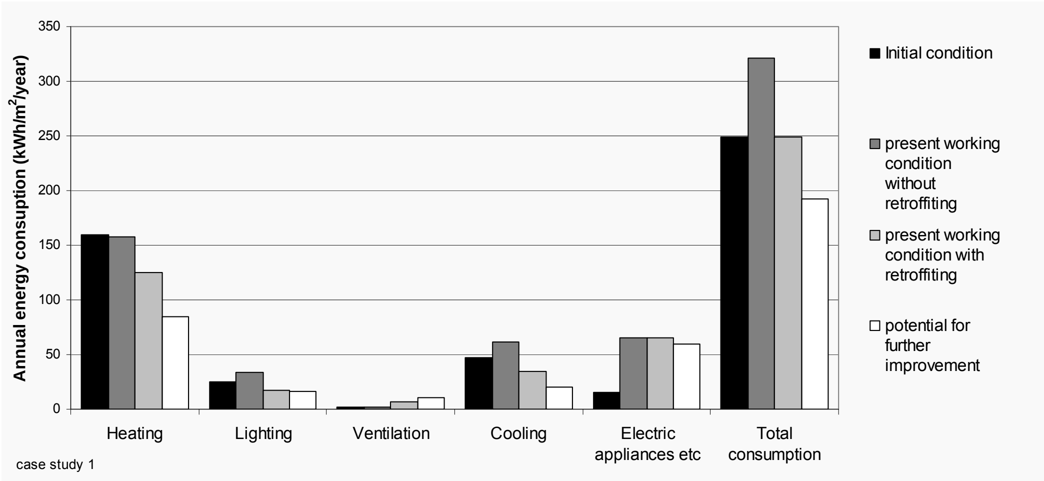


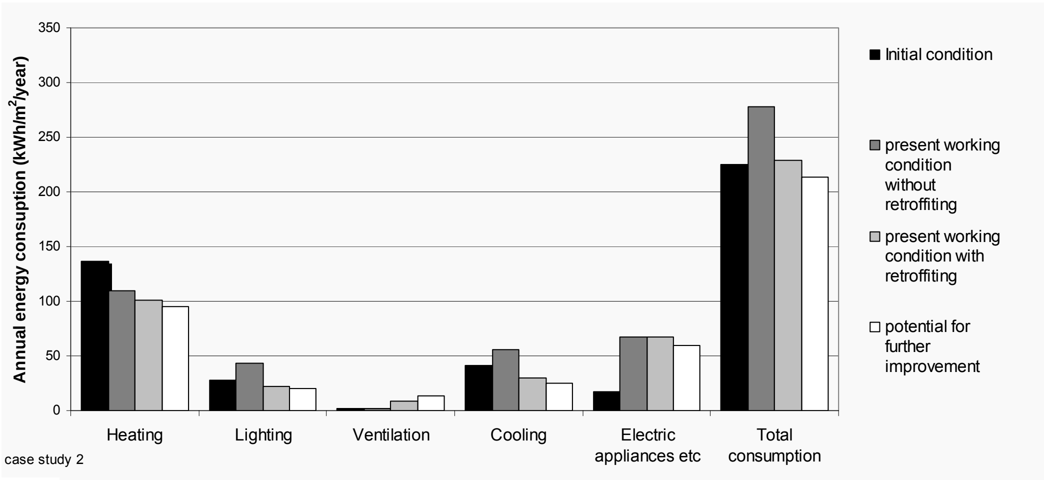
Fig. 3 Thermal comfort sense according to Fanger diagrams, for the two case-studies. Winter and summer measurements.



F/V=0.72

Retrofitting scenario:

	energy consumption						comfort percentage	
	Heating	Lighting	Ventilation	Cooling	Electric appliances etc	Total consumption	winter 8:00-10:00	summer 12:00-14:00
	100%	100%	100%	100%	100%	100%	100%	100%
	99%	136%	100%	143%	300%	123%	104%	49%
	78%	68%	350%	81%	300%	93%	162%	249%
	53%	64%	550%	43%	273%	69%	173%	271%



F/V=0.39

Retrofitting scenario:

	energy consumption						comfort percentage	
	Heating	Lighting	Ventilation	Cooling	Electric appliances etc	Total consumption	winter 8:00-10:00	summer 12:00-14:00
	100%	100%	100%	100%	100%	100%	100%	100%
	80%	154%	100%	137%	271%	114%	151%	37%
	74%	79%	450%	73%	271%	92%	260%	330%
	69%	71%	650%	61%	253%	87%	271%	352%

Fig. 4 Specific energy consumption and thermal comfort for various retrofitting scenarios. 1st case study (above), 2nd case-study (below).

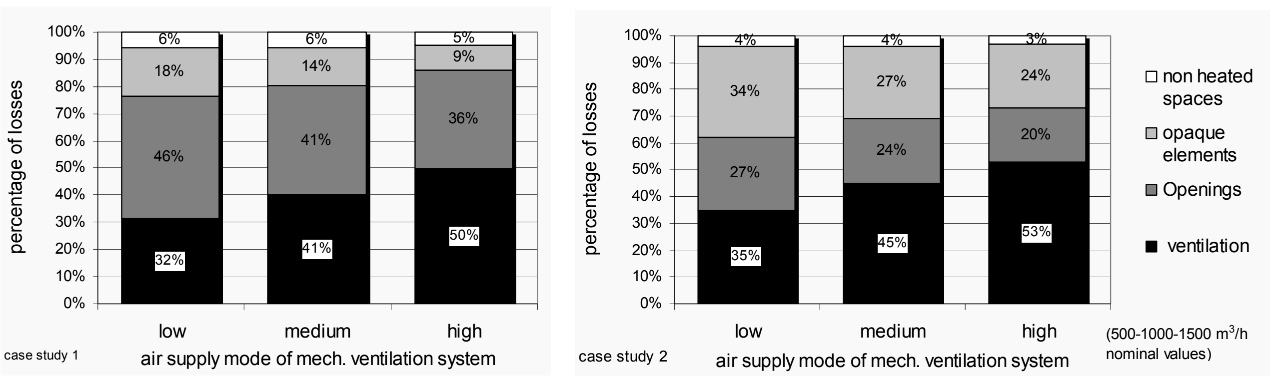


Fig. 5. Distribution of ventilation losses for different air supply mode of mechanical ventilation in the 1st case-study (left) and in the 2nd case-study (right).

5. CONCLUSIONS AND REMARKS

As derived from energy consumption calculations in Fig. 4, the night mechanical ventilation (night purge) proved to be a practical strategy to decrease cooling demand during summer and could be programmable. In the first case study the high building surface to volume (F/V) ratio and the configuration of the building with internal atrium and the extended eastern and western facades resulted in summer overheating problems due to extensive direct solar radiation. Only internal venetian blinds could were used for architectural reasons and the night purge ventilation reduced the cooling demand to 81% of the initial condition, compared to 143% of the initial condition without ventilation retrofitting (fig. 4 above). In the 2nd case study where direct solar radiation is limited due to the dense urban environment and the northern orientation and the F/V ratio is rather small, night mechanical ventilation reduces the cooling demand at 73% of the initial condition, compared to 137% if there was only equipment renovation and no ventilation retrofitting (fig. 4 below). The benefits of this strategy on thermal comfort were immediately noticeable by the end-users. Cooling demand could be further slightly decreased at 61%, if awnings are placed. This solution is generally difficult to implement in these buildings. In the first case study mechanical ventilation should be combined more with natural ventilation though the extended facades and the sometimes end users often cause energy malfunctions such as they open windows near operation fan coils, and they under- or over- use mechanical ventilation. On the contrary, in the second case-study the office building is more mechanically controlled and mal-uses are avoided in most cases.

The specific heating and cooling consumptions in the two case studies were 110 and 101 kWh/m^2 per year for heating and 38 and 30 kWh/m^2 per year for cooling demands for the 1st and 2nd case-study respectively. The most significant factors affecting energy consumptions were, the F/V ratio, the glazing facades and the incident solar radiation. These are the reasons why the newer building has slightly higher consumption, despite the higher energy standards. The energy consumption of the first building could be significantly higher. If the heat transfer coefficient of the 1st case building envelope was the same as the 2nd case-study, the energy consumption would be significantly higher [4], [5].

Taking also into consideration that the major equipment renovation project of SSI increases the thermal and cooling demands, the ventilation retrofitting proved to be a major adjusting factor for energy efficiency and indoor environment design. The total cost of the ventilation retrofitting measures was less than 4% of the total budget and the benefits include a tripling of the percentage of satisfied end-users and the reduction of the cooling demand by more than 40%.

REFERENCES

[1]. Koinakis, C.J. (2001). Internal report of the integrated IT equipment and building renovation project – initial phase. *Supervision Team for Northern Greece, Social Insurance Institute (SII), Greece, (in Greek).*

[2]. Koinakis, C.J. (2003). Internal report of the integrated IT equipment and building renovation project – initial phase. *Supervision Team for Northern Greece, Social Insurance Institute (SII), Greece (in Greek).*

[3]. TOTEE (1986). Technical guide-lines of the Technical Chamber of Greece (TOTEE 2425/86). *Technical Chamber of Greece, Athens, Greece (in Greek).*

[4]. GTIC (1979). Greek Thermal Insulation Code (GTIC). *Greek State Journal no. 362/Δ/4-7-79, Greece (in Greek).*

[5]. KOXEE (1998). Regulations for Energy Efficiency Use and Energy Saving (KOXEE). *Resol. 21475/4707/98, State Journal no. 880/B/19-8-98, Greece, (in Greek).*

ON THE INFLUENCE OF THE AIR INFILTRATION HEAT LOSSES ON THE ENERGY PERFORMANCE OF ITALIAN RESIDENTIAL BUILDINGS

Michele Zinzi[1] ,Gaetano Fasano[1], Augusto Maccari[1]

1 ENEA-UDA National Agency for Energy & Environonmment
via Anguillarese 301, 00060 Rome, Italy

ABSTRACT

It is often discussed about the possibilities that more efficient windows offer to reduce the energy loads in residential buildings. Often such results can be achieved reducing the thermal transmittance or optimising the solar gains, not so often the influence of the air permeability is taken into account. This issue is, on the contrary, very important in countries, as Italy, where the age of the building stock is accompanied by the installation of very old windows, characterised by high air leakage, which causes strong heat losses and discomfort phenomena for users. This paper aims at giving an idea of the achievable heating energy savings coming from the application of more tight fenestration systems at national and dwelling level. This should give also some useful indication for users about the economic savings that can be obtained during the life cycle of the installed product. It is also presented the ENEA experimental building, where testing and evaluation of different fenestration products, concerning the energy and the thermal comfort performances, are scheduled for the next heating season .

KEYWORDS

Windows, air infiltration, residential buildings, space heating.

INTRODUCTION

One of the main issues related to the Italian building stock is its advanced age. The last census showed that, of the 26.5 million of Italian dwellings, around the 25% was built before the world war two and the 80% was built before 1980, that is the period when policies of energy savings started to be taken into account in the building sector. Another important factor is the 65 to 70% of single glazed window actually installed in the Italian building, considering that in commercial buildings more efficient fenestrations systems are installed since several years, it is evident the poor state of the windows stock in the Italian residential sector. Even if new energy regulations were implemented in the past years, their effect was very limited, since the refurbishment aiming at improving the energy performance of existing building growing quite slowly. The residential sector reflect this negative trend, with the heating needs of Italian building among the highest in Europe, considering the climatic conditions.

It is often discussed and indicated, especially at normative level, the importance of the *U* value of the windows to improve the thermal performances of buildings, without considering the influence of the air permeability of such components, in particular in case of old and leaky fenestration systems. In addition, discomfort phenomena may arise close to the windows due to the presence of cold air streams. It must be noted that Italian dwellings are seldom equipped with mechanical ventilation system, this imply that the indoor air exchange and quality relies only on the natural ventilation, which, especially in winter time, does not have an adequate rate and, as a consequence, a limited energy impact. Improving the air tightness of the windows and, as a consequence of the buildings, is necessary to compensate the higher energy loads coming from the application of mechanical ventilation system, bound to be mandatory according to the forthcoming new national energy methodology.

A STUDY FOR AN ENERGY RATING SYSTEM IN RESIDENTIAL BUILDINGS

A self financed study for the implementation of an energy rating system for windows in the Italian residential buildings was carried out at the end of the nineties. the results of the study are largely presented elsewhere, Maccari et al. (2000). Here are summarised the basic principles of that research, while more focused will be the analysis related to the air permeability evaluation. It is also important noting that, even this study was never turned into real policies at standard and normative level, it made arise an important discussion on how and why improve the fenestration stock in the Italian market.

The energy balance of the building depends on the *Uvalue* (thermal losses), *g* (solar gains) and the air infiltration through the fenestration. The main idea to rate the windows was to analyse how a fenestration system, with known properties, affected the building performance. To do this, it was necessary to have a large amount of data and use them for a best fit regression, in order to obtain a simple equation to compare different kind of windows. Hence were selected: 3 type of buildings (row houses, 6 building, with pilotis at ground level, 4 level building), 5 cities (representative of all the climatic zones, but the hotter with not significant settlements); 6type of windows, summarised in table 1. More over the energy performance of buildings were calculated for 8 different orientation. All the simulation were performed with a well known dynamic code fo building energy analyses, TRNSYS (1996). Ad hoc routine can be developed in the code to model some particular system or components. In this case a new routine was implemented to take into account the air infiltration through the windows, property difficult to consider in building simulation program.

At the time the study was performed, the Italian standards, UNI 7979 (1979) (now substituted by European standards, EN 12207 (2000)), consider 4 classes of windows, related to the maximum infiltration rate acceptable as a function of pressure. As an example at 100 Pa it must be: 50 $m^3/h \times m^2$ for class A1, 20 $m^3/h \times m^2$ for A2, 7 $m^3/h \times m^2$ A3, no classification if leak is worse than A1. The routine, developed in the Fortran language allowed to calculate the thermal loads due of not treated outdoor air passing through the fenestration systems, as a function of the climatic conditions (temperature, humidity, solar radiation, wind and so on…). The permeability of a building (*Qo*), as a function of permeability of transparent components, can be evaluated with the following equation, Eqn. 1:

$$Q_0 = \frac{\Delta P}{V}\left[\sum_q (mA)_j + \sum_r (vL)_j\right]$$

where:

q	number of windows	A	windows area [m^2]
r	number of roller-shutter box	L	roller-shutter box length [m]
ΔP	out/indoor gap pressure [N/m^2]	m	permeability of window [$m^3/s \times m^2$]
V	heated volume [m^3]	v	perm. roller-shutter box [$m^3/s \times m$]

The air infiltration rate of the building Q was computed using the following relation, Eqn. 2:

$$Q = \frac{\sqrt{(a_1 \cdot h^{b_1} + a_2 \cdot h^{b_2})}}{75} Q_{075}$$

where:

Q	air infiltration flow rate [m^3/h m^2]
h	building height [m]
Q_{075}	air infiltration rate at 75 Pa [m^3/h m^2]
a_1, a_2, b_1, b_2	numeric coefficients related to location, vertical permeability and wind speed.

Table 1 Characteristics of the reference windows

Code	Glass (mm)	Frame	U (W/m^2°K)	g	τ_v
A	Single Glass	Metal w/o TB	6.1	0.87	0.90
B	Clear DGU	Metal w/o TB	4.5	0.76	0.81
C	Clear DGU	Metal TB	3.1	0.76	0.81
D	DGU low-e (0.2)	Metal TB	2.6	0.72	0.73
E	DGU low-e (0.1)	Metal TB	2.4	0.64	0.76
F	DGU low-e (0.1) + argon	Metal TB	2.2	0.64	0.76
G	DGU low-e + solar filter	Metal TB	2.6	0.47	0.71

Considering all the variables, more than 1000 building simulation were performed. By a multilinear regression, the following formula, Eqn. 3, was determined:

$$NHLR = 52 - 9.4 \times U + 32.2 \times g - 0.25 \times Q_{75}$$

This formula calculates the heat load reduction, normalised to the degree days a,nd to the square meters of building, when using windows, whose characteristics are to be inputted in the formula itself, respect to the reference windows (window A in table 1). To be noted that the air tightness of the window now determined according to EN 12207, must be corrected, by means of well known formula, to input the value at 75 Pa in the above formula.

INFLUENCE OF THE AIR PERMEABILITY OF WINDOWS ON THE ENERGY AND ECONOMIC BALANCE OF TYPICAL DWELLINGS

Extrapolating some of the simulation results, it is possible to check in detail the influence of the infiltration rate on the building energy performances. In particular, the attention is focused on 4 cities, corresponding to the climatic zones, where the majority of the population leaves. The presented results refers to the four level building, which represents a diffuse typology on the Italian territory. The graphs in figure 1 and 2 show the heating loads in Turin (2553 degree days) and Rome (1440). As expected, the heating loads decrease improving the *U-val*ue (except for window E, due to a strong reduction of the solar gains) and the air tightness. Focusing the black lines in the two figures, it can be noted the not negligible influence of the air permeability. In fact, the building equipped with a very good window (F) of class A1 can have worse performance if equipped with a normal window (C) but in class A2 or 3. To be noted that the class of air infiltration are those defined in the old Italian standard.

Tables 2 to 5 summarise the percentage reduction of heating loads due to more air tight window, for each window and locality. Beside Turin and Rome, also Olbia, Sardinia (1142 degree days, typical southern peninsular climate), and Palermo (751, hot Sicilian climate), were considered. In Olbia the heating loads are comprised between 98.5 and 21.1 giga joule, in Palermo between 5.29 and 0.83. Window A is not considered, because both in renovation and new building is obsolete. In each table, the first 3 rows show the reduction respect to the not classified window, the 4th row shows the reduction of A3 respect to A1 and the 5th respect to A2. As expected the lower the air permeability, the higher the energy savings. An A3 window, whatever their thermal characteristics are, can reduce the heating loads of the building of 35-50% respect to a window A, the limit is in Palermo where the reduction can reach the 60%. Good improvements are obtained comparing A1 and A3 windows, between 20 and 30%, again the more rigid is the climate, the lower is the energy reduction. And finally, acceptable results are obtained comparing both windows as A2 and A3. In Turin, cold climate, the advantage are limited (5-7%), in Rome they are close to 10% and better results, as expected are obtained for Olbia and Palermo.

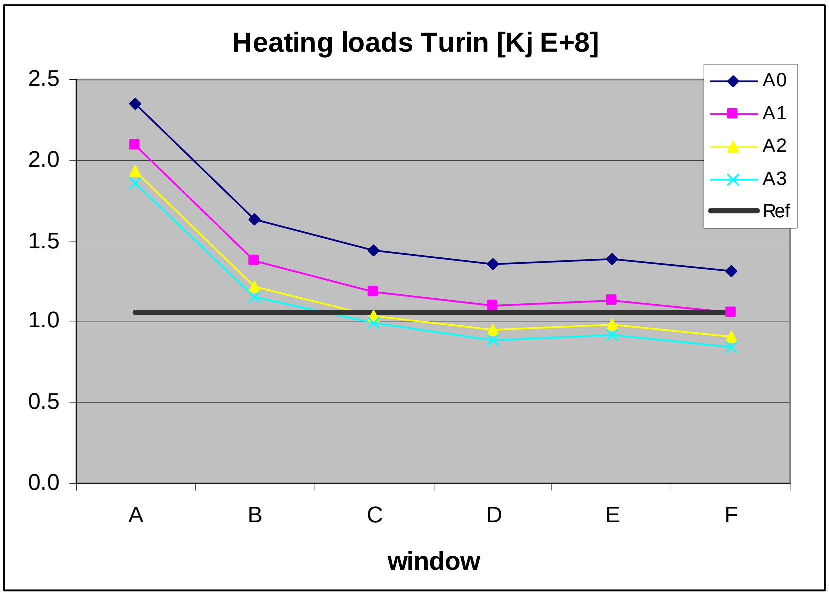


Figure 1 Heating loads of the reference buildings in Turin

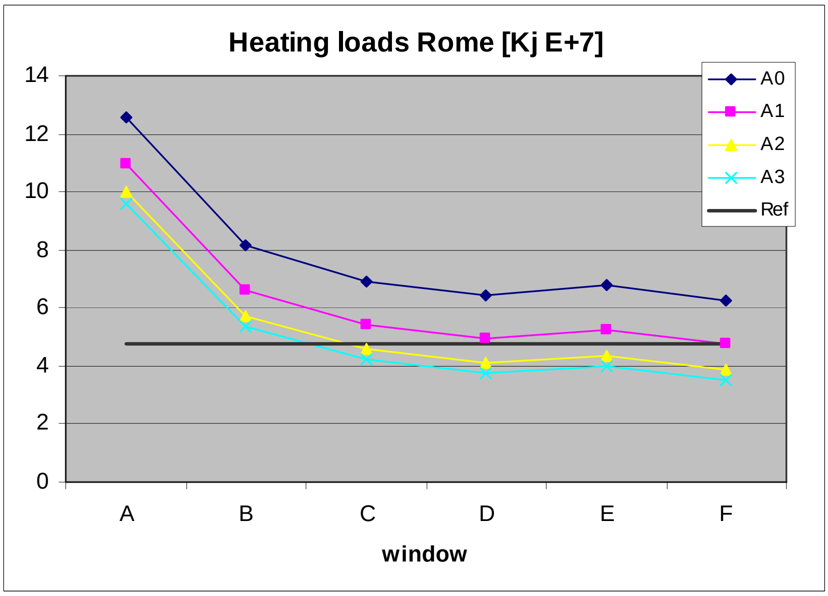


Figure 2 Heating loads of the reference buildings in Rome

Table 1 Percentage reduction of heating loads in Turin

	Turin					Rome				
	B	C	D	E	F	B	C	D	E	F
A0_A1	84	82	81	81	81	81	78	77	78	77
A0_A2	75	72	70	71	69	70	66	64	65	62
A0_A3	71	69	67	66	64	65	61	58	59	57
A1_A3	84	84	81	81	80	81	77	76	76	74
A2_A3	95	96	93	93	93	93	92	91	92	91

Table 2 Percentage reduction of heating loads in Turin

	Olbia					Palermo				
	B	C	D	E	F	B	C	D	E	F
A0_A1	75	71	70	70	69	72	68	66	67	64
A0_A2	61	55	53	54	51	57	51	47	49	46
A0_A3	55	49	46	47	45	51	44	40	42	39
A1_A3	73	69	66	67	65	70	65	62	63	60
A2_A3	90	88	87	88	87	89	87	85	86	84

The application of Eqn. 3 permits the calculation of the energy savings that can be reached when using more efficient windows. It is interesting the economic effect of more efficient windows in case of new and retrofitted building. It is considered an apartment of the reference building, around 120 m2 and with 15 m2 of windows. It is supposed that the building has an gas heating system (70% as efficiency of the whole system) and the price is 0.72 € per cube meter. According to the actual national situation the interest and inflation rates are respectively fixed in 3 and 2.5%. The NPV (net present value) and the PBT (pay back time) are calculated considering a life cycle of 30 years for the product.

Considering new buildings equipped with low emittance double glazing units (U of the window 2.2 W/m^2°K). A class A4 (according to the actual EN standards) window costs around 5% more of the same window in class A2 (considering the market price of assembled windows, supplied by the association of wood, PVC and metal frames), with the annual achievable energy savings it comes out a PBT of 2.8 years and NPV of 1300 € in Turin, and 5 years and 640 € in Rome.

The same analysis for retrofitting has, of course different results. In the previous case the investment was only the extra cost of the selected windows, in this case the investments regards the full price of the new products to install. The NPV of new windows, both in class A2 and A4, respect, is very high, more than 13000 € in Turin and 7000 € in Rome, because of the better performance respect to the old installed ones. Of course the relative difference between A2 and A4 gives the same results of the new building case. Concerning the PBT, in Turin it is calculated in 6.1 and 5.8 years for A4 and A2 respectively, in Rome 10.8 and 10.3. In this case the economic analysis does not change very much, even if an added values is always kept. To keep in mind that the energy balance of the building is positively affected and energy and environmental issues are accomplished.

EXPERIMENTAL CAMPAIGN AT THE EXPERIMENTAL BUILDING “CASA INTELLIGENTE”

The experimental building “Casa Intelligente” (Smart House) at ENEA was funded by the Italian Ministry of Industry, in order to carry on experimental researches to improve the energy performance, the safety, security and comfort for users, in residential dwellings. It is a two level building, the two floor are identical: the first one has a not heated basement below, the latte has a flat roof.

Some experiences and monitoring were already performed during the past years. A new campaign on the energy performance of windows is going to take place next winter. During the campaign it will be performed an energy monitoring to analyse the performance of different products at the building level, at the same time a thermal comfort monitoring will be carried out. The aim is to evaluate how less efficient products affect the comfort for occupants, for what concerns infrared thermal exchange of cold surfaces and cold air stream entering in to the build environment because of leaky frames and windows. This activity should be carried on to push the Italian market towards products more energy efficient and already economically competitive on the market. This analysis should also support the new national and international legislative actions with the definition of more performing benchmark in terms of energy efficiency in building.

CONCLUSIONS

The renovation of the Italian stock buildings is a necessary step to be taken in the next year. It will be done by new constructions and by refurbishment of the existing building. Within these actions, great care on the energy and environmental issues will be dedicated. The stock of the installed windows is very poorly performing and lot of chance for energy efficient products are offered by the market. From the above analyses some conclusions can be inferred:

- The air permeability is an important factor for thermal losses, in many cases good thermal and solar properties of windows can be mocked if the product is not adequately air tight.
- In cold areas windows with low permeability (A4) can improve the building performance of 20 to 35% if poor windows are installed (A1 and A2). Minor energy savings, even if not negligible, can be obtained even respect to A3 windows. In milder climates such percentages increase, even if the amount of saved energy is of course reduced.
- Using high class products is also economically convenient, the extra cost for a more tight windows is generally around 5% and the pay back time is of few years. In existing building the pay back time is of course higher, but also the net present value is.
- In order to push the market towards more efficient products, it seems important the implementation of experimental campaigns and the dissemination of collected results in order to stress the advantage that such products give in terms of energy end economy savings, environment safeguard and users comfort and quality of life.

REFERENCES

A. Maccari, M. Zinzi (2000) Simplified algorithms for the italian energy rating scheme for fenestration in residential buildings; Solar Energy Vol. 69, Nos 1-6, pp. 75-92;.

UNI 7979 (1979) “Edilizia – Serramenti Esterni Verticali. Classificazione in base alla Permeabilità all’Aria, Tenuta all’Acqua e Resistenza al Vento”.

EN 12207 (2000) Windows Air and Doors: Air Permeability – Classification

TRNSYS a Transient System Simulation Program (1996) Solar Energy Laboratory, University of Wisconsin – Madison, WI 53706 USA.

EXPLOITATION OF SOLAR GREENHOUSE IN VENTILATION SYSTEM OF BUILDING

M. Jaros, P. Charvat, K. Krajca and M. Trunda

Brno University of Technology, Faculty of Mechanical Engineering,
Dept. of Thermomechanics and Environmental Engineering,
Technicka 2, 616 69 Brno, Czech Republic

ABSTRACT

The paper deals with on-site measurements of energy benefits resulting from exploitation of a solar greenhouse, which was created in the attic under the southward-oriented glazed roof for pre-heating of the ventilating air. This conception of the solar energy utilisation is used in the residential complex of the senior citizen home in Svitavy, 60 km north of Brno. Based on the data collected with the use of an automation monitoring system during the heating season 2001–2002, the main characteristics of the investigated solar greenhouse operation were established. The maximum temperatures exceed 20°C on sunny winter days, with temperature difference between outdoor and inner temperature approx. 25 K, and so the preheated air can be used directly for warm-air heating. Resulting benefits are dependent on the time and way of operation. Nevertheless, experience of other similar applications (e.g. solar energy facades, see Jaros et al., 2004) shows, that the annual energy savings up to 10 % of the total heat consumption of the building can be reached this way.

KEYWORDS

solar energy, building ventilation, energy savings

INTRODUCTION

Low energy consumption is one of the major objectives of new projects as well as of retrofitting of the existing buildings. In situation, when thermal losses of well-insulated buildings are quite low, the energy consumption of ventilation starts to play an important role. Among other possibilities, the utilisation of solar energy can be used for its decreasing.

Solar greenhouses represent one of the low-cost options of solar energy utilisation, which can be used both in newly built as well as in retrofitted buildings. Collected heat can be employed in different ways. The proposed paper deals with the exploitation of a solar greenhouse for pre-heating of ventilating air, which is sucked into the ventilation system of a building.

DESCRIPTION OF THE BUILDING

This conception of the solar energy utilisation is used in the residential complex of the senior citizen home in Svitavy, 60 km north of Brno (Fig.1). The complex consists of five apartment buildings with 115 apartments. Wide exploitation of principles of a “solar architecture” in the design resulted in a considerable decrease in the energy consumption. Moreover, two active solar systems, which exploit the solar energy collected in the solar greenhouse, were used here. Besides the above-mentioned pre-heating of ventilating air used in three smaller

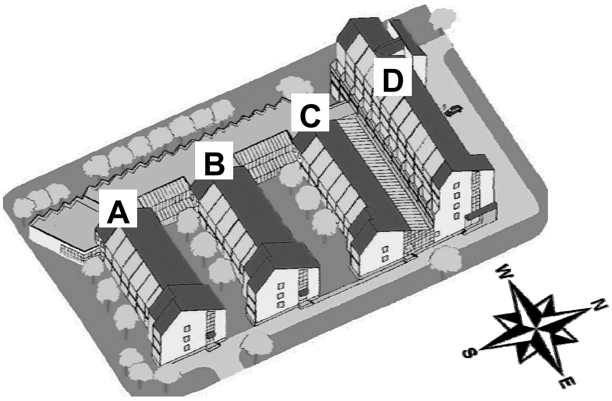


Figure 1. Schematic view of the residential complex in Svitavy.

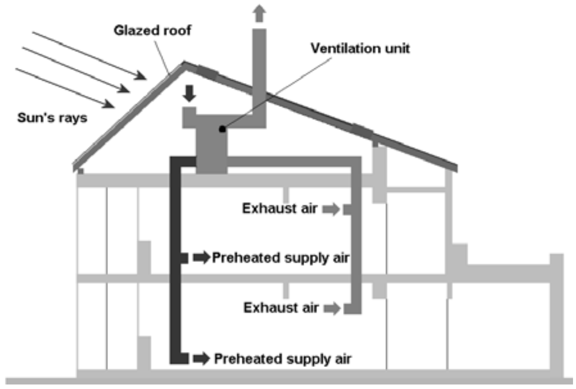


Figure 2. Scheme of ventilating system in buildings “A”, “B”, “C”.

buildings (in Fig.1 labeled “A”, “B”, “C”), the solar greenhouse acts as a heat source for air-water heat pumps used for hot water preparing in main building of the complex (labeled “D”).

The solar greenhouses were created in attics under the southward-oriented glazed roofs. Floors of the attics are covered with concrete blocks in order to ensure better heat storage. Outdoor air enters the attics through the slots located on the bottom side of the roofs. Preheated air is supplied to the rooms through the ventilation system with heat recovery (Fig.2). In summer season, the ventilation system is set on a suction of cold outdoor air.

Our investigations were carried out with the aim to establish the thermal conditions in the solar greenhouse under different weather circumstances and estimate the energy savings resulting from its exploitation. For this purpose, a data acquisition system has been installed in the attic of the southern building (“A”). A hot wire anemometer was used to measure the air temperature and velocity in the ventilation system inlet. Thermocouples were used for measuring the temperature of the air and the surrounding surfaces (roof, floor, glazing). Weather conditions, like air temperature, wind speed and direction, as well as solar irradiation, were also monitored. The location of the sensors is shown in Fig.3. The data were stored with the time step of one minute.

EVALUATION OF MEASURED DATA

Based on the data collected during the heating season 2001–2002, the main characteristics of the investigated solar greenhouse operation were established. Because the temperature conditions in the solar greenhouse depend particularly on the solar radiation intensity (SRI), the evaluated days have been sorted out according to the prevailing type of the solar radiation (direct or diffusive) into three categories: sunny, somewhat cloudy, and cloudy days (Fig.4).

Temperature Conditions in the Solar Greenhouse

As far as the energy savings are concerned, the conditions in winter and transitional seasons (spring, autumn), when the preheated air is sucked, are crucial. As it can be seen from Fig.5, the maximum air temperatures in the greenhouse exceed 20 °C on sunny winter days, with temperature difference between outdoor and inner temperature approx. 25 K. On sunny days in spring and autumn, the temperatures are still higher. In such a situation, the preheated air can be used directly for warm-air heating. On the other hand, the average temperature difference between outdoor and inner temperature is only 5–7 K on cloudy days (Fig.6).

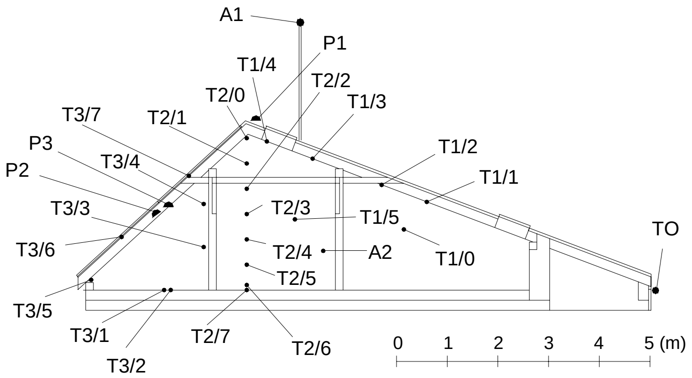


Figure 3. Location of sensors in the solar greenhouse.

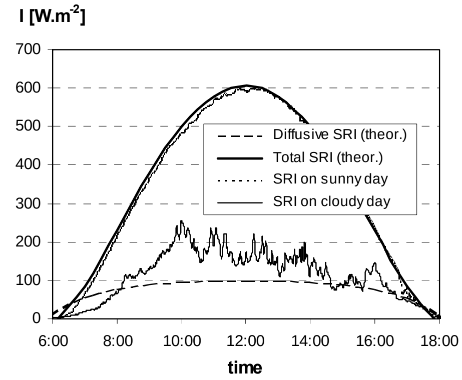


Figure 4. SRI on sunny and cloudy day (March 14 and 25, 2002).

The temperature field in the greenhouse is not homogeneous – temperature stratification (i.e. increasing of the temperature along the height of the greenhouse) arises in most cases (see Fig.7). Temperature differences in the space depend again on the solar radiation intensity, and so they reach 5–6 K on sunny days (this result is in good agreement with the outcomes of the numerical modeling, see Charvat et al., 2001), while in cloudy days and at night only 1–2 K, respectively. Considerable decrease in the inner air temperatures is evident after turning on the ventilation (Fig.5, 7). This is caused by a penetration of cold outdoor air into the attic, which was also forecast by numerical models (Jaros et al., 2002).

Assessment of Energy Savings

The energy savings resulting from the exploitation of the solar greenhouse were considered as a heat that would be necessary for heating of the air from the outdoor temperature to the temperature in the ventilation inlet:

$$Q = \dot{m} \cdot c_p \cdot (t_i - t_o) \cdot \tau = \dot{V} \cdot \rho \cdot c_p \cdot (t_i - t_o) \cdot \tau \tag{1}$$

where $\dot{m}$, $\dot{V}$ – mass and volumetric flow rate of air, t_i, t_o – air temperature in the ventilation inlet and outdoor temperature, c_p, ρ – specific heat and density of air, τ – time of operation.

Fig.7 shows that the air temperature in the inlet duct, when the ventilation is off, is higher than in the attic. After the ventilation is turned on, the sucked air reaches the same temperature as the surrounding air in the corresponding height (250 cm). Next decreasing of both temperatures is caused by suction of cold outdoor air into the attic (as mentioned above).

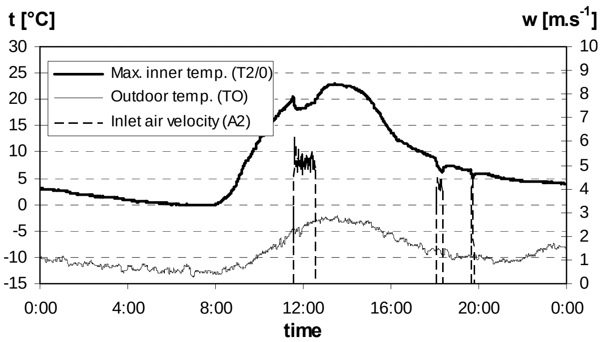


Figure 5. Air temperatures in the solar greenhouse on sunny winter day (December 9, 2001).

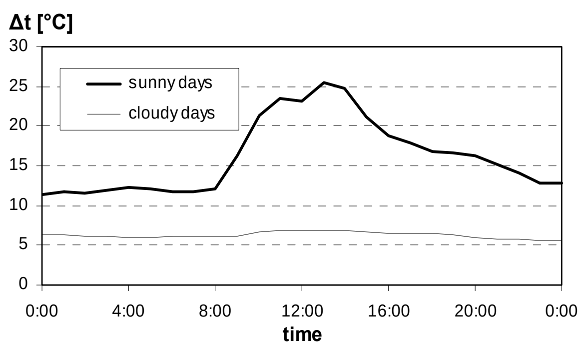


Figure 6. Average difference between outdoor and maximum inner temperature in winter days.

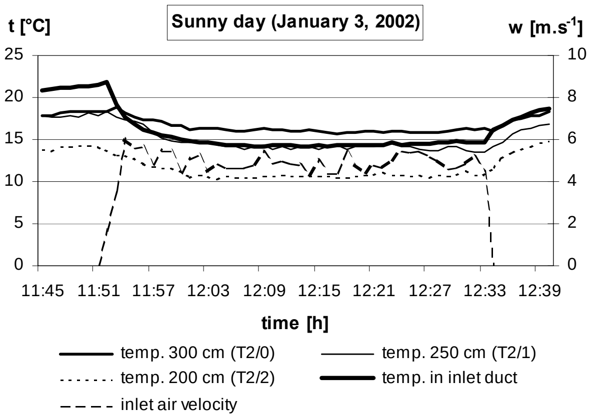


Figure 7. Air temperatures in the inlet duct and its surroundings on sunny winter day.

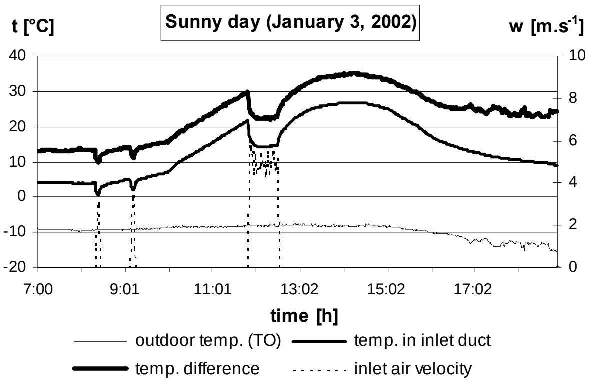


Figure 8. Day course of air temperatures in the ventilation system on sunny winter day.

The temperature difference $t_i - t_o$, which is crucial for the amount of energy savings (see Eqn.1), therefore decreases too, but it is still high enough on sunny days (Fig.8).

The assessment of the energy savings is complicated by the fact that the time of operation, which substantially affects the savings, was not the same every day. Typically, the ventilation is turned on centrally twice for half an hour during sunny days, but only for a short time (or not at all) on cloudy winter days.

The evaluation of the annual energy savings was based on the assumption that January is the coldest month, while February vs. December and March vs. November have approximately the same temperatures. Therefore, the day values of the energy savings in the characteristic days of these three periods (always three days with sunny, somewhat cloudy and cloudy weather) were evaluated according to Eqn.1. Next, one-minute values of the energy savings, which are more convenient for the comparison of particular types of the day (they are not dependent on the time of operation), were determined (Tab.1). Monthly energy savings were then estimated from the average day values of the energy savings and the number of days with a certain type of weather in the given month (Tab.2).

TABLE 1
One-minute energy savings in characteristic days during heating season 2001–2002

Sunny days					
Date	q [kJ.min^{-1}]	Date	q [kJ.min^{-1}]	Date	q [kJ.min^{-1}]
3.1.2002	833,88	3.2.2002	480,5	6.3.2002	655,77
23.1.2002	489,94	15.2.2002	844,45	9.3.2002	506,34
29.1.2002	293,13	19.2.2002	693,71	11.3.2002	549,09
Mean value	538,98	Mean value	672,89	Mean value	570,40
Somewhat-cloudy days					
2.1.2002	114,64	1.2.2002	390,25	3.3.2002	576,79
20.1.2002	177,15	14.2.2002	772,19	7.3.2002	250,42
25.1.2002	247,33	28.2.2002	382,67	10.3.2002	401,49
Mean value	179,71	Mean value	515,04	Mean value	409,57
Cloudy days					
1.1.2002	31,15	7.2.2002	210,58	2.3.2002	246,02
9.1.2002	279,87	13.2.2002	179,36	22.11.2001	114,17
24.1.2002	105,95	25.2.2002	145,15	29.11.2001	189,18
Mean value	138,99	Mean value	178,36	Mean value	183,12

TABLE 2
Assessment of energy savings resulting from the solar greenhouse exploitation in heating season 2001–2002

Month	Clear days		Somewhat cloudy days		Cloudy days		Monthly savings
	#	Ø ΔQ [MJ]	#	Ø ΔQ [MJ]	#	Ø ΔQ [MJ]	ΔQ [MJ]
11/01	1	60,23	4	45,01	25	10,35	499,0
12/01	6	41,37	6	5,46	19	1,63	312,0
1/02	4	41,37	6	5,46	21	1,63	232,5
2/02	6	69,54	12	49,18	10	8,37	1091,1
3/02	13	60,23	11	45,01	7	10,35	1350,6
Total	30	–	39	–	82	–	3485,2

CONCLUSION

The obtained outcomes reveal that the solar greenhouse represents a possibility of exploiting the solar energy for the energy savings in ventilation, which can be applied in newly built as well as in retrofitted buildings. Resulting benefits naturally depend on the time and way of operation. Nevertheless, experience of other similar applications (e.g. solar energy facades, see Jaros et al., 2004) shows that the annual energy savings up to 10 % of total heat consumption of the building can be reached this way.

ACKNOWLEDGEMENT

The financial support from the Research Plan of BTU No. 26210001 granted by the Czech Ministry of Education is gratefully acknowledged.

REFERENCES

Charvat, P., Jaros, M., Katolicky, J., and Svorcik, P. (2001). Numerical modeling of airflow and temperature fields in a glazed attic. In: Lamberts, R. et al., eds. *Proc. 7th Int. IBPSA Conf. Building Simulation 2001*, 441-447, Rio de Janeiro, Brazil, August 13–15, 2001.

Charvat, P. and Jaros, M. (2002). The exploitation of solar energy for energy saving in ventilation. In: H. Levin, eds. *Proc. 9th Int. Conf. Indoor Air 2002*, 1080-1085, Monterey, California (USA), June 30–July 5, 2002.

Jaros, M., Katolicky, J., and Svorcik, P. (2002). Numerical computation of suction of ventilating air from the solar greenhouse. In: *Proc. Conf. Air Conditioning and Ventilation 2002*, 57-62, Prague, Czech Rep., January 29–30, 2002. (In Czech)

Jaros, M., Charvat, P., Kouril, T., and Orel, V. (2003). The exploitation of solar air collectors for preheating of ventilating air. In: Kubota, H. et al. (eds.) *Proc. 7th Int. Symp. Ventilation 2003*, 115-120, Sapporo, Japan, August 5–8, 2003.

Jaros, M., Krajca, K., Charvat, P., Sedlak, J., Mohelnikova, J. and Plsek, D. (2004). Using double-skin solar energy façade for pre-heating of ventilating air. *9th Int. Conf. Roomvent 2004*, Coimbra, Portugal, September 5–8, 2004 (paper accepted).

AIRFLOW PERFORMANCE CHARACTERISTICS OF VENTILATORS IN HYBRID VENTILATION SYSTEMS

N. Chilengwe[1] and S. Sharples[2]

[1,2] Centre for the Built Environment, Unit 9 Science Park, School of Environment and Development, Sheffield Hallam University, Sheffield S1 1WB, UK
Tel. +44 (0) 114 225 3249 Fax +44 (0) 114 225 3206
n.chilengwe@shu.ac.uk s.sharples@shu.ac.uk

ABSTRACT

Part of the task in the design of ventilation systems involves selection and specification of system components - components sizes and expected performance characteristics or criteria to achieve specific ventilation objectives for anticipated environmental conditions. Careful selection of these components is required to ensure that they are able to react to changes in environmental conditions. For ventilators (air inlets and outlets) this implies that the airflow performance characteristics need to be established in relation to the widely varying pressure driving forces (in natural ventilation mode the pressure differentials are typically less than 10 Pa whilst for mechanical ventilation the driving force can be as high as 100Pa). At present "pure" hybrid ventilators are non-existent hence, a combination of natural and mechanical ventilation components are used for hybrid ventilation applications. The desire to initiate interest of manufacturers to consider development of hybrid ventilators was the motivation behind this paper. To gain some fundamental understanding of potential airflow characteristics of such hybrid ventilators this study resorted to basic elements (slots and orifices) and employed general natural ventilation theory to predict how these components would behave when subjected to the range of pressure differentials expected in hybrid ventilation applications i.e. 0 to say 100 Pa. The study investigated via a series of laboratory experiments variations in airflow performance characteristics of simple ventilators comprising rectangular slots and round-wire mesh screens. The main objectives were to investigate and quantify variations in characteristic equations of ventilators in relation to the whole range of pressure differentials expected and also with regard to changes in dimensions of the ventilator. Results obtained indicate that the characteristic equations are not only influenced by the pressure range from which they are generated but also by the constituent components of a ventilator.

KEYWORDS

Airflow, hybrid ventilation, ventilators, mesh screen, rectangular slots

1.0 Introduction

Hybrid ventilation systems are two-mode systems that combine the best aspects of natural and mechanical ventilation at different times of the day or season of the year to provide a comfortable indoor environment and good air quality. Part of the task in the design of hybrid ventilation systems involves selection and specification of system components i.e. determining component sizes and expected performance characteristics or criteria to achieve specific ventilation objectives for anticipated environmental conditions. Careful selection of these components is required to ensure that they are able to react to changes in prevailing environmental conditions. For ventilators (air inlets and outlets) in hybrid ventilation systems, this implies that the airflow performance characteristics need to be established and understood in relation to the widely varying pressure driving forces (in natural ventilation mode the pressure differentials are typically less than 10 Pa whilst for mechanical ventilation the driving force can be as high as 100Pa).

However, at present "pure" hybrid ventilators are non-existent, hence a combination of natural and mechanical ventilation components are used for hybrid ventilation applications. To gain some fundamental understanding of potential airflow characteristics of such hybrid ventilators this study resorted to basic elements such as slots and orifices and employed general natural ventilation theory to predict how these components would behave when subjected to the range of pressure differentials that would normally be encountered in hybrid ventilation applications. This served as a starting point to gaining some indication of how components such as trickle ventilators would behave when incorporated into a hybrid ventilation scheme and operated over the whole range of pressure differentials. This study investigated via a series of laboratory experiments variations in airflow performance characteristics of simple ventilators comprising rectangular slots and wire mesh screens. The main objectives were to investigate and quantify variations in characteristic equations of ventilators in relation to the whole range of pressure differentials expected, and also with regard to changes in dimensions of the ventilator.

2.0 Methodology

2.1 Airflow performance of ventilators

Current practice for estimating airflow through ventilation openings involves establishing a relationship between the pressure differential ΔP across an opening and the consequent airflow Q through that opening. The quadratic equation (Eqn. 1) is often called on in discussing problems of the leakage of airflow through small gaps. It has been suggested that the quadratic equation of the form:

$$\Delta P = \mathbf{a}Q^2 + \mathbf{b}Q \qquad \text{Eqn. (1)}$$

is more suitable for estimation of leakage area through ventilation components and provides a more accurate assessment of the flow through crack type openings than the power law [Baker *et al*, 1987]. In addition, the quadratic equation is dimensionally homogeneous and the coefficients **a** and **b** in the quadratic equation can be related to the geometry of the crack [Etheridge, 1998].

2.2 Experimental Set-up

The experimental test rig (Figure 1) used to assess the airflow characteristics of the ventilator components had an airtight plenum box measuring 1m x 1 m x 1 m to suit the requirements of the European Standard BS En 13141-1: 2004 for the size of ventilator components tested. The air handling unit consisted of a Soler & Palau type COT 130 variable speed centrifugal fan (Beatson Fans & Motors Ltd) fitted with an Excal inverter type SFS controller. The AHU was connected to the plenum chamber via galvanised steel ductwork and was capable of generating pressure differentials in excess of 100Pa across the test piece.

2.3 Components Tested

Two sets of laboratory-manufactured 300mm wide wooden rectangular slots were used to investigate the basic airflow performance of trickle ventilator type openings. Set A (Figure 2) consisted of fixed opening height (H = 12mm) slots with varying depths (D) ranging from 6mm to 36mm. Set B (Figure 3) consisted of fixed depth (D = 12mm) slots and varying opening heights (H) ranging from 6mm to 36mm. The slots were used both in isolation and in combination with a fine round-wire type insect-screen mesh with hole size 0.2mm x 0.2mm to assess the resulting airflow characteristics.

2.4 Experimental Procedure

In accordance with current practice the experimental method employed generally involved subjection of ventilator components to a pressure differential and noting the resulting airflow rate. This method is recommended in BS En 13141-1 and has widely been used by several researchers [McGrath *et al* 1984, Baker *et al* 1987, Yakubu *et al* 1991, Maghrabi *et al*, 2000] over the years.

Figure 1: Experimental test rig

Figure 2: Slot type A:- Fixed depth, varying height

Figure 3: Slot typeB:- Fixed height, varying depth

3.0 Results

Figures 4 -11 show graphical representations of the results obtained to illustrate the behaviour of the ventilators over the whole range of pressure differentials to which they were subjected. In these graphs a relative airflow (Q/Q_{12}) has been used and is in this study defined as the ratio of the airflow rate for a given slot size to the airflow rate for the slot with both depth and height equal to 12mm for a particular pressure differential. The 12mm slot was chosen as reference simply because it happened to be the intersection between the two sets of slots used in this study. Figures 4 - 7 illustrate variations of relative airflow characteristics with respect to the pressure differential for both sets of slots used in isolation and in combination with a mesh-screen. To appreciate the connection between relative airflow performance, dimensions of slots and pressure differential graphs of meshed/unmeshed slots are aligned side by side for ease of comparison.

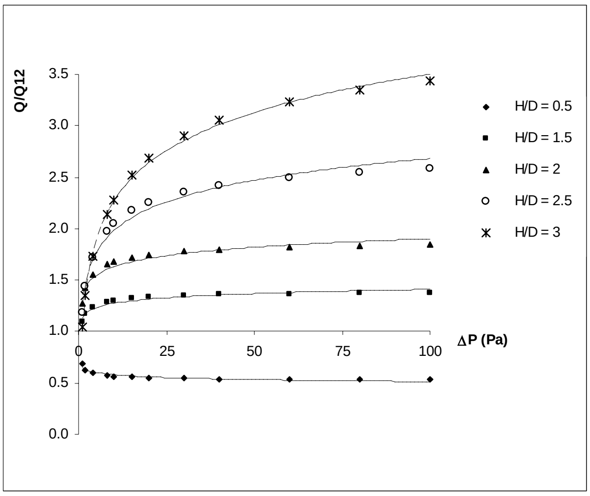


Figure 4: Q/Q_{12} as a function of ΔP for slot type A without mesh

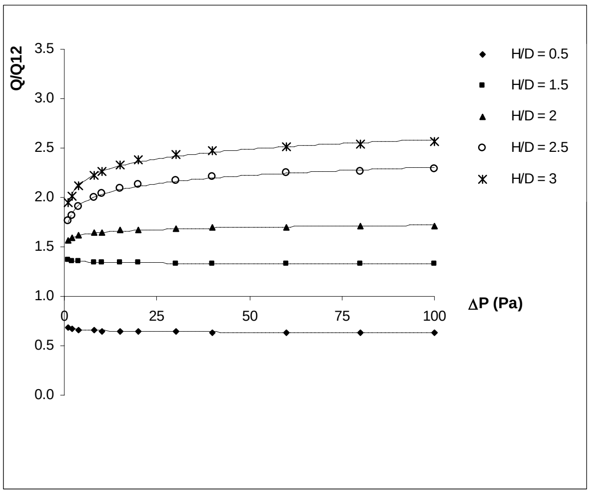


Figure 5: Q/Q_{12} as a function of ΔP for slot type A with fine mesh

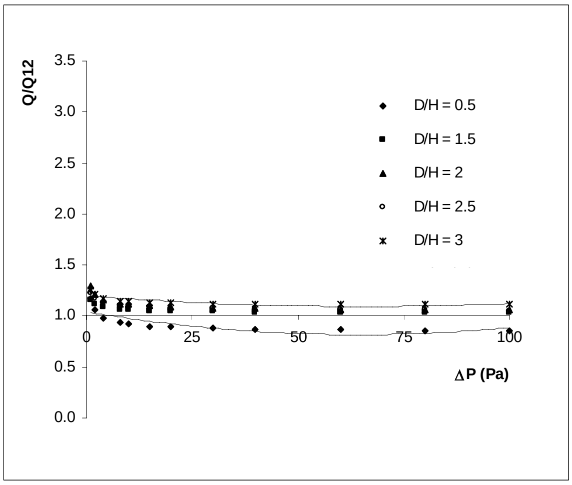


Figure 6: Q/Q_{12} as function of ΔP for slot type B without mesh

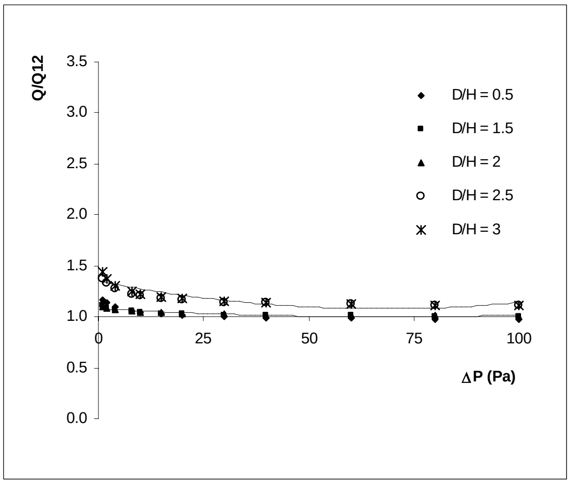


Figure 7: Q/Q_{12} as a function of ΔP for slot type B with fine mesh

Figures 8 - 11 below illustrate variations of the relative airflow (Q/Q_{12}) characteristics with respect to the height-depth ratio (type A) and depth-height ratio (type B) of slots used in isolation and also in combination with a mesh-screen. Here again graphs of meshed and unmeshed slots are aligned side by side for ease of comparison.

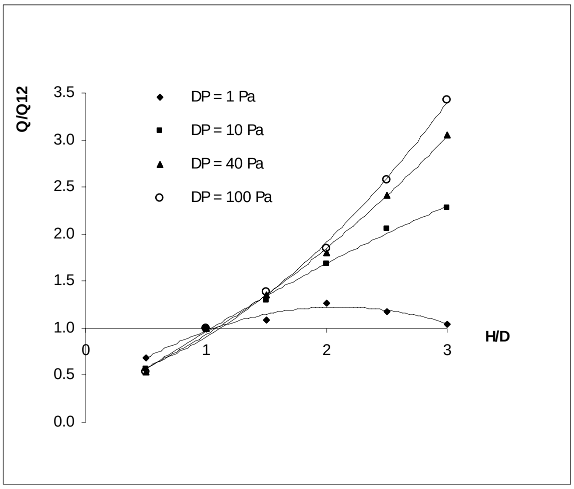


Figure 8: Q/Q_{12} as a function of H/D for slot type A without mesh

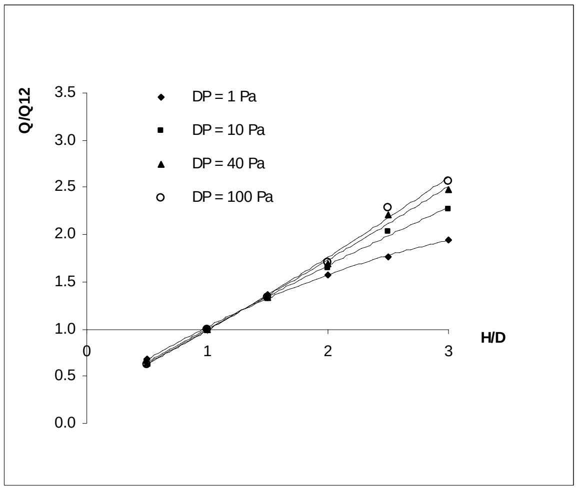


Figure 9: Q/Q_{12} as a function of H/D for slot type A with fine mesh

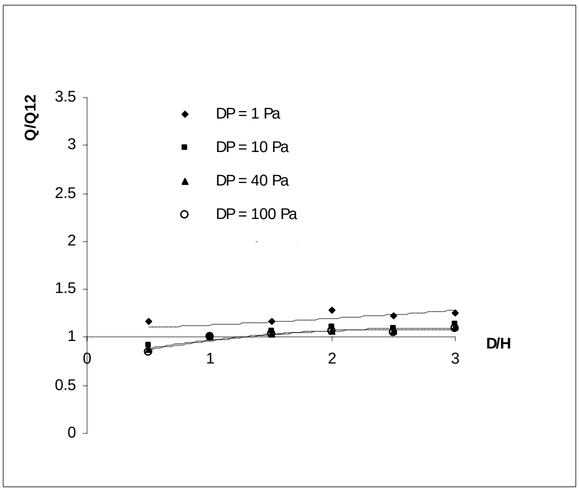


Figure 10 : Q/Q_{12} as a function of D/H for slot type B without mesh

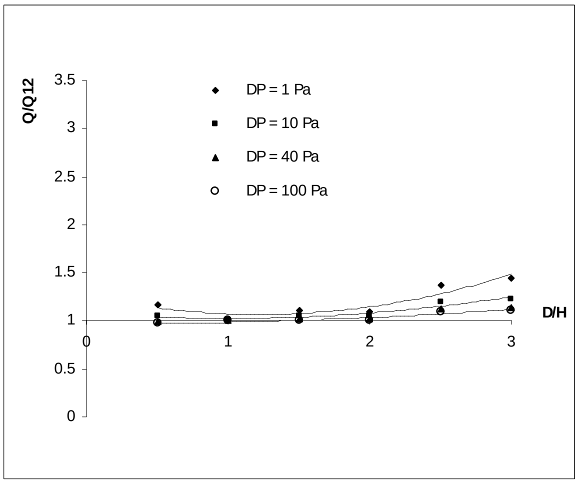


Figure 11: Q/Q_{12} as a function of D/H for slot type B with fine mesh

4.0 Discussion

Regression analysis quadratic curve fits to measured data resulted in correlation coefficients better than 0.99 in all cases considered. For slots of fixed depth and varying heights (slot type A), Figure 4 and Figure 5 showing the variation of the relative airflow (Q/Q_{12}) revealed that the cases with and without a mesh were very strongly dependant on the pressure differential at low pressures (say < 10Pa). The influence of the pressure on the relative airflow characteristic is less significant at higher pressure differentials. For slot type A it is evident that the addition of a mesh to the slots levels off the dependence on pressure at much lower values than those without a mesh. Slots of fixed height and varying depths (slot type B) revealed a more flatter relative airflow characteristic with increasing pressure differential (Figure 6 and Figure 7). Here again the effect of the pressure appears to be more significant at lower pressures.

Figure 8 and Figure 9 show the variation of relative airflow with increasing height-depth ratio for slots type A. At low values of H/D < 1 the relative flow appears to be independent of the pressure differential i.e. airflow performance at 1Pa was not much different from that at 100Pa. However, as H/D increases for the case without mesh, the dependence on pressure differential becomes significant with the lower pressure characteristic deviating away from those exhibited by higher pressure curves. It can be seen from Figure 9 that addition of a mesh to the slots reduces the deviation of the lower pressure characteristic from the trend followed at higher pressures, and converges the various characteristic curves. This suggests that a single line chosen for some intermediate pressure could be used to represent the various relative airflow characteristics without introducing significant errors.

On the other hand, for slot type B, Figure 10 and Figure 11 suggest less variation of the relative airflow with respect to the depth-height ratio. For both cases (with and without a mesh) the lower pressure characteristic (1Pa) appears to deviate away from those for higher pressures (10, 40 & 100Pa). At pressure differentials above 10Pa the graph suggests that the relative airflow performance could be represented by a single curve without introducing much errors. Without a mesh the difference between low pressure and high pressure relative airflow characteristics was approximately constant for all values of depth-height ratios. Addition of a mesh appeared to introduce a greater dependence on pressure differential for the relative airflow characteristic at depth-height ratios greater than 2.

5.0 Conclusion

From the analysis/discussion above it emerges that the characteristic equations of the simple rectangular slots and meshes are not only influenced by the pressure range from which they are derived but also by the constituent components. The results obtained suggest that by carefully selecting and combining components general solution airflow characteristics can be deduced to represent the performance of ventilators over the whole range of pressure differentials encountered in hybrid ventilation systems. To avoid significant errors the general solution could incorporate some methods to adapt resulting airflow characteristics to account for variations in pressure differentials and dimensional parameters for a given ventilator. This would ensure that the ventilator maintains a consistent airflow pattern over the whole range of pressure differentials encountered resulting in improved controllability, impact on comfort and indoor air quality. Further, although traditionally the procedure has been to establish the airflow performance of ventilator components by tests/measurements on manufactured components, by following simple analyses such as the one in this study the trend could be reversed such that ventilators are manufactured to deliver a pre-established airflow performance regime, with subsequent tests carried out only to substantiate the design.

Acknowledgements
This study was part of the work funded by the UK's EPSRC (Grant No. GR/R70637) to which the authors extend their gratitude.

References

Baker P H, Sharples S. and Ward I C (1987). Air Flow Through Cracks. *Building and Environment,* Vol 22:No. 4, pp 293 - 304.

European Standard BS EN 13141-1: 2004. Ventilation for buildings - Performance testing of components/products for residential ventilation. Part 1: Externally and internally mounted air transfer devices.

Etheridge D W. (1998). A note on crack flow equations for ventilation modelling. *Building & Environment*, Vol. 33, pp 325 -328.

McGrath P T. and Howarth A T. (1984). Measurement of air flows through cracks between building components. *Building Services Engineering Research and Technology*, Vol 5: No. 2, pp 43 - 48.

Maghrabi A A and Sharples S. (1999). Airflow characteristics through modulated louvred windows. *Proc. 16th International Conf. on Passive & Low Energy Architecture*, pp 507 - 514, Brisbane.

Yakuba G S & Sharples S. (1991). Airflow through modulated louvres. *Building Services Engineering Research & Technology*, Vol 12 No.4, pp 151 - 155.

GLASS PARTITIONS, VENTILATION AND THERMAL MASS AS RETROFITTING MEASURES IN AN ATTACHED SUNSPACE

C. Koinakis[1], N. Papamanolis [2]

[1]. *Laboratory of Building and Construction Physics, Dept. of Civil Engineering, Aristotle University, 54006 Thessaloniki, Greece, e-mail: chrisko@civil.auth.gr*

[2]. *32 Heraklia St., Thessaloniki Greece, e-mail: npapama@tee.gr*

ABSTRACT

In this paper the effectiveness of retrofitting strategies in a sunspace attached to a one-storey building has been investigated. Natural and hybrid ventilation, air-tight glass partitions, awnings and increased thermal mass retrofitting scenarios were implemented, mainly for the Greek climate. Window openings and sensor-controlled fans were used to create a controllable and secure environment. Combined ventilation and thermal simulation were applied, taking into account all the related physical phenomena, such as ventilation, infiltration and solar radiation. The thermal and air tightness characteristics of the building's envelope and the built environment were also simulated. The results are presented in the form of hourly temperature variations for typical winter and summer period in three Greek and one U.S. city and outcomes and comparisons have been derived for the retrofitting scenarios.

KEYWORDS

Attached sunspace, hybrid ventilation, flow through large openings, retrofitting scenarios.

1. INTRODUCTION

Sunspaces are one of the most widespread types of passive solar systems that are used both as a solar collecting system and an additional pleasant living space. Sunspaces can also be constructed as part of the retrofitting of an existing building, forming a glazed envelope on a balcony or a new building extension. The main function of an attached sunspace should be twofold: to reduce the auxiliary energy demand for the building and to create a comfortable and secure living area. The first function should comprise a reduction in the heating energy demand during the heating period and a reduction in overheating problems during the cooling period, especially in southern latitudes. The role of the sunspace during the heating period is threefold: to act as a buffer zone by reducing conduction losses, to supply pre-heated ventilation air and to exploit direct solar gains through conduction. The main role of the sunspace during the summer period is to be serve as an open air space, preventing overheating and thermal charge in the attached building, through implementing effective solar control and passive cooling techniques as night ventilation, hybrid ventilation etc. In this paper the thermal behavior and the potential of indoor climate control in a one-storey building with an attached sunspace are examined, through the implementation of various strategies:

- Shading devices on the roof and the vertical glazed surfaces to control sunspace overheating and to reduce the direct solar gains on the south façade of the main building.
- Night ventilation techniques, by implementing the use of top windows and inclined half-opened doors, in order to maintain security and to control access.

- Hybrid ventilation by implementing ventilators activated by temperature sensors to reduce overheating.
- Thermal mass consisting of heavy concrete walls between the house and the sunspace.
- Retrofitting of the glazed envelope of the sunspace by implementing airtight windows and doors. The occupant behavior related to the use of the sunspace openings is also simulated.

2. RETROFITTING STRATEGIES AND THERMAL PERFORMANCE

The influence of the sunspace on the thermal behavior of the building and the comfort conditions inside the sunspace, for the strategies mentioned in the previous paragraph, is investigated through implementing the Suncode and Comis simulation programs [1, 2, 3], which are coupled by implementing the sequential coupling technique. The under examination house is a single-storey heavy-structure building, which is heavily insulated and connected to the attached sunspace at the southern façade (Fig 1.). The ground floor is treated as a uniform zone of 64 m^2 and the sunspace as an autonomous zone of $16m^2$. The thermal performance of the above building has been simulated for three cities in Greece at different latitudes: Athens (lat. 37.58^o, long. 23.4^o), Thessaloniki (lat. 40.39^o, long. 23.1^o), and Chania on Crete (lat. 35.1^o, long. 24.1^o). Simulations are also performed for a southern-latitude and mild-climate US city: Los Angeles (lat. 33.56^o, long. 118.2^o), in order to compare the results and to focus on the effectiveness of the implemented strategies in combating winter and summer overheating problems.

Two typical days in the cold and warm period are examined, January 21st and July 21st. Hourly values of the typical reference years (TRY AND TMY2) in the four cities have been used for the calculations: global horizontal radiation (KJ/m^2 h), direct normal radiation (KJ/m^2 h), ambient air temperature (^{o}C), dew point temperature (^{o}C), wind speed (m/s), wind direction (degrees), humidity ratio (g/kg) and atmospheric pressure (kPa).

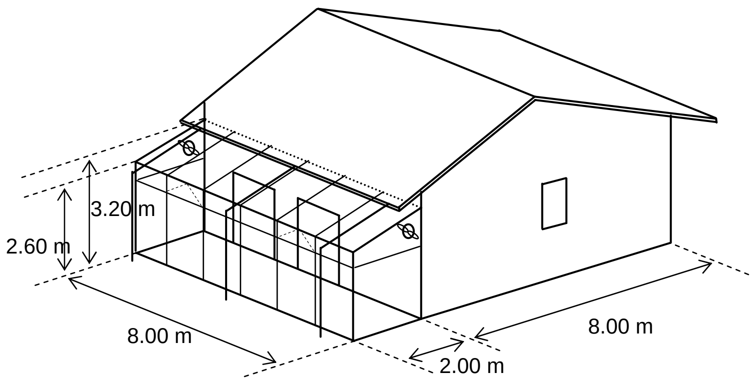


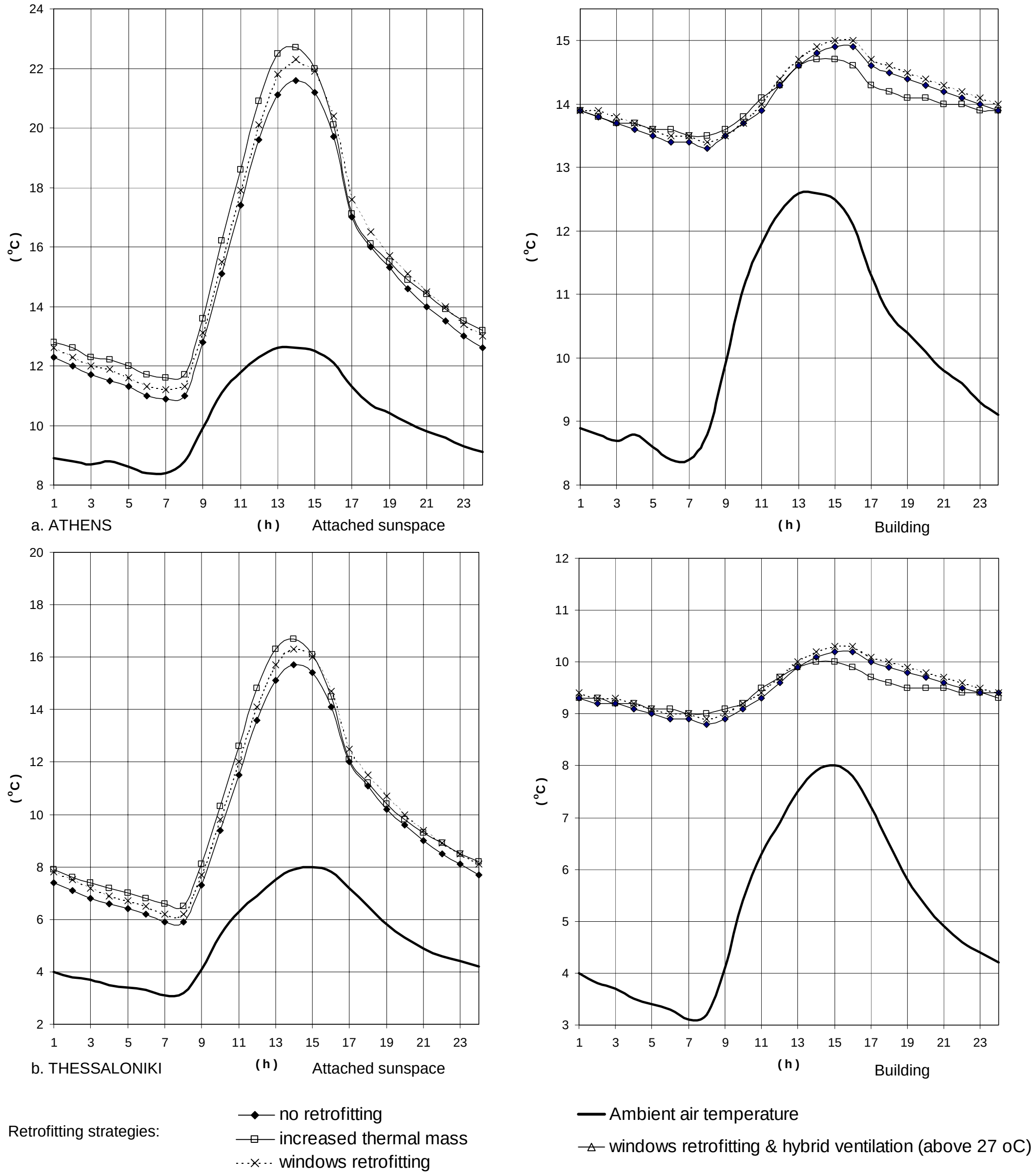
Fig. 1. The simulated attached sunspace and the building

2.1 Winter period

In Figs. 2 a to d the hourly variations in the ambient and zone air temperatures are presented for the sunspace and the building for the abovementioned cities. The examined retrofitting strategies for the heating period include the following scenarios:

- No retrofitting: the sunspace remains with a non-airtight glazing envelope, no shading and venting devices, while user behavior is taken into account by simulating the use of the large openings for 5-minute opening periods. Thermal mass is relatively low, including a 15cm-thick concrete floor covered with marble flagstones and a20cm-thick common brick wall on the southern façade.

- Increased thermal mass: the brick wall is replaced by a 40cm-thick concrete mass wall. All other features remain unchanged.
- Window retrofitting: the glazed envelope of the sunspace is replaced by a more airtight one, by implementing leakage specifications of existing products in the Greek and E.U. construction market. The mean air change values in the sunspace are visibly affected by this retrofitting scenario which reduces the air change rates from 1.7 ach to approx. 0.5 ach for the examined cases and configurations. All other features remain as in the "no retrofitting" scenario.
- Window retrofitting and hybrid ventilation: the above "window retrofitting" scenario is changed by implementing hybrid ventilation with two ventilators placed at the top of the lateral surfaces of the sunspace (500 m^3/h nominal total ventilation rate). The ventilators are sensor-controlled at a set point of 27^oC and the mean air change rates inside the sunspace were between 9 ach and 11 ach. This strategy has been implemented in practice in the warmer cities (in this paper Los Angeles), where sunspace overheating also occurs during the winter period. This strategy is most useful during the summer period.



Figs. 2 a and b. Temperature distributions of the ambient and zone air temperatures for the sunspace and the building in the cities of Athens and Thessaloniki, for the retrofitting strategies of the winter period.

In order to achieve a detailed and credible simulation of all the natural phenomena involved such as ventilation, infiltration and solar radiation, the airflow around the building and through the large openings and the effect of the neighboring buildings were taken into account. The simulation technique has been analyzed and validated in previous publications [3, 4, 5].

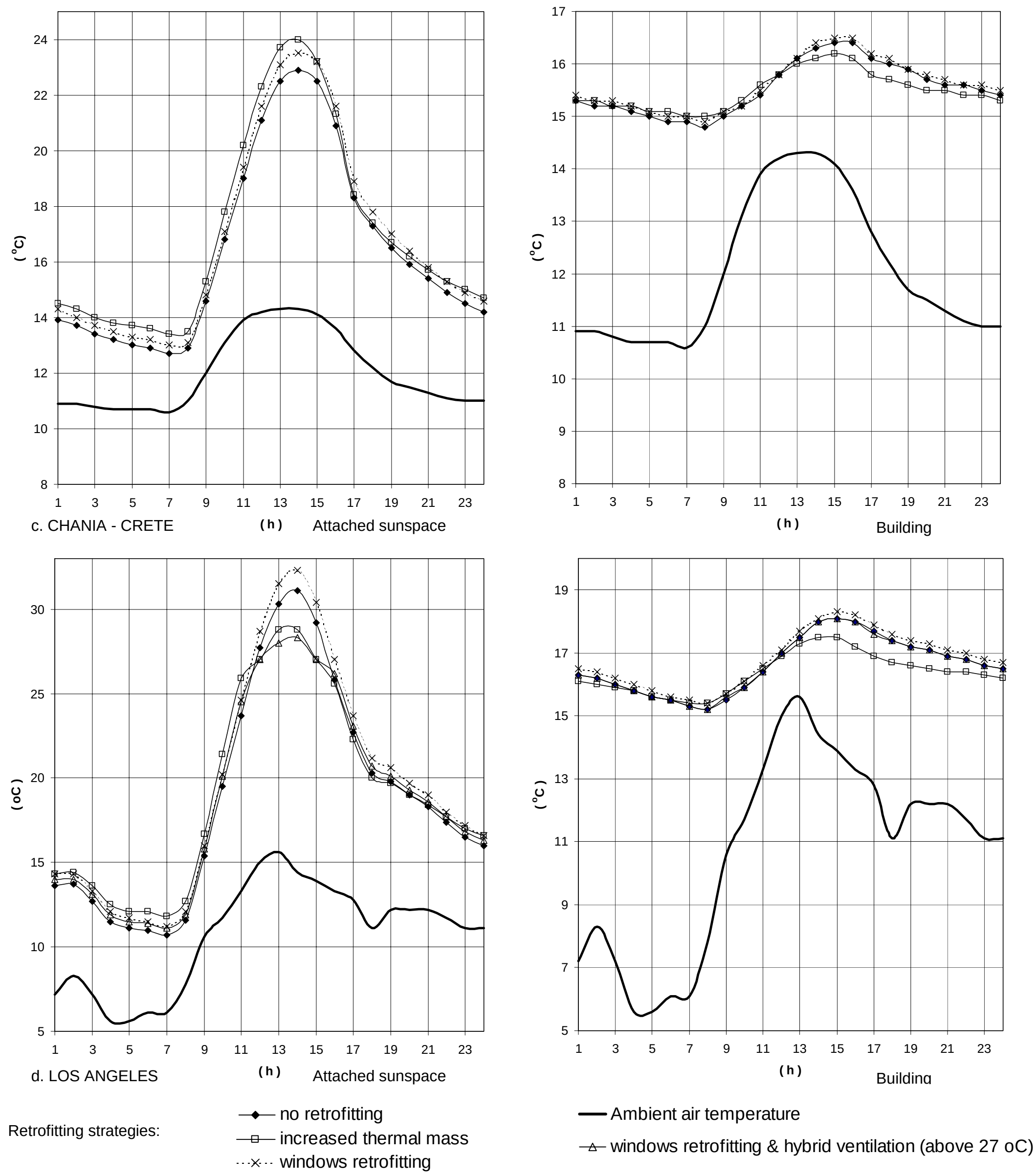


Fig. 2 c and d. Temperature distributions of the ambient and zone air temperatures for the sunspace and the building in the cities of Chania (Crete) and Los Angeles (CA), for the retrofitting strategies of the winter period.

From Figs. 2 a to d, outcomes regarding the effectiveness of the retrofitting scenarios may be derived for the winter period. Increased thermal mass and window retrofitting appeared more effective for the Greek cities where no overheating appeared and the temperature variations between day and night were greater. The temperature on a typical January day in the Greek cities varies from 8.5 to 12.6 ^{o}C in Athens, from 3.1 to 8.0 ^{o}C in Thessaloniki and from 10.6 to 14.3 ^{o}C in Chania. The maximum indoor air temperatures in the sunspace in the increased thermal mass scenario, are 22.8 ^{o}C, 16.7 ^{o}C and 24.0 ^{o}C for the cities of Athens, Thessaloniki and Chania respectively. The maximum indoor air temperatures in the sunspace in the window retrofitting scenario appeared approximately 0.5 ^{o}C higher in the abovementioned cases. The values for the non retrofitting scenario were 0.9 to 1.1 ^{o}C lower compared to the thermal mass scenario. This pattern also occurs in the night temperatures. The temperature variations in the sunspace were more than two times greater compared to the ambient air temperature.

Inside the building, the thermal mass scenario leads to less divergent temperature variations due to thermal inertia. Window retrofitting leads to higher temperatures: during the early morning hours the building air temperature is 0.2 ^{o}C higher and during the early afternoon hours 0.4 ^{o}C lower, compared to the window retrofitting scenario. Nevertheless the mean air temperature inside the building is about 3 ^{o}C higher compared to the mean ambient temperature and adequately steady, due to the combination of sunspace, thermal mass and heavy insulation.

On the other hand, for the mild climate of Los Angeles, hybrid ventilation appeared more effective and reduced the overheating phenomena at noon even without shading devices. The peak values of the air in the sunspace were reduced by about 4^{o}C. Overheating was almost eliminated for the mild oceanic climate of Los Angeles.

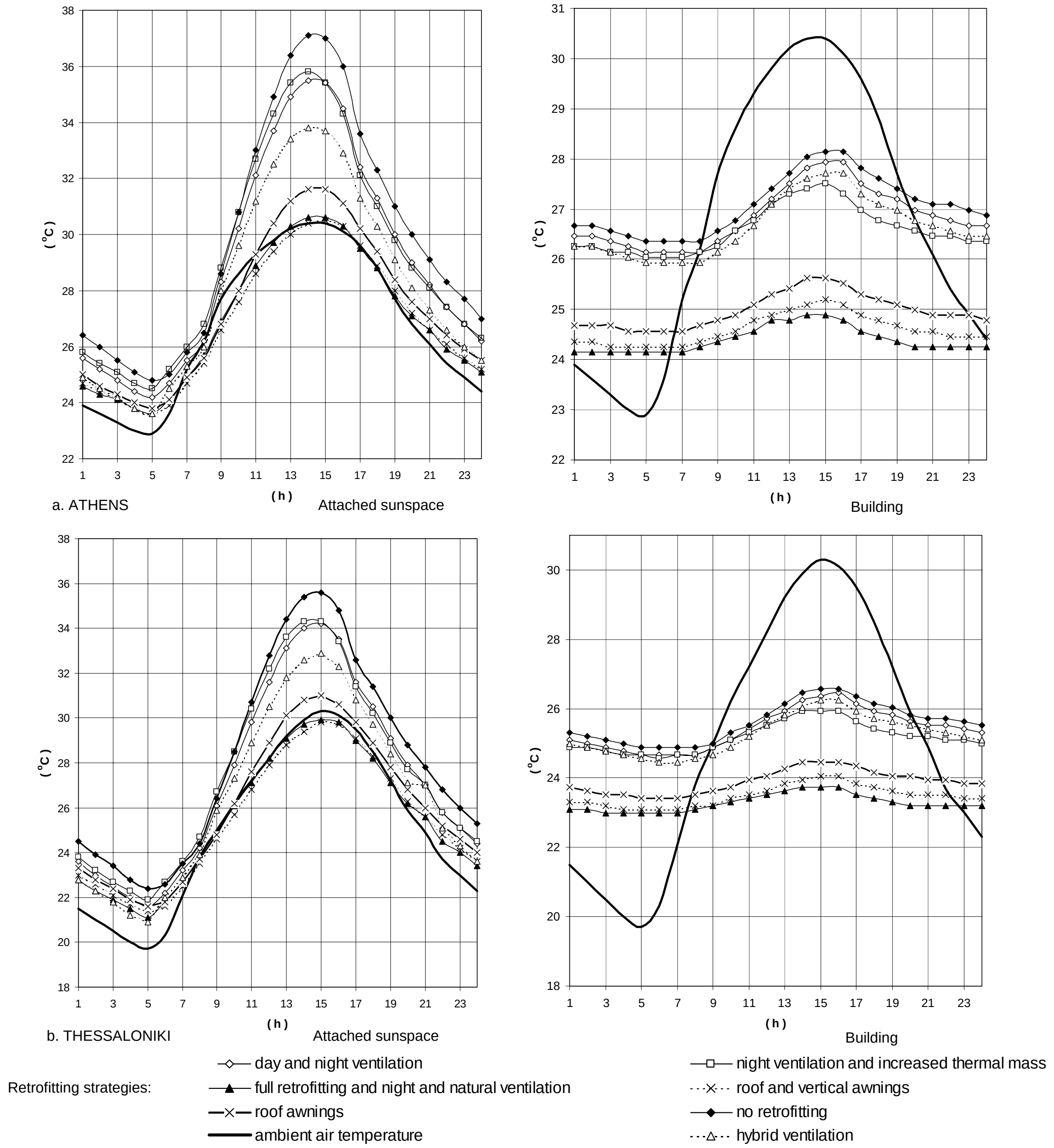
2.2 Summer period

The examined retrofitting strategies for the summer period include the following scenarios:

- No retrofitting: includes all the features of the corresponding “no retrofitting” scenario for the winter period.
- Day and night ventilation: this is based on the “no retrofitting” scenario implementing extensive natural ventilation during the day and passive cooling ventilation during the night.
- Night ventilation and increased thermal mass: the brick wall is replaced by a 40cm-thick concrete mass wall. All other features remain as in the “no retrofitting” scenario.
- Roof awnings: awnings are placed at the top of the sunspace during daytime. All other features remain as in the “no retrofitting” scenario.
- Roof and vertical awnings: awnings are placed vertically on the external vertical surface during the daytime. All other features remain as in the “roof awnings” scenario.
- Full retrofitting and day and night ventilation: includes window retrofitting, increased thermal mass, night and day ventilation and hybrid ventilation and roof and vertical awnings.
- Hybrid ventilation: hybrid ventilation in the form of two ventilators placed at the top of the lateral surfaces of the sunspace, sensor-controlled at a set point of 27^{o}C as described in the winter period strategies.

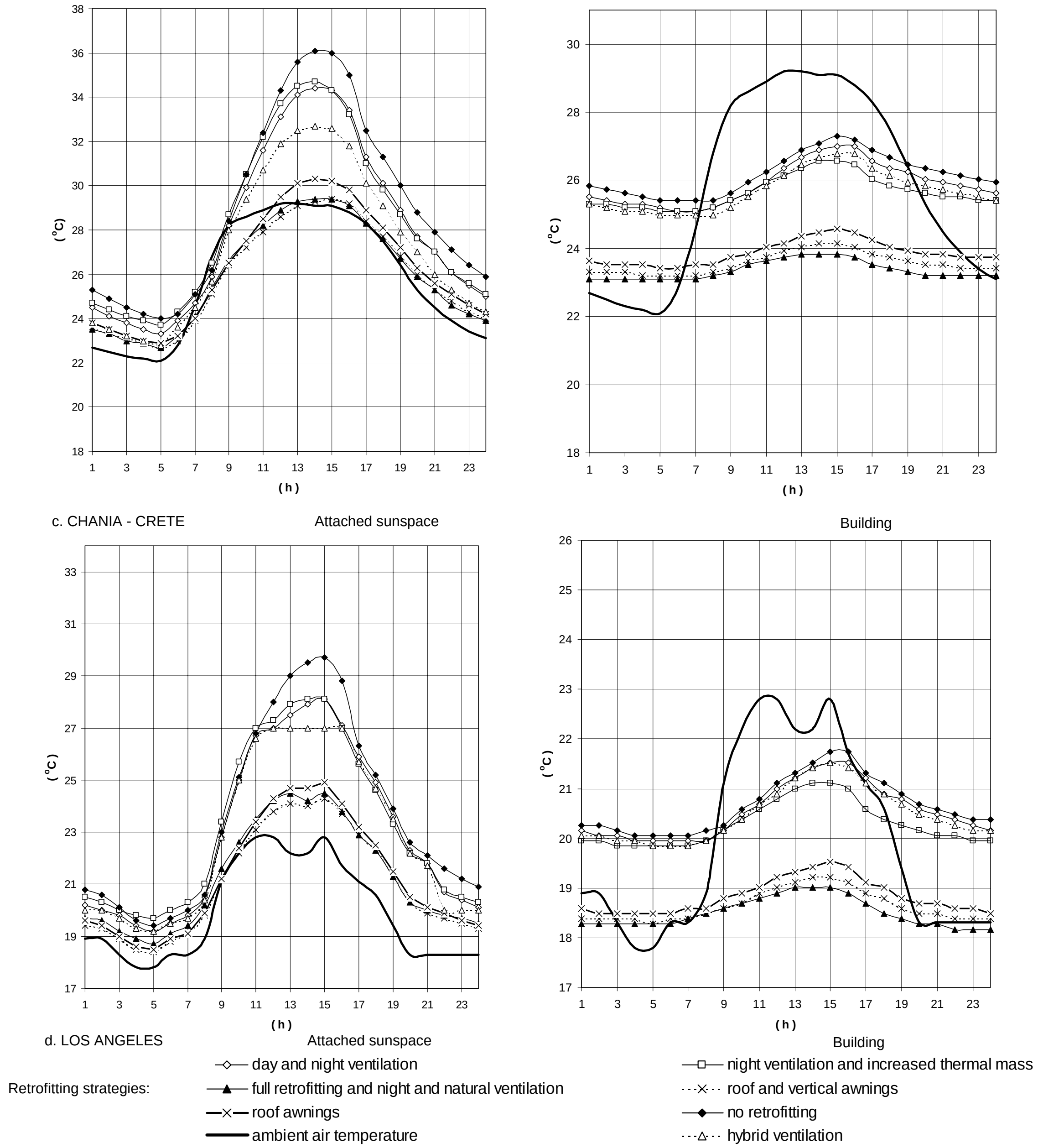
From Figs 3 a to d, outcomes regarding the effectiveness of the retrofitting scenarios may be derived for the summer period. Of the summer retrofitting scenarios implemented, solar shading proved to be the most effective retrofitting factor, followed by night and hybrid ventilation. Thermal mass did not appear to be significantly effective and therefore is not presented as an individual strategy, but is combined with night ventilation in order to exploit the benefits of thermal mass and time lag in the temperature variations.

In the case of the sunspace the main aim is to reduce indoor air temperature variations an make them match ambient air temperature variations as closely as possible. The “no retrofitting” scenario results in unacceptably high temperatures during almost all hours for all the examined cities, with peak values reaching 37.1 °C, 35.7 °C and 36.1°C, for the cities of Athens, Thessaloniki and Chania respectively. These peak values are about 6 °C greater than the respective ambient air temperature peak values. In the Los Angeles case the sunspace air peak value is 29.8 °C, almost 7 °C greater than the respective ambient temperature. The “hybrid ventilation” scenario led to a reduction in these temperature differences of about 50% in all cases. The full retrofitting scenario could achieve the abovementioned aim, bringing the temperature variations in the indoor and ambient air close to each other, as presented in Figures 3 a, b and c for the Greek cities. The abovementioned target is partially achieved in the case of Los Angeles, where the temperatures inside the sunspace are from 0 to 2 °C greater than the respective ambient temperatures.



Figs. 3 a and b. Temperature distributions of the ambient and zone air temperatures for the sunspace and the building in the cities of Athens and Thessaloniki, for the retrofitting strategies of the summer period.

In the case of the main building the basic aim is to reduce indoor temperatures by implementing the shading devices of the attached sunspace and hybrid ventilation to gain the benefits of the thermal discharge of the south mass wall.



Figs. 3 c and d. Temperature distributions of the ambient and the zone air temperatures for sunspace and the building in the cities of Chania (Crete) and Los Angeles (CA), for the retrofitting strategies of the summer period.

In the case of main building the shading scenarios proved significantly effective, reducing the building’s indoor temperature by approximately 1.5 to 2^{o}C in all cities, compared to the “no shading” scenarios. Therefore, two groups of temperature variations were formed in the main building’s summer diagrams with a temperature shift of 1.5-2 ^{o}C, one for scenarios including shading and one for no shading. In each group the scenarios which include increased thermal mass and night ventilation were more effective than the others. Another advantage of these scenarios is that their effectiveness is increased during noon and afternoon hours due to the time lag of thermal inertia, as seen in Figs. 3 a to d. The same phenomenon appeared during the winter period, as can be seen in Figs. 2 a to d, but its effectiveness is rather undesirable for winter.

Overall, the implementation of retrofitting scenarios during summer appears to be positive in both the sunspace and the main building. If the complete retrofitting scenario is implemented, the air temperature variations in the sunspace are very close to the respective ambient variations and even slightly lower in the morning and early noon hours. In the main building the combination of shading and increased thermal mass leads to acceptable thermal comfort conditions, with a maximum air temperature lower than 25 ^{o}C in all cities.

3. CONCLUDING REMARKS

The effectiveness of the retrofitting strategies in a sunspace attached to a one-storey building was investigated in three representative Greek sites and a southern-altitude U.S. city, throhgh implementing combined thermal and ventilation modeling. Special emphasis was given to the simulation of ventilation phenomena and the investigation of thermal performance during both the winter and summer periods. From the results it has been concluded that the sunspace could significantly help to reduce heating loads demand during the winter. Retrofitting strategies such as renovation of the glazed envelope with more airtight windows and thermal mass increase the energy benefits, while hybrid ventilation diminishes the sporadic overheating problems during the winter period. The retrofitting techniques also appeared effective in reducing summer overheating problems. Solar shading devices combined with hybrid and natural night ventilation achieve acceptable indoor temperatures in most cases in both the sunspace and the house, reducing the cooling energy demand even in relatively warm climates.

4. REFERENCES

[1]. H.E. Feustel et al, COMIS calculation routines, Air Infiltration and Ventilation Center, Bracknell, UK, new edition, 1996.

[2]. T. Weeling and Larry Palmiter, Suncode Program User's Manual, Ecotope, 1985.

[3]. C.J. Koinakis, Combined thermal and natural ventilation for long-term energy assessment. Validation with experimental measurements, article in press, Energy and Buildings, 2004.

[4]. C. Koinakis, N. Papamanolis,«Natural Cross Ventilation for Refrigerative Cooling Reduction in a Well Insulated Apartment», Ventilation and Cooling, 18th AIVC Conference, Athens, Greece, 23-26 September, 1997.

[5]. C. Koinakis, N. Chrisomallidou, «Ventilation Strategies for Thermal Performance Improvement of an Attached Sunspace» 19th AIVC Conference, Oslo, Norway 28-30 September, 1998: Ventilation technologies in urban areas.

LOW ENERGY COOLING TECHNIQUES FOR RETROFITTED OFFICE BUILDINGS IN CENTRAL EUROPE

Miloš Lain[1)], František Drkal[1)], Jan Hensen[2)], Vladimír Zmrhal[1)]

[1)] *Department of Environmental Engineering, Faculty of Mechanical Engineering*
Czech Technical University in Prague Technická 4, 166 07 Prague 6, Czech Republic
e-mail: lain@fsid.cvut.cz
[2)]*Center for Building & Systems TNO-TU/e, Group FAGO - V 06H12*
Technische Universiteit Eindhoven, P.O. Box 513, 5600 MB Eindhoven, The Netherlands

ABSTRACT

Until the 1970's most office buildings in central Europe were not equipped with mechanical cooling (air-conditioning). Due to increasing requirements for thermal comfort and warmer summers, nowadays mechanical cooling is often applied to such buildings, however without caring for energy consumption and without considering possibilities of low energy or passive cooling.
This paper discusses options for incorporating low energy cooling technologies when retrofitting office buildings in central Europe. Climate analysis, design recommendations and role of computer simulation of building and system in the design process are presented. Applicability of night ventilation, evaporative cooling, and cooled ceiling panels, which can provide optimal thermal comfort in a conditioned space in relation to low energy consumption, will be analyzed. The slab cooling using existing slab heating system is stressed in the paper.

KEYWORDS

low energy cooling, slab cooling, computer simulation, retrofit, office building

INTRODUCTION

In Europe buildings account for approximately 40 to 50% of total primary energy consumption. In office buildings, about 10% of the total energy consumption is needed for comfort cooling. More and more offices are fully air-conditioned. In the Czech Republic, most new or reconstructed offices are equipped with full air-conditioning. The increasing use of computer and auxiliary equipment has led to an increasing demand for cooling in commercial buildings. The energy consumption for comfort cooling is significant . The associated impact on greenhouse gas emissions is enhanced by the fact that these cooling systems are usually electrically driven and electricity in the Czech Republic is mostly produced by coal power plants (Santamouris 1996, Heap 2001).
Based upon the Kyoto Protocol, European countries have agreed to agreed to decrease energy consumption in buildings and thus to cut down greenhouse gas emissions. One promising way to solve the discrepancy between increasing demand for thermal comfort and the necessity to reduce CO2 emissions is the application of low energy cooling techniques .

LOW ENERGY COOLING TECHNIQUES

Low energy cooling techniques aim to reduce energy consumption and peak electricity demand. They do so by making use of low exergy (ie. low quality) cooling sources such as the ambient air, the ground or surface water. These technologies are also referred to as passive or hybrid cooling systems. Passive cooling systems should not be confused with passive cooling building design, which mainly focuses on reducing the cooling load.

Low energy cooling techniques can be divided into two groups: those, which include a cooling source and those that focus solely on delivery of cooling to the treated space (IEA 1995, Liddament 2000).

The first group of systems rely on natural sources of cooling, but fans or pumps are required for most of them. The following technologies can be placed in this group:

- Night ventilation – lowers the temperature of the building thermal mass by night ventilation
- Evaporative cooling – sensible heat is absorbed as a latent heat to evaporate water
- Ground cooling – the air is cooled by the ground via matrix of piping or groundwater (aquifer) cooling

The second group of technologies focus on delivering the cooling to the treated space in an efficient manner, those technologies work usually well with lower grade sources of cooling. The following systems can be placed in this group:

- Slab cooling – thermal mass of slab is cooled by air or water
- Chilled ceilings and beams – ceiling panel or beam is cooled
- Displacement ventilation – conditioned air is emitted at low level at very low velocity

RETROFIT OF OFFICE BUILDINGS

Office buildings in the Czech Republic can be roughly categorized into three main groups according to construction style in relation to the time of building

A. Massive construction (brick, concrete), window area up to 30% of the façade, build up to the 1950-ies. Those buildings are usually not air-conditioned, or mechanically ventilated. Retrofit of such buildings is always individual. High thermal mass usually helps to maintain thermal comfort if passive cooling rules (low internal gains, shading) are obeyed during retrofit.
B. Buildings with a heavy concrete frame and floors and light prefabricated envelope, windows up to 60% of the facade. Neither air-conditioning nor mechanical ventilation was standard for this type of buildings. A very high percentage of current Czech stock of office buildings fall into this category. Retrofit of this type is an actual problem, and since there is no mechanical ventilation system and there is limited space to incorporate an all-air system, cooling possibilities are limited.
C. Modern office buildings with glass façade, lowered ceilings, carpets, usually fully air-conditioned.

This paper mainly addresses type B buildings and focuses on options for using existing water based ceiling heating systems for cooling purposes. The effects of natural ventilation and shading will be discussed as well.

Since traditionally type B buildings do not have mechanical ventilation, it would be very unpractical to apply any system requiring central air treatment such as systems based on evaporative cooling, ground cooling or forced night ventilation.

CEILING HEATING AND COOLING

Many of the B type buildings are heated by a ceiling (slab) heating system, commonly known as Critttal system. This system consists of a serpentine heating pipe embedded in the concrete massive ceiling. The system is based on the 1932 patent of the Dutchman J.K.C. van Dooren.
A radiant cooled ceiling is a relatively efficient cooling system, which is nowadays popular for new commercial buildings. Sensible room heat gains are dissipated by large-area water-cooled ceiling panels. Another type of radiant cooling system is slab cooling, in which the thermal mass of the floor/ceiling slab is cooled by water. For both system types, the supply airflow can be limited to the fresh air frequirements.
This paper is about using/converting the existing Crittal heating system for cooling in the summer.
Condensation risk is one of the main issues in radiant cooling systems. The inlet water temperature for the cooled ceiling has to be such that no surface condensation will occur (ie. the ceiling surface temperature has to be higher than the room air dew point temperature). For the light ceiling systems a fine control can be used to assure that the minimal surface temperature remains higher than the dew point temperature. It is not possible to use a fast control system for the ceiling slab embedded cooling system, because there is a large time delay (hours). Therefore the surface temperature must be kept higher than for the lightweight systems. In Czech offices with no additional moisture sources the maximum dew point temperature is about 16°C.
This is why for real systems the supply water temperature usually varies from 16 °C to 20 °C and the temperature difference between inlet and outlet cooling water is commonly $2 \le \Delta T \le 4$ K.

THERMAL COMFORT- OPERATIVE TEMPERATURE

The operative temperature t_o was chosen as the evaluation criterion for thermal comfort in air-conditioned spaces with radiant cooling or heating. The operative temperature depends on air temperature t_a; mean radiant temperature - *MRT* and air velocity w_a. From these quantities the thermal comfort in conditioned spaces can be predicted by means of the *PMV* (predicted mean vote) / *PPD* (predicted percentage dissatisfied) index according to ISO Standard 7730. The comfort range of thermal comfort is normally considered as $-0.5 < PMV < 0.5$ corresponding to $PPD < 10$ %.
The operative temperature t_o is defined as the uniform temperature of a radiantly black enclosure in which an occupant would exchange the same amount of heat by radiation plus convection as in the non-uniform environment. The following formula is used

$$t_o = At_a + (1 - A)MRT \qquad [\ °C\ ] \qquad (1)$$

where A is a function of the relative air velocity (from 0,5 to 1). When the air velocity is lower than 0.2 m/s, operative temperature approximately equals the globe temperature t_g and can be calculated as the average of air temperature and MRT.
The influence of the surface temperature on thermal comfort is significant; therefore if there is a cooled surface in the room it is possible to keep a higher indoor air temperature to achieve the same thermal comfort.

MODEL DESCRIPTION

Simulations were carried out for a typical office of 4.92 by 5.5 m with a room height of 3.2 m. There are two south-east facing windows resulting in 55% glazing of one of the walls. The model of the office is shown in Figure 1. As indicated, the office model consist of two thermal zones (with uniform air temperature) representing the “office zone” and the “cooled ceiling zone”.
Internal heat gains representing three occupants (3 x 62 W) each with PC (3 x 40 W) and monitor (3 x 58 W) are incorporated in the model. The heat gain schedule for a working day is shown in Figure 2. In the model no heat exchange through the internal wall is assumed since the surrounding rooms are assumed to have the same thermal conditions.

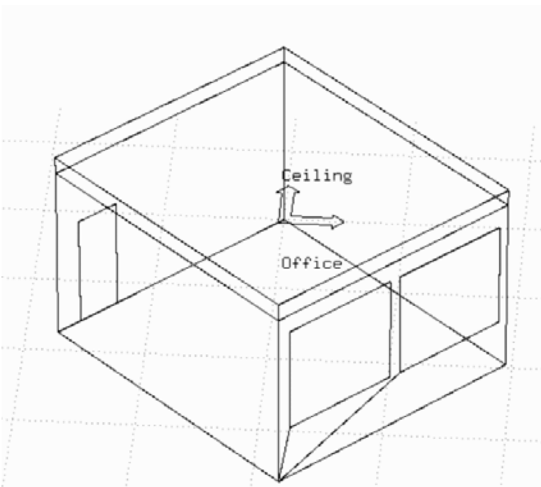


Figure 1: Office model in ESP-r software

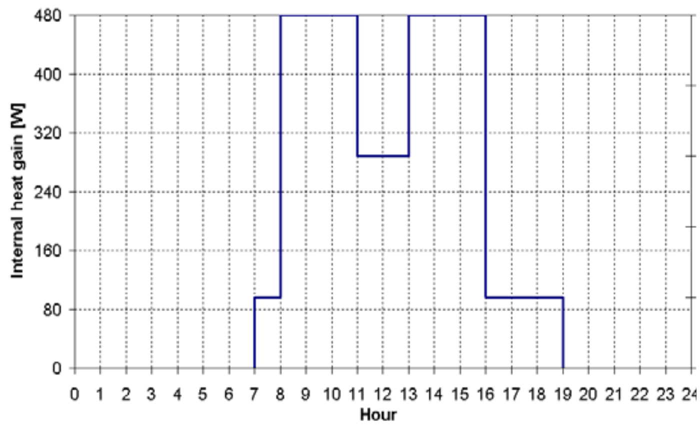


Figure 2: Schedule of the internal heat gain

SIMULATION AND RESULTS

Two passive cooling methods for improving thermal comfort in the not air- conditioned office in the summer were tested: decreasing the solar heat gains by shading or reflection and natural ventilation strategies.
The simulations were carried out for three ventilation strategies:
V1 only infiltration - air exchange rate 0,5 h^{-1}; for 24 hours a day
V2 night ventilation - air exchange rate 5 h^{-1}; from 18:00 to 7:00
V3 daytime ventilation - air exchange rate 10 h^{-1}, from 7:00 to 18:00 (if the outside temperature exceed 24 °C the ventilation was set back to basic infiltration 0,5 h^{-1})
Three types of glazing were simulated.
S1 Standard double glassing with solar factor 0,71
S2 Antisun bronze glassing with solar factor 0,48
S3 Glassing with internal blinds, solar factor 0,2
All cases have been simulated without slab cooling (C0) and with slab cooling (C1), the cooling layer temperature was set to 17 °C for 24 hours a day, 7 days a week. This makes 18 combinations.
The simulations were carried out for three summer months, using a weather test reference year (hourly data) for Prague.

Some of results for a selected period of two weeks are presented in Figure 3, Figure 4 and Figure 5. The 3 months results are summarized in the Table 1.

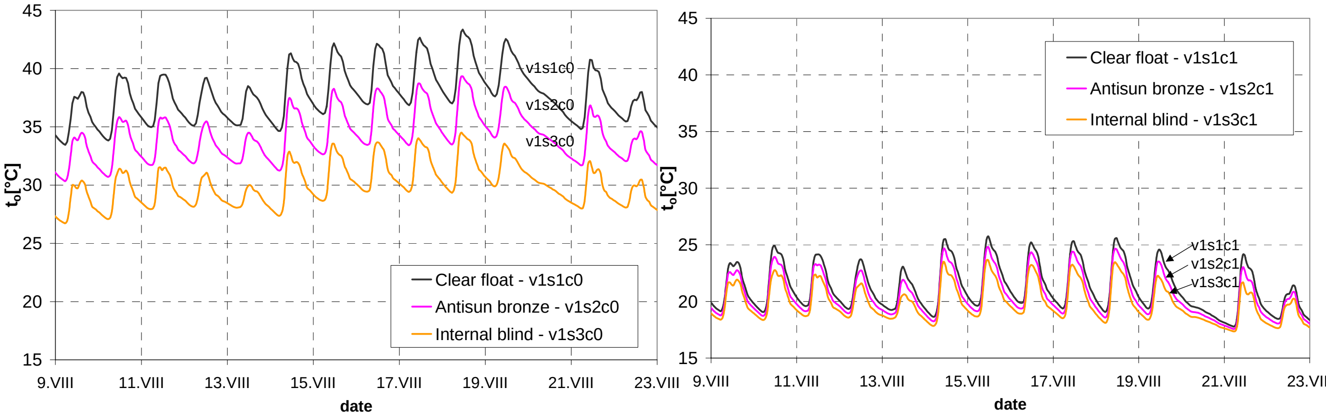


Figure 3: Operative temperature during two summer weeks assuming infiltration only, different glazing types, without (left) and with ceiling cooling.

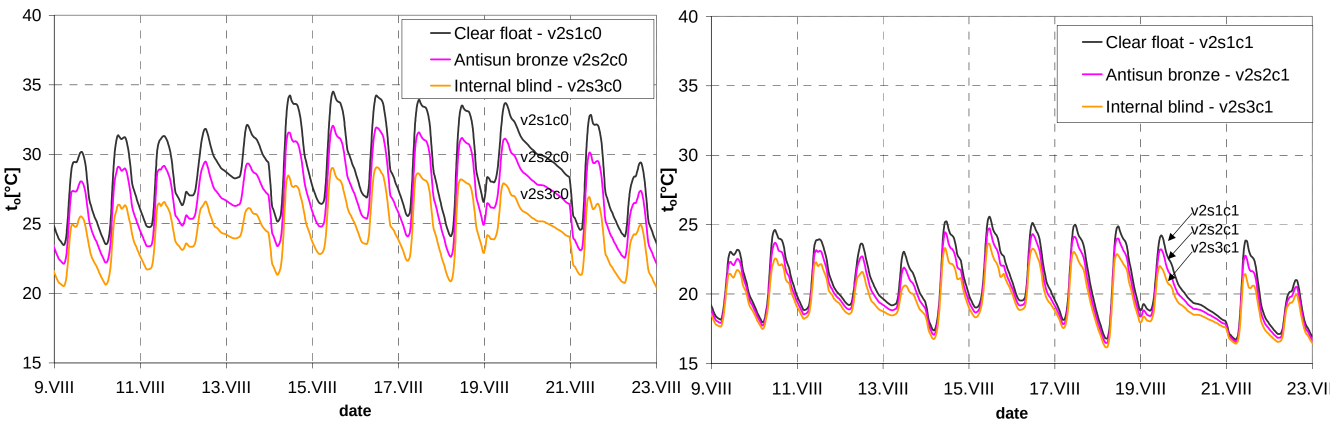


Figure 4: Operative temperature during two summer weeks assuming night ventilation, different glazing types, without (left) and with ceiling cooling.

Table 1: Number of working hours during three summer months with the operative temperature in a specific interval

Operative temperature	**from**		**18**	**24**	**28**	**32**		**18**	**24**	**28**	**32**
	to	**18**	**24**	**28**	**32**		**18**	**24**	**28**	**32**	
Ventilation	**Glassing**	**Without ceiling cooling**					**With ceiling cooling**				
Infiltration	Std.	0	0	0	143	583	23	648	55	0	0
Infiltration	Antisun	0	0	74	346	306	41	678	7	0	0
Infiltration	Blinds	0	48	370	271	37	71	655	0	0	0
Night vent.	Std.	0	104	367	218	37	54	647	25	0	0
Night vent.	Antisun	0	270	337	119	0	74	648	4	0	0
Night vent.	Blinds	5	487	218	16	0	115	611	0	0	0
Day vent.	Std.	133	415	172	6	0	192	522	12	0	0
Day vent.	Antisun	165	434	126	1	0	216	508	2	0	0
Day vent.	Blinds	227	464	35	0	0	256	470	0	0	0

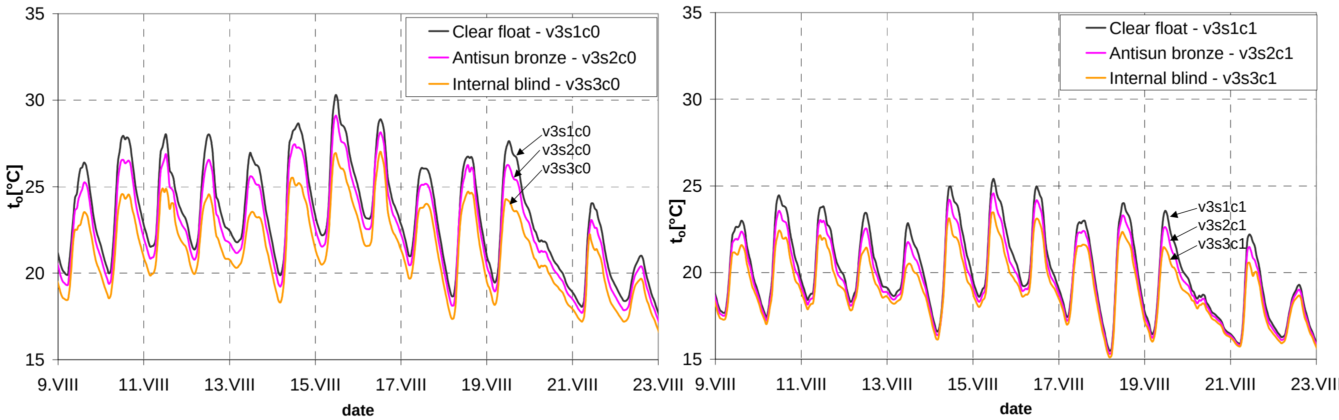


Figure 5: Operative temperature during two summer weeks assuming daytime mechanical ventilation, different glazing types, without (left) and with ceiling cooling

CONCLUSION

According to the simulation results all three low energy cooling strategies help to improve the indoor thermal comfort in the office. It is recommended to use antisun glassing with blinds especially if there is not other cooling technology. The operative temperature was decreased by 10 K if just infiltration was used (Figure 3. left) and by 5 K for night ventilation (Figure 4. left). The natural ventilation has even a bigger effect on the inside temperatures; this is due to the fact that in our simulation very high air exchange rates have been selected. In reality it is difficult to reach such values and there are other practical problems with such intensive natural ventilation (safety, draft etc.).

The ceiling cooling was approved as a system, which only one can fully guarantee thermal comfort in the office. The effect of ceiling cooling was much stronger that other considered technologies. The simulation results even show occasional overcooling of the office. The question of the optimal ceiling (cooling water) temperature and the control of the slab cooling system remain for future research.

REFERENCES

[1] ASHRAE Handbook 2001 Fundamentals, ASHRAE, Atlanta, 2001.
[2] ISO Standard 7730, Moderate thermal environments – Determination of the PMV and PPD indices and specification of the conditions for thermal comfort.
[3] Loveday, D.L., Parsons, K.C., Taki, A.H., Hodder, S.G., Jeal, L.D., Displacement ventilation environments with chilled ceilings: thermal comfort design within the context of the BS EN ISO7730 versus adaptive debate. Energy and Buildings 34, 2002, p. 573 – 579.
[4] Barnard, N., Jaunzens, D., 2001, Low Energy Cooling – Technology Selection and Early Design Guidance, Building Research Establishment Ltd, London, 109 p.
[5] Heap, R.D., 2001, Refrigeration and air conditioning – the response to climate change, Bulletin of the IIR - No 2001-5.
[6] IEA, 1995, Review of Low Energy Cooling Technologies, Natural resources Canada, Ottawa, Canada, 88 p.
[7] Liddament, M.W., 2000, Low energy cooling, ESSU, Coventry, U.K., 32 p.
[8] Santamouris, M., Asimakopoulos, D., 1996, Passive Cooling of Buildings, James&James Ltd., London, U.K., 472 p.

EFFECT OF IMPROVED AIR DISTRIBUTION ON PERCEIVED INDOOR CLIMATE AND PRODUCTIVITY - A CASE STUDY IN A LANDSCAPE OFFICE

R. Niemelä[1], S. Kemppilä[2], P. Korhonen[1], E. Nykyri[1], K. Reijula[1] and O. Seppänen[3]

[1]Finnish Institute of Occupational Health, Topeliuksenkatu 41 a, FIN-00250 Helsinki, Finland
[2]Tampere University of Technology, PO Box 541, FIN-33101 Tampere, Finland
[3]Helsinki University of Technology, PO Box 3000, FIN-02015 HUT, Finland

ABSTRACT

The aim of this paper is to investigate the effect of improved air distribution on symptoms and self-evaluated productivity in a landscape office in which the air was distributed with ventilated cooled beams. The intervention consisted of the improvement of evenness of the air distribution by installing an extra whirl diffuser at the end of every second cooled beam. As a consequence, the draught risk quantified by the draught rating model DR, was reduced to some extend. During the pre-intervention conditions 34 % of the respondents experienced draught whereas after the intervention the corresponding value was 17%. The indoor questionnaire also showed that the prevalence of dry throat, stuffy nose and fatigue reduced by 4 to 8 percent-units. The self-estimated productivity increased, because 17% of the employees during the pre-intervention conditions were working below the average efficiency whereas only 12 % after the intervention. This paper shows that a relatively small decrease in air velocities may result in reduction of symptoms and increase in the self-estimated productivity.

KEY WORDS

Draught discomfort, thermal climate, symptoms, intervention study, cooled beam

INTRODUCTION

Modern office equipment and lighting installations generate notable amount of heat and consequently large airflows are needed even in winter. Distribution of large airflows in landscape offices without draught discomfort is a challenging task particularly if the room is low and densely occupied. In these conditions people are very sensitive for draught caused by air movement. Several field studies show an elevated risk for complaints on indoor environment in large landscape offices with densely located work stations, Leyten (2002), Niemelä et al (2002), Pitchurov et al (2002). Symptoms and discomfort may lead to the reduced worker performance and therefore productivity losses, Niemelä et al (2003). It is worth noting that productivity in densely occupied spaces mainly depends on performance of the employees.

The aim of this paper is to investigate the effect of improved air distribution on symptoms and self-evaluated productivity in a landscape office in which the air was distributed with ventilated cooled beams. These relatively new air distribution systems have been installed to an increasing extent, particularly in Scandinavia and Central Europe, Kosonen et al (2000).

BUILDING AND METHODS

The study was performed in an insurance department of a company with 166 employees working in the landscape offices on two floors (area 890 m^2 / floor). The study was launched in the building, because the occupational health service unit had received complaints on draught discomfort and found elevated sick leave rates. The work tasks consisted of client services on car insurance by telephone. The offices were quite densely occupied with a packing factor of 10.7 m^2/ person. The inlet air was distributed by the ventilated cooled beams which have been installed to an increasing extent during resent years. In this application the air flow supplied through the nozzles induces room air through the heat exchanger of the beam (Figure 1). The building was equipped with two central air handling units and control systems. In order to reduce air movement in the occupied zone the air diffusion efficiency was improved by installing a piece of a ventilation duct and a swirl diffuser at the end of the every second ventilation cooled beam (56 swirl diffusers). The air flow rates were also adjusted and balanced after the installation.

Because the starting-point of the study was improvement of air distribution and reduction of air movement in the occupied zone, the indoor air measurements were focused on the thermal climate and perceived work environment and symptoms. In addition, a limited number of contaminant concentrations were measured. The measurements and questionnaires were performed before and after the intervention i.e. the installation of the swirl diffusers. The before- conditions were measured at the end of January and the after-conditions in March.

Both long term and short-term thermal climate measurements were performed. Air velocity and temperature at the work stations were momentarily measured with a Dantec multipoint flow analyser according to ISO 7730 (1995). The averaging period of air velocity sampling was three minutes. In addition, the room air temperature and inlet air temperature were monitored one week before and after the intervention by the building automation system. The indoor air questionnaire with extra questions on psychosocial factors and self-reported performance evaluations was conducted by the internet. Descriptive statistics was used in analyzing the questionnaire data. Each employee served as her own reference before and after the intervention.

In order to assess discomfort caused by draught, a draught rate (DR)-index was used, Fanger et al (1988). The index predicts the percentage of persons dissatisfied due to draught according to equation below

$$DR = (34 - t_a)\,(v_a - 0.05)^{0.62}\,(3.14 + 0.37\,SDv_a),$$

where

t_a	=	air temperature,
v_a	=	air velocity, m/s
$SD\ v_a$	=	standard deviation of air velocity

Figure 1. The ventilated cooled beam (above) and the swirl diffuser (below)

RESULTS

Air temperature and velocity

After the installation of the swirl diffusers the air velocities in the occupied zone were a little reduced. Before the improvement the velocities ranged from 0.05 to 0.22 m/s (mean 0.10 m/s) and after the improvement 0.02 to 0.17 m/s (mean 0.09) (Table 1). Air velocities were clearly reduced at the head level of a sitting or standing person where air movement may easily perceive as draught (Figure 2).

TABLE 1
The summary of the air velocity measurements

	Before		After	
	mean	range	mean	range
Air temperature, °C	22.4	20.2-24.7	23.0	21.4-24.8
Air velocity, m/s	0.10	0.05-0.22	0.09	0.02-0.17
Relative humidity, %	16		19	

The results of the air quality measurements conducted in the pre-intervention conditions indicate that content of TVOC was low (30-60 mg/m^3) and the number of mineral fibres at surface was less than the detection limit (< 0.1 $fibre/cm^2$). Owing to these low values the air quality measurements were not repeated after the intervention. The CO_2 concentrations in both conditions remained at the same level of about 500 ppm.

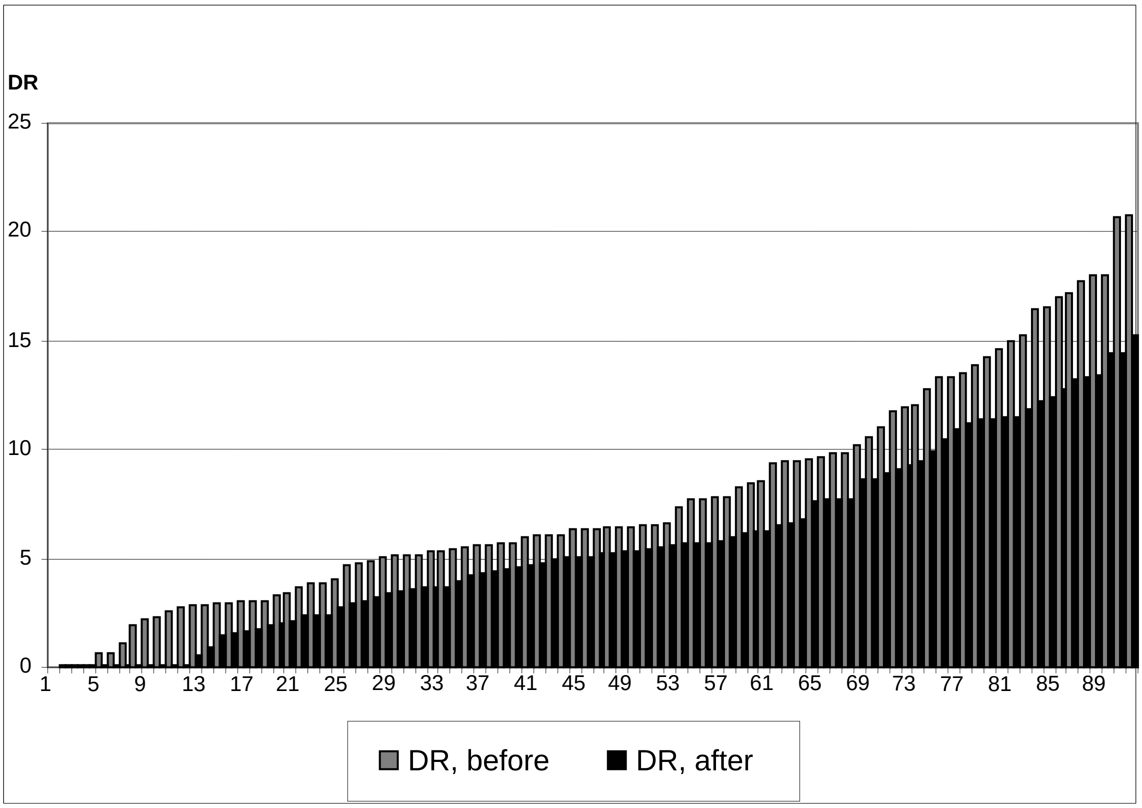


Figure 2. Draught rating model results

Perceived climate, symptoms and self-estimated productivity

Before the installation of the swirl air diffusers 34 % of the employees reported on draught, 53% on stuffy air, 49 % on dry air, and 59 % on noise (TABLE 2). The prevalence rates of these factors are higher than the corresponding prevalence rates in the reference material i.e. 22%, 34%, 35% and 17%, which are based on the responses of 11,000 office employees, Reijula & Sundman-Digert (2004).

After the installation of the extra air diffusers the prevalence rate of draught was reduced from 34 % to 17 %, and that of too low temperature from 22% to 13 % (TABLE 2). Sensation of too high temperature, stuffy air and dry air were increased whereas that of noise was remained as the same.

Prevalence of the SBS symptoms was in the pre-intervention condition was at the same level as that in the reference material (given in parenthesis). The employees reported most on irritated, stuffy nose 23% (20%), irritation of the eyes 17% (17%) and fatigue 18% (16 %). After the installation of the extra air diffusers both irritation symptoms and central nervous symptoms, excluding headache, were reduced. (TABLE 3).

TABLE 2
The perceived indoor climate

Indoor parameter	Number of respondents		Prevalence of the complaints	
	before	after	before	after
Draught	92	92	34	17
Temperature too high	90	91	21	36
Varying temperature	89	91	19	18
Temperature too low	90	92	22	13
Stuffy air	93	92	53	58
Dry air	92	91	49	56
Noise	92	92	59	55
Dim light or glare/reflections	93	93	20	16

TABLE 3
Prevalence of the SBS symptoms

Symptom	Nr of respondent		Prevalence of symptoms	
	before	after	before	after
Fatigue	93	93	18	11
Feeling heavy in the head	93	93	14	10
Headache	93	93	5	10
Difficulties in concentrating	93	93	7	4
Eyes itching, stinging or irritated	93	93	17	16
Irritated, stuffy nose	93	93	23	15
Hoarse or dry throat	93	93	15	11
Cough	93	93	4	2

DISCUSSION

As a consequence of the improvement of evenness of the air distribution, the draught risk quantified by the draught rating model DR, was reduced to some extend. The highest DR values were at a level of 21 % before the intervention but below or at 15% after the intervention. Of the complaints related to the draught discomfort, prevalence of the draught was diminished 17 absolute %-units and that of too low temperature 9 %-units. Prevalence of varying temperature remained at the same level whereas prevalence of too high temperature and dry and stuffy air were increased after the intervention. The elevated values of these complaints may be due to the slightly higher air temperature in the post-intervention condition. It has been proven that the increased temperature has impact on the perceived air quality, Toftum (2002).

The indoor questionnaire also showed that prevalence of the central nervous symptoms, excluding headache, reduced 3 to 7 absolute %-units whereas all irritating symptoms were reduced. The increased prevalence of headache may be associated with the slightly higher room temperature after the intervention.

The self-estimated productivity increased, because 17% of the employees during the pre-intervention conditions were working below the average efficiency whereas only 12 % after the intervention. This finding is in the line with the reduced SBS symptom prevalence rates.

CONCLUSIONS

This paper shows that a relatively small decrease in air velocities may result in reduction of symptoms and increase in productivity expressed as self-reported productivity, even though the air velocities were not particularly high before the intervention. In addition, the improvements were achieved with moderate retrofitting measures.

ACKNOWLEDGEMENTS

This study is a part of the 'Productive Office 2005' project supported by The National Technology Agency and The Work Environment Fund in Finland. Thanks are due to Mr Henri Riuttala on the data treatment.

LITERATURE

EN ISO 7730 (1995) Moderate Thermal Environment - Determination of the PMV and PPD Indeces and Specifications for Thermal Comfort. Geneve.

Fanger, P.O., Melikov, A., Hanzawa, H., Ring, J. (1988). Air turbulence and sensation of draught. *Energy and Buildings* **12**, 21-39.

Kosonen, R., Horttanainen, P., Dunlop, G. (2000). Integration of heating mode into ventilated cooled beam. *Proceedings of the 7th International Conference on Air distribution in Rooms, ROOMVENT'2000*, 9-12 July 2000, Reading. 381-386.

Leyten, J. (2002). The effects of cellular and landscape offices on workers' complaints. *Proceedings of the 8th International Conference on Air Distribution in Rooms, ROOMVENTt'2002*. 8-11. Sep. 2002, Copenhagen 477-478.

Niemelä, R., Hannula, M., Rautio, S., Reijula, K., Railio, J.(2002). The effect of air temperature on labour productivity in call centres - a case study. *Energy and Buildings* **34,** *759-764*

Niemelä, R., Seppänen, O., Reijula, K. (2003). Prevalence of SBS-symtoms as an indicator of health and productivity in office buildings. *In: Proceedings of the 7th International Conference: Healthy Buildings 2003*; 2003 Dec 7-11; Singapore.251-256.

Pitchurov, G., Naidenov, K., Melikov, A., Langkilde, G. (2002) Field survey of occupants thermal comfort in rooms with displacement ventilation. *Proceedings of the 8th International Conference on Air Distribution in Rooms, ROOMVENT'2002*. 8-11. Sep. 2002, Copenhagen 479-482.

Reijula, K., Sundman-Digert, C. (2004). Assessment of indoor air problems at work with a questionnaire. *Occupational and Environmental Medicine* **61**, *33-38*

Toftum, J. (2002). Human response to combined indoor environment exposures. *Energy and Buildings* **34**, *601-606.*

ENERGY SAVINGS AND INDOOR AIR QUALITY IN RETROFITTING OF EDUCATIONAL BUILDINGS

R.Cantin, G.Guarracino, M.Morain

Ecole Nationale des Travaux Publics de l'Etat, Laboratoire des Sciences de l'Habitat, DGCB-CNRS URA 1652, Rue Maurice Audin - 69518 Vaulx-en-Velin, France.
cantin@entpe.fr, guarracino@entpe.fr, morain@entpe.fr

ABSTRACT

A significant part of existing educational buildings have to be retrofit in the next years in France. The economical, environmental and social requirements have increased with the international targets of reduction of greenhouse emission and sustainable development. Thus, retrofit scenarios have to reduce energy consumption and have to maintain a high quality of indoor environment.

However, various studies showed that measurements of energy savings, combined with an improvement of indoor air quality, are rarely applied in retrofitting, because of a lack of knowledge of decision makers conecrning the potential improvements.

In order to improve knowledge of these decision makers and for best results in retrofitting, we have studied performance in retrofitting of several existing educational buildings, in Rhône Alpes area. In particular, we have investigated energy savings (building envelop and systems) and indoor air quality (ventilation, pollutants) aspects in these case studies. Diagnosis, monitoring data and questionnaires have allowed to characterize the quality of indoor air and energy savings of each building. With these studies, we have identified complex constraints for high perfrmance goals in retrofitting of educational buildings.

In this paper, the results about five retrofitting of existing educational buildings are presented. They show quantitative and qualitative performance about indoor air quality and energy savings. Then, the significant difficulties for decision makers are exposed in order to improve the future elaboration of retrofit scenarios in educational buildings sector.

KEYWORDS

Retrofitting, school, energy, indoor air quality, case studies

INTRODUCTION

Numerous existing educational buildings have to be retrofit in the next years in France for historical and demographical reasons. The economical, environmental and social requirements have increased with the international targets of reduction of greenhouse emission and sustainable development. Thus, retrofit scenarios of educational buildings have to reduce energy consumption and have to maintain a high quality of indoor environment.

However, energy savings and indoor air quality are not optimized in retrofitting because of a lack of knowledge of decision makers concerning the potential improvements. In order to improve the knowledge of decision makers and for best results in retrofitting of educational buildings, we have studied performance in 5 case studies, in Rhône Alpes Area. We have investigated energy savings and indoor air quality aspects in two retrofitted schools, in one school before and after retrofitting, and in two schools before retrofitting. Diagnosis,

monitoring data and questionnaires have allowed to characterize the constraints to optimize the energy savings and the indoor air quality in retrofitting of educational buildings.
In this paper, we will describe and will present the results of the 5 case studies in France, and we will show main quantitative and qualitative performance about energy savings and indoor air quality in retrofitting of these 5 educational buildings. Then, significant difficulties for decision makers will be exposed in order to improve future elaboration of retrofit scenarios in educational buildings sector.

CASE STUDIES DESCRIPTION

Five educational buildings have been studied: two after retrofitting, one during and two before retrofitting. They are in 5 different sites in the Rhône Alpes Area and their main features are described in table 1:

TABLE 1
Main characteristics of 5 case studies

Educational Buildings	Louise Labé	Léon Gambetta	Danielle Casanova	Gaspard Monge	Hippolyte Carnot
City	Lyon	Bourgoin Jallieu	Givors	Chambéry	Roanne
Latitude	45°4N	45,6°N	45,75°N	46°N	46,1°N
Altitude	200 m	255 m	150 m	270 m	280 m
Year of construction	1953	1930	1965	1969	1900/1962
Year of retrofitting	2000	1995	2003	Study in progress	Study in progress
Total floor area	9000 m²	9200 m²	3900 m²	33000 m²	11700 m²
Number of pupils	600	540	350	1800	1200

The basic temperature is -9°C (RT, 2000) and these 5 schools are in the winter climate "H1" (colder climate in France) and in summer climate area "Ec" (moderate climate).
The typology of educational buildings show strong similar features when the educational have been built in the same period. For the 5 case studies, the building envelops and existing heating, ventilation, cooling and lighting systems before retrofitting have been investigated.

TABLE 2
Technical retrofit technologies in the 5 case studies

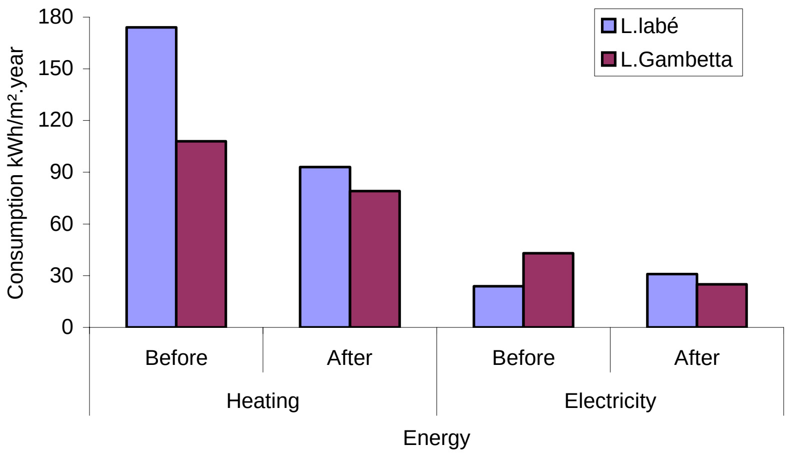
Educational Buildings / Technologies	Louise Labé	Léon Gambetta	Danielle Casanova	Gaspard Monge	Hippolyte Carnot
Insulation	●	●	●	●	●
Low emissivity windows	●	●	●	●	●
Atria		●			
Heating systems	●	●	●	●	●
Insulation of pipes	●	●	●	●	●
Natural ventilation	●		●	●	●
Mechanical ventilation	●		●	●	●
Ventilation with heat recovery				●	
Demanded controled ventilation			●	●	
Fixed shading	●	●		●	●
Movable shading			●	●	●
Building Management System	●	●	●	●	●

The diagnosis and analysis of these 5 case studies have been made with the methodological approach of the annex 36 (IEA Annex36, 2003). In these 5 case studies, the different technical retrofit measures were usual. The decision makers did not have specific knowledge about quantitative and qualitative performance of energy savings and indoors air quality in educational buildings.

ENERGY SAVINGS AND INDOOR AIR QUALITY FEATURES

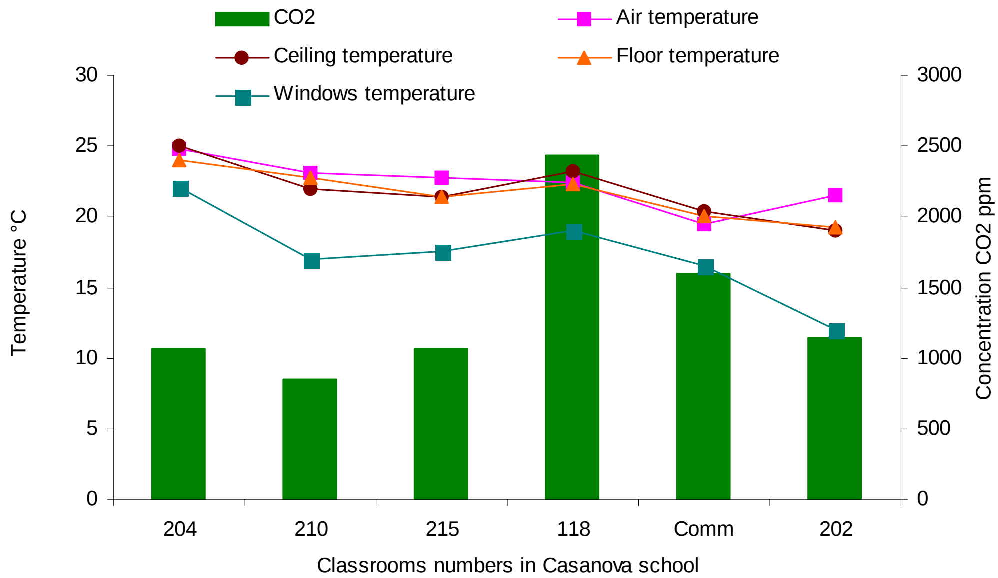
In order to identify energy savings and indoor air quality features in these 5 case studies, we have followed the 4 first levels of energy certification procedure for educational buildings (Adra et al, 2002). This approach integrated the first level of global energy performance, a second level of indoor environmental quality, then two levels with diagnosis and calculation.
The energy consumption has decreased (Figure 1), but complementary diagnosis allows to precise energy and indoor air quality features.

FIGURE 1
Energy savings before and after retrofitting



- In Labe school, after retrofitting, regarding the temperature, the set point design temperature as designed are not fulfilled, especially the set-back temperature seems to be too high in the classrooms and the corridors. The building is largely glass, which improves daylight penetration but causes some comfort problems due to summer overheating. The relative humidity, about 30% in spring, is too low. Problems of strong smells were reported by the surveyed people. The CO_2 concentration, recorded in some classrooms, showed that levels specified for comfort were exceed during lessons. The Building Management System is not totally used and there are not efficient ventilation strategy in the different spaces.
- In Gambetta school, after retrofitting, regarding the temperature in spring, the set point temperature as designed are not fulfilled, especially set-back temperature seems to be too high in the classrooms (between 20°C and 24,5°C). The relative humidity is acceptable in the classrooms (between 40% and 60%). Problems of indoor air quality have been reported by 50% of the surveyed people for the toilets, and by 41% for the gym and the changing rooms.
- In Casanova school, during the indoor comfort diagnosis and monitoring made in november/december 2003, the retrofitting works were just finished, and the BMS was not yet commissionned. Regarding the air temperature recordings, the indoor temperature in Casanova school is a bit high (average 23°C). The air temperature was high in cumputerized classrooms (25°C) and the relative humidity was inferior to 40%. High asymetric radiations (more than 10°C) have been measured in some classrooms between the north windows and the indoor vertical walls.

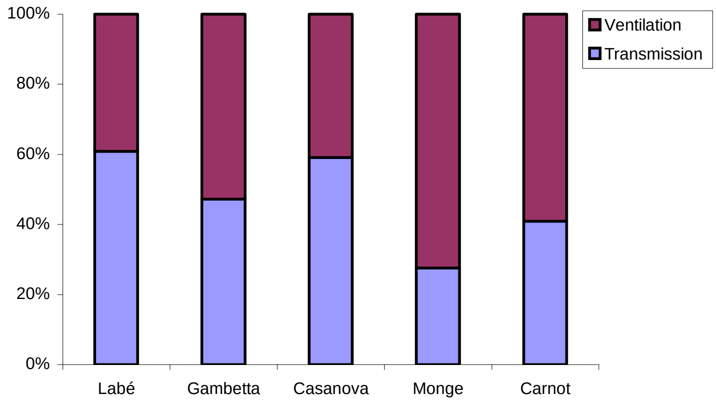
FIGURE 2
Indoor comfort indicators in Casanova School after retrofitting



High levels of CO_2 concentration have been measured in some unoccupied classrooms (more than 1000 ppm). The ventilation systems was stopped or worked with very low air flow. In some classrooms, manual systems for Ventilation Mechanical Control were not used by the teachers or the pupils.

In the five educational buildings, each ventilation strategy is a strong link between energy savings and indoor air quality. The energy losses for each school has been calculated (RT, 2000). The distribution between energy losses by ventilation systems and by envelop transmission shows the significant part of the ventilation in the energy savings (figure 3).

FIGURE 3
Distribution of energy losses in 5 educational buildings



In average, 50% of energy savings depend on the ventilation strategies in retrofitting of educational buildings. However, in these 5 educational buildings, a simple interaction has not been established only between indoor air quality, mechanical ventilation technologies and energy savings. This diagnosis has shown that it is necessary to consider others parameters like, for instance, the occupants' behaviour, the openings of windows being quite frequent in these 5 educational buildings.

DIFFICULTIES IN RETROFITTING OF EDUCATIONAL BUILDINGS

This study shows other sources of difficulties and the frequency of each difficulty among these 5 case studies, given in the following table.

TABLE 3
Sources of difficulties in retrofitting of five educational buildings

Five Educational buildings	**L.Labé**	**L.Gambetta**	**D.Casanova**	**G.Monge**	**H.Carnot**	**Frequency of each difficulty**
Year of retrofitting	**2001**	**1995**	**2003**	**In progress**	**In progress**	
Wall insulation		•		•	•	3
Windows	•	•	•	•		4
Ground floor on underfloor space	•	•	•	•	•	5
Covered playgroung roof	•			•	•	3
Roof	•		•		•	3
Summer overheating	•	•	•	•	•	5
Asymmetric radiation	•	•	•		•	4
Ventilation	•		•		•	3
Lighting	•		•	•	•	4

Detailed investigations provide complementary explanation about the encountered difficulties and others parameters to take into account in retrofitting of schools. For instance, contrary to the other projects, the retrofitting of existing envelop in Gambetta school, was very light and not optimized. In particular, there was not insulation for the whole envelop, but only one change of the HVAC systems, and a reduction of heating volumes with the installation of false ceilings in the several classrooms.
In all case studies, the weakness of thermal performance of existing windows before retrofitting was known and all the projects envisaged a change of the windows. However, the solutions were weak with the sight of the requirements of the french thermal regulation (RT, 2000), adapted for new buildings, or the case studies in other countries (IEA Annex 36, 2003). The energy losses, through windows transmission, represented between 25% and 54 % of the total losses by transmission in the 5 studied cases.
The roofs did not represent the most important losses by transmission. However the weaknesses of the vertical walls were not systematically considered. For instance, only the extension part of the Gambetta school has been insulated. Moreover, it appears that the gables insulation were sometimes forgotten (Casanova, Monge, Carnot).
All the case studies took into account air flows by mechanical ventilation lower than the required flows (18m3/h.person). A complementary ventilation flow was often planned by openings of windows. Thus, in the 5 case studies, the efficency of HVAC systems was not optimized and depended on several parameters such as the air infiltration, the ventilation strategies, the occupancy of classrooms, and the opening or not of windows.
These new systems, brought with retrofitting, seemed difficult to use for the occupants in some schools. The analysis of the information collected by the systems was not systematically made.
The retrofitting of educational buildings was often carried out with important extensions. This increased in floor areas and the unoccupied classrooms were heated like the others all the days. The planning of occupation of the classrooms was not coordinated with the HVAC systems.

CONCLUSION

The case studies presentation has shown that technical retrofit measures are similar for the educational buildings. However, the synthesis of the encountered difficulties, and their frequency in the 5 educational buildings, has shown the complexity for getting a high energy and indoor air quality performances in a retrofitting project. Many various qualitative and quantitative parameters, and their interactions, have to be take into account.
The energy needs can be fully different with a retrofitted educational building. With new pedagological targets in the schools, and a new building envelop, a significant reduction of energy can be get. A new envelop building needed to consider a new design of the HVAC systems, with often new energy sources.
Moreover, the indoor air quality was not sufficient in numerous classrooms in spite of mechanical ventilation systems. The openings of windows had to be take into account in an educational building. In this case, the hybrid ventilation strategies seemed to be interesting solutions in retrofitting.
The BMS installations were not completely well operated by users. The high occupant loads and the transient occupancy were design parameters in retrofitting of schools. The behaviour of occupants had to be considered in the ventilation strategies.
To take full advantage of new HVAC systems, the operating staff must be able to read all the indicators of the building facilities, and to adjust and control technical parameters (HVAC). Efficient operation of a BMS requires training according to the user 's needs.
These 5 case studies have shown that difficulties, are closely linked to find best retrofit measures. There are many interactions between the building envelop, the HVAC systems and the occupants. A retrofit measure for an educational building needs always to take into account complex interactions between the different components of the existing building.

ACKNOWLEDGMENTS

This work, presented in this paper, is undertaken in part thanks to a financial support by ADEME and is also developed with a research project with Rhône-Alpes Region.

REFERENCES

ADEME, AICVF. 1993. Programmer, concevoir, gérer des bâtiments d'enseignement à hautes performances énergétiques, Ed, PYC.
Adra, N. Cantin, R. Guarracino, G. 2003. Indoor Air Quality in retrofitting educational buildings. Conference AIVC BETEC. Washington DC, USA.
Adra, N. Cantin, R. Guarracino, G. 2002. Energy certification procedure for educational buildings. Conference EPIC 2002 AIVC. Lyon.
Cantin, R. Adra, N, Guarracino, G. 2002. Sustainable comfort for retrofitting educational buildings. Sustainable buildings 2002, International conference. Oslo, Norway.
CHPS. 2001. High Performance Schools, Best Practices Manual, The collaboration for High performance schools. Vol. I, II and III: design, planning and criteria.
Daisey, Joan M. and William J. Angell. 1999. Indoor Air Quality, ventilation and health symptoms in schools: an analysis of existing information. The 8th international conference on Indoor Air Quality and Climate. Vol 2.
IEA Annex 36 ECBCS. Retrofitting in educational buildings - Energy Concept Adviser for technical retrofit measures. 2003. www.annex36.bizland.com
RT. 2000. French Thermal Regulation. Arrêté du 29 novembre 2000 relatif aux caractéristiques thermiques des bâtiments - Règles de calcul.

HYBRID VENTILATION IN RETROFITTED BUILDINGS – CONCEPTS, STRATEGIES AND MEASUREMENTS

Alice Andersen[1], Steen Hagelskjær[2] and Mette Havgaard[3]

WindowMaster A/S, Skelstedet 13, 2950 Vedbaek, Denmark
[1]Phone: +45 45 67 03 47, aan.dk@WindowMaster.com
[2]Phone: +45 45 67 03 32, sh.dk@WindowMaster.com
[3]Phone: +45 45 67 03 43, mha.dk@WindowMaster.com

ABSTRACT

How can hybrid ventilation and natural ventilation significantly improve the indoor climate in retrofitted office and education buildings? During the last 5 years hybrid ventilation and natural ventilation have increasingly been utilised in refurbished and retrofitted buildings with great results. Utilising a newly developed system solution concept, it is illustrated how intelligent control of buildings can establish a good indoor climate with satisfied users. This article contains results from 4 building cases including two schools and two office buildings in Denmark and Switzerland.

KEYWORDS

Hybrid ventilation, natural ventilation, refurbishment, indoor climate, schools, offices, natural cooling.

1. INTRODUCTION: VENTILATION CONCEPT OF NON-DOMESTIC BUILDINGS

A complete ventilation concept has been developed by WindowMaster A/S in co-operation with building owners, architects and engineers. The concept includes a system solution for the building design with focus on a control system for hybrid ventilation (natural ventilation with mechanical assistance). The main variables in such a system solution include the ventilation strategies for each individual building as determined in the design phase, which are subsequently developed and implemented into a control system. In order to create a good indoor climate together with high energy efficiency the control is adaptive to the building depending on the indoor and outdoor climate.

In the next two sections 2 and 3, experiences and measurements from building cases with reference to the integrated control system are illustrated. Common to all the buildings is that they are serviced with internal sensors and a weather station on top of the building. The weather station gives information about the current outside temperature, wind velocity, wind direction and rain. Along with CFD-calculations of the wind pressures on the building envelope for different wind directions this information is used in determining of how much the windows should open.

Based on the empirical experiences and measurements the paper concludes in section 4 that the developed concept successfully can be utilised in retrofitted buildings.

2. SCHOOL BUILDINGS

General experiences

Generally school buildings are characterised with a very high people load in the lessons and lower people load in the breaks. Besides temperature sensors CO_2-sensors are therefore often integrated. In the summer period the required fresh air exchange can easily be achieved by natural ventilation alone, but during the winter season it may be necessary to support the natural ventilation system by mechanical ventilation.

For a large part of the year, the required ventilation for cooling is often higher than the required fresh air change. From practical experiences cooling by natural ventilation is very effective, and it is possible to lower the operative temperature by 2-3°C because of the air movements by natural ventilation.

Noerremark School

The Noerremark School is a Danish school from 1955, which has been utilized one year after the refurbishment in the spring of 2003. Since the school had problems with mould and bad indoor climate the ceilings and roof insulation were changed, and the school was serviced with automatically controlled windows for natural ventilation.

The school has around 440 students divided into 24 classes and the size of the classes varies from 13 to 21 students. Each classroom is 60 m^2 and has an adjacent corridor. The floor to ceiling height in the zones 1-13 varies from 2.4–3.7 m and is constantly 3.5 m in the rest of the zones. The building is constructed of bricks and the thermal mass judged to be medium to high.

Ventilation principles and strategies

In Figure 1 the ventilation principles in the school can be seen. In connection with the renovation the windows were renewed and atomised windows positioned highly in the façades were installed.

Every classroom has four windows: two façade windows and two skylights in zone 1-13 and two windows in the internal walls of zone 14-20. In addition the corridors have automatically controlled windows resulting in an effective cross ventilation and a more even indoor climate in the entire building.

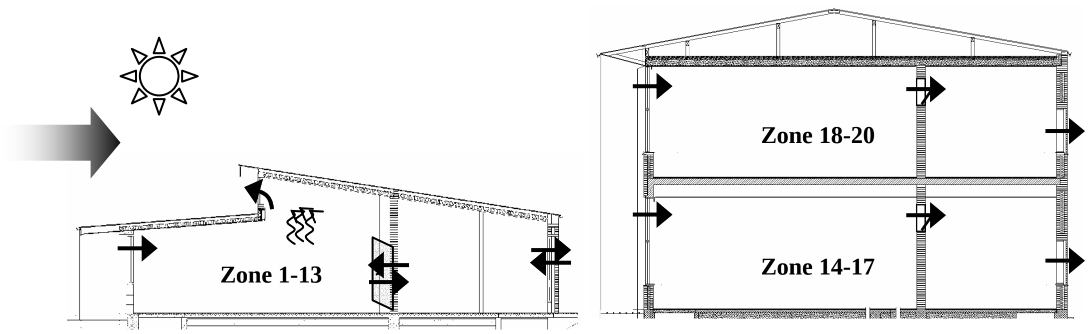


Figure 1: Ventilation principles of the natural ventilation in the school. Zone 14-20 have openings in the internal walls facing the corridors in order to provide cross ventilation.

During the heating season the zones are pulse ventilated automatically every half hour in order to secure a fresh indoor climate. According to the building manager of the school the users do not notice the pulse ventilation. The window operators operate very slowly automatically and almost soundlessly.

During the summer season the zones have comfort ventilation during the daytime and optimised night cooling during the night. During comfort ventilation the windows are more or less opened constantly automatically in order to secure a comfortable thermal indoor climate without overheating.

Results of temperatures

The school has just had the one year examination with a very positive result. The users are very satisfied with the indoor climate and natural ventilation during the year.

In Figure 2 the annual number of hours above 26 and 27°C in the different classrooms can be seen during the occupancy time (all weekdays from 8AM-3PM).

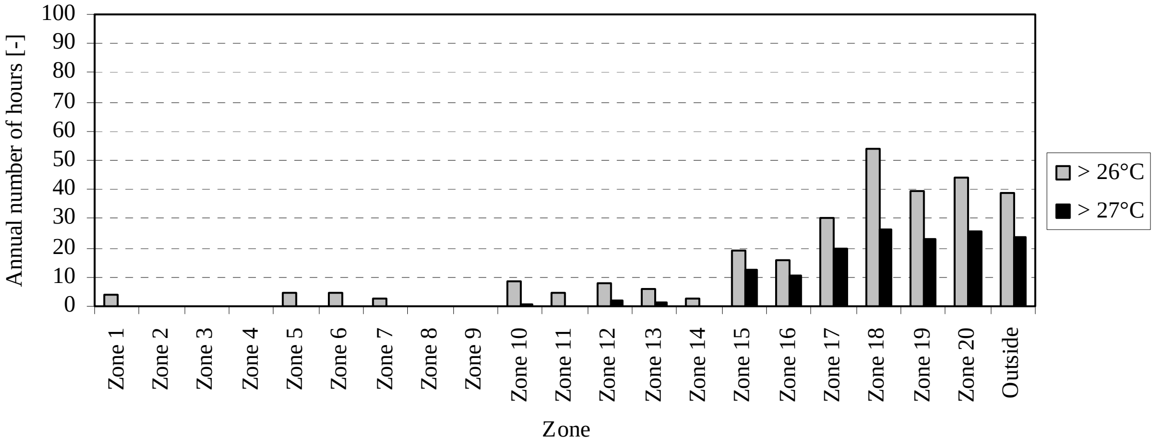


Figure 2: Annual number of hours above 26 and 27°C in the occupancy time in the different classrooms and outside.

In Figure 3 the temperature variations during a summer and a winter week can be seen in three different zones in school.

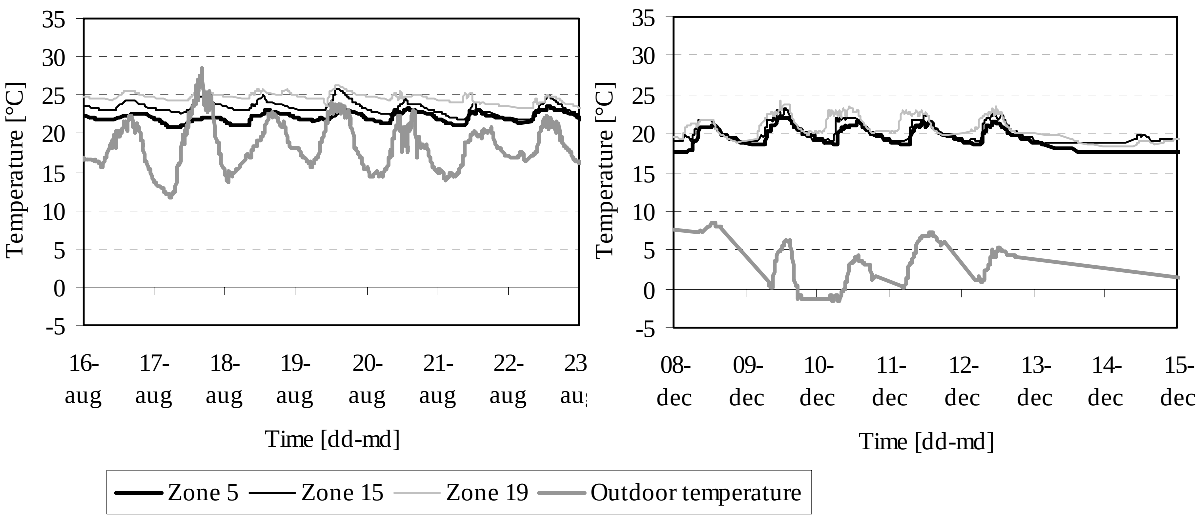


Figure 3: Temperature variations outside and in three different zones.

Dyssegaard School

The Dyssegaard School is a Danish school situated close to Copenhagen. In conjunction with a refurbishment of the building, natural ventilation was installed in the winter 2003/2004. The building is from 1932 and is characterized by a big assembly hall in the middle surrounded by classrooms. The assembly hall reaches from the ground floor through all the storeys up to the roof, where day light pours down to the assembly hall through rows of roof lights.

In the natural ventilation system the assembly hall and the roof lights provide excellent conditions for thermal buoyancy, where the used and warm air can rise and leave through the roof lights. Cool and fresh air is provided through façade windows in each classroom. Between the classrooms and the assembly hall large sliding doors ensures air flow with minimum pressure loss. In Figure 4 the ventilation principle is illustrated for part of the building. During classes the sliding door can sometimes be closed and the classroom will then be ventilated by single sided ventilation.

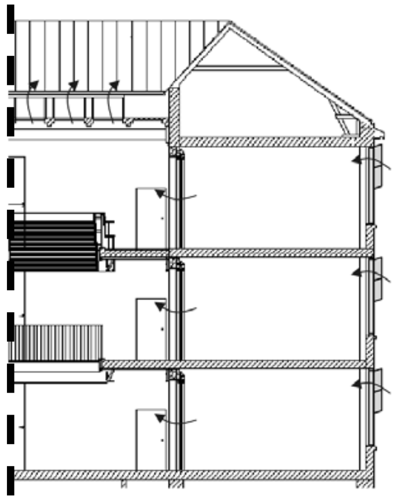


Figure 4: Ventilation principles of the natural ventilation in the Dyssegaard School.

For the natural ventilation the building is divided into a number of zones (one per classroom) where the opening degree of the windows is controlled according to measurements of temperature and CO_2-concentrations in each zone.

In the wintertime the main purpose of ventilation is to preserve a good air quality in the building during the whole day, whilst in the summertime the air change will be dictated by the thermal climate in order to maintain comfortable temperatures indoors. In the summer time the windows will therefore be more or less open all day, and the indoor air quality will be very high.

In Figure 5 the temperatures of the indoor air in zone 3, 15 and 25 can be seen for a cold winter week and the CO_2-concentrations during a cold winter day. The zones all have façade windows to the west and are situated on the ground floor, the 1st floor and the 2nd floor respectively.

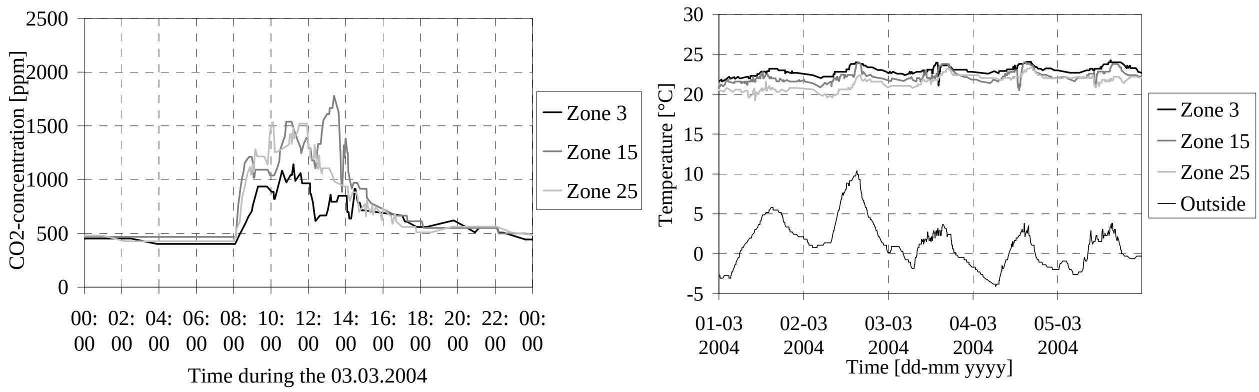


Figure 5: CO_2-concentrations and temperatures during a winter day respectively wither week for zone 3, 15 and 25.

In the graph showing the CO_2-concentrations it is easily seen at which hours the rooms are occupied. In the winter period the ventilation strategy for the natural ventilation is pulse ventilation as in the Noerremark School. The pulses are mainly placed in breaks, where the children move around and most of them leave the room. It is seen on the temperature graph that the pulse ventilation only causes small drops in the indoor temperature in spite of the low outdoor temperatures.
Generally the mean CO_2-concentration in the occupancy hours from 8 AM to 2 PM is around 1000 ppm in the three zones during the week shown in Figure 5, and only for short periods it has exceeded 1500 ppm. The good indoor air quality is partly due to the assembly hall, which has a great air volume and functions as a buffer for the classrooms. However with mechanical assistance the developed CO_2-concentration in the Dyssegaard School can be lowered further.

3. OFFICE BUILDINGS

General experiences

Office buildings are in general very suitable for hybrid ventilation and natural ventilation. The cooling obtained by natural ventilation is very high, which is positive for the indoor climate and the performance of the users. In many cases dynamic calculations are pessimistic about natural ventilation being able to create a stable indoor climate. Practical experiences from many different office buildings give another picture. Hybrid ventilation and natural ventilation work when an advanced control is used and provide a good indoor climate.

The Bodum Head Quarters, Switzerland

The Bodum Head Quarters is situated in the middle of Switzerland and contains two buildings – one refurbished and one new. The two buildings are very similar and were built/refurbished together in the year 2000-2001. Each building is 1100 m^2 distributed on 4 levels. Due to the large window sections the solar heat gain is the largest heat load in the buildings.

Ventilation principles and strategies

Both buildings have open plan offices built around an open stairwell/atrium in the middle of the building. In Figure 6 the ventilation principle of the hybrid ventilation can be seen.

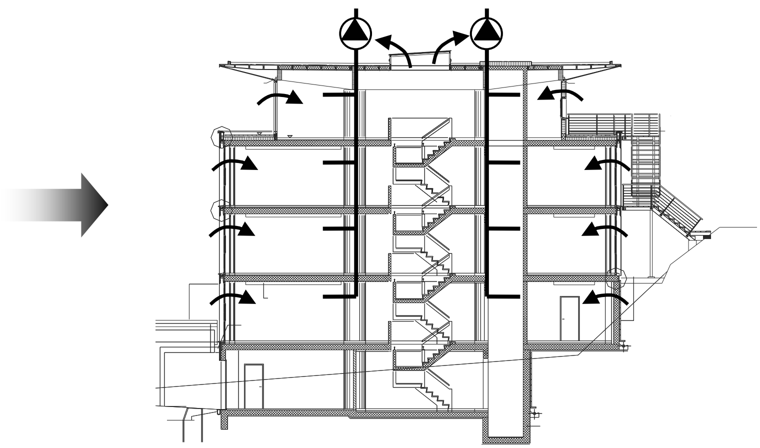


Figure 6: Ventilation principle of the natural ventilation with assisting mechanical exhaust from each level when necessary.

The mechanical exhaust is integrated in the bearing columns in connection with the stairwells. The mechanical exhaust is activated automatically when the temperature in the individual zone gets too high.

Results of temperatures

In Figure 7 the annual temperatures above 26°C outdoors and inside the new and refurbished building can be seen during the occupancy time (all weekdays from 8AM-4PM). All zones have hybrid ventilation except the attic floor in the refurbished building. All zones shown have open plan offices except the ground floor in the refurbished building, which is a reception and show room.

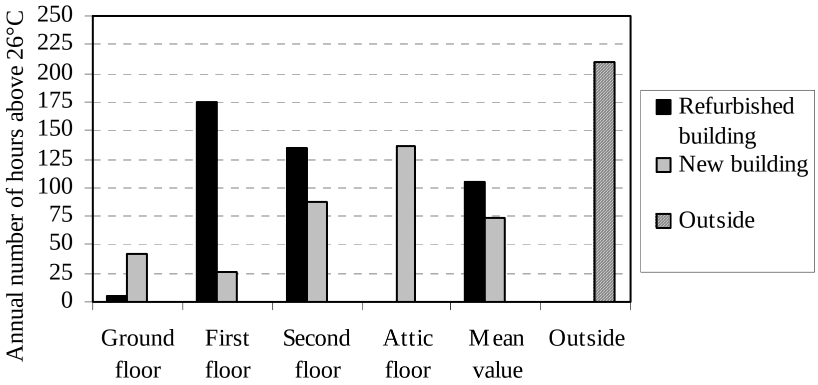


Figure 7: The annual number of hours above 26°C during the occupancy time based on measurements.

According to the user response and the results in Figure 7 it is possible to establish a stable indoor climate in the buildings. Due to the air movements that are possible to create with natural ventilation the operative temperature is lowered 2-3°C, which is very positive during the warmer periods.

In Figure 8 the percentage and variation of the time with mechanical assistance can be seen.

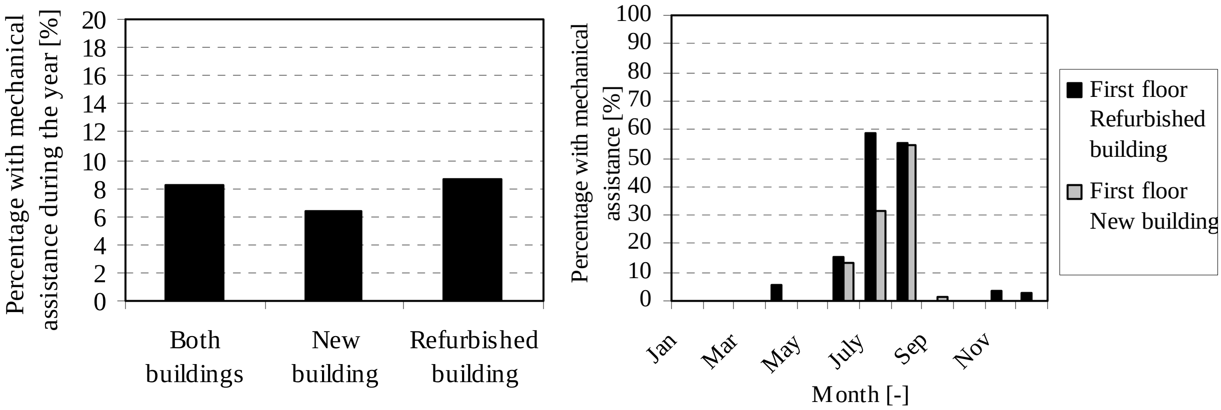


Figure 8: To the right: The annual percentage of the time with mechanical assistance in both buildings. To the left: The monthly variation of the mechanical assistance on the first floors.

The need for mechanical assistance is 8% on average varied from 7-14% in the different zones - smallest on ground level and similar on the other floors. The mechanical assistance in all zones is mainly utilized during the summer months as illustrated in the figure. The mechanical assistance is mainly utilized during the night for night cooling. During the daytime the natural ventilation has been sufficient to create a stable thermal indoor climate.

VOLVO Headquarters

In the spring of 2002 Volvo moved into a refurbished industrial building from 1949. The building was built for production of colours and had been unused for 7 years before the refurbishment. The building has natural ventilation in the offices on the ground and first floor and mechanical ventilation in the canteen. The ventilation principles vary depending on where you are in the building and the usage of the building. In Figure 9 the basic ventilation principles can be seen.

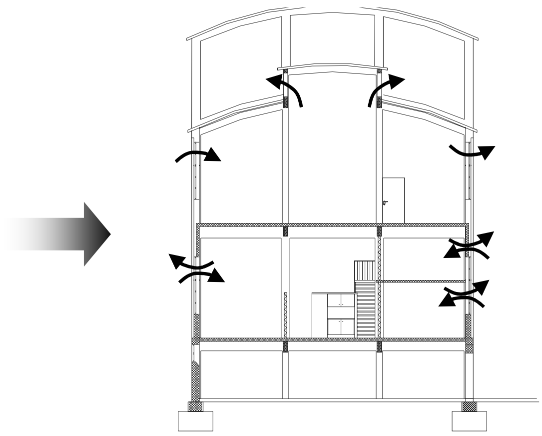


Figure 9: Typical ventilation principles of natural ventilation in Volvo: single-sided, cross and stack ventilation.

In Figure 10 the annual number of hours above 26 and 27°C can be seen in the different zones together with a comparison of the measurements and calculations in a specific zone. The number of warm hours is in the occupancy time (all weekdays 8AM-4PM).

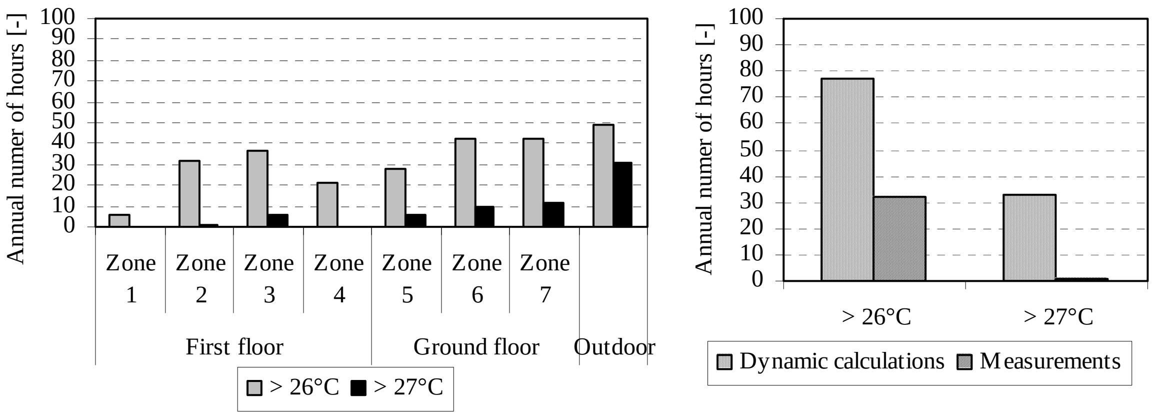


Figure 10 To the left: The measured number of hours above 26 and 27°C in the occupancy time. To the right: Comparison of dynamic calculations and measurements of a specific zone (zone 2).

Based on Figure 10 (to the left) and the users the thermal indoor climate has been very stable in the building. The comparison with the dynamic calculation (to the right) shows that the predicted number of hours above 26°C is higher than the measurements. The difference is mainly because the effect of the thermal mass and natural ventilation in the building had been underestimated. However relative to the total occupancy time the difference is small.

4. CONCLUSION

In connection with refurbishments of existing buildings, hybrid and natural ventilation can successfully be integrated in the design on an aesthetic basis as well as on a performance basis. This paper is based on four different building cases which illustrate how hybrid and natural ventilation with great results can be implemented in retrofitted buildings. Common for all cases is that they have undertaken an integrated system solution concept. This has proven to be important for a good indoor climate and satisfied users when hybrid or natural ventilation is applied. Those results are also in accordance with our experiences from a range of other building references across Europe, which have utilised the same concept of a system solution. In connection with this concept, a control system with focus on hybrid ventilation has been developed.

In section 2 two examples of refurbished schools are given. Based on the measurements from these schools it can be seen how it is possible to create a stable indoor environment by means of both thermal and atmospheric indoor climate. Due to the high people loads in schools it may be necessary with assisting mechanical ventilation during the winter season in order to lower the concentration of CO_2. However in the school example with CO_2-measurements the concentration is low with natural ventilation, which is partly due to the usage of the classrooms and the opening areas into the assembly hall in the middle, which has a great air volume and functions as a buffer for the classrooms.

In section 3 two examples of refurbished office buildings are given, one with natural ventilation and one with hybrid ventilation located in Denmark and Switzerland, respectively. Based on the user response and the measurements the indoor climate has been very good in both cases despite the very different conditions of the outdoor climate and annual number of hours above 26°C inside the buildings. However relative to the total occupancy time the difference numbers of hours is small. Due to the air movements that are possible to create with natural ventilation, the operative temperature can be lowered by 2-3°C, which is especially an advantage for the building located in warmer climate conditions. Based on the temperature statistics and the user response the cooling by natural ventilation is significant. Similar to the office building in Switzerland the need for mechanical assistance in connection with cooling is often limited due to the obtained cooling effect by natural ventilation. Since cooling by natural ventilation is a passive cooling technique this lowers the energy consumptions.

In order to develop a good indoor climate together with good energy efficiency of the building it is important with an intelligent control system. In order to utilise the natural driving forces as much as possible it is, besides many other factors, important that the control considers the actual wind pressures on the building. The wind is a strong driving force and important to consider in order to obtain a comfortable indoor climate and thereby utilisation of natural ventilation. By CFD-calculations the wind pressure coefficients of the individual buildings are determined for different wind directions and implemented in the control system.

PROSPECTS FOR HYBRID VENTILATION IN POLAND

T. Trusewicz and R. Finster

Polish Ventilation Association
ul. Dluga 29/125, 00-238 Warszawa, Poland

ABSTRACT

Approximatly over 90 percent of buildings in Poland are ventilated in a natural manner. The scale of problems in the functioning of ventilation in our opinion is serious.
In about 3 million apartments inhabitants use gas water heaters, burning fuel in an open chamber. Therefore in these types of apartments the use of mechanical exhaust ventilation is forbidden
Experiences in using mechanical ventilation is not always positive (frequent complaints about the excessive noise of the installation and the high consumption of energy by the fans). An interesting alternative could be hybrid ventilation systems.

KEYWORDS

hybrid ventilation, natural ventilation, retrofiting

Poland has nearly 40 million inhabitants. In cities, where there is found two thirds of all apartments building, multifamily buildings dominate, and in smaller cities, individual buildings. Together in Poland there are about 12 million apartments, whereof about 75% were built after the year 1944, and only about 10% were erected after 1988. In the last years there were constructed yearly 60.000-80.000 apartments. In the most intensive period of development 200.000 apartments were built.

In regards to the various age of buildings and the differences in construction technologies used, it is hard to point to a prevailing type of building. However, it is much easier to characterize the ventilation systems used. In apartment buildings, the majority use natural ventilation systems. Indeed there is not given any precise statistical data, but one can estimate that over 90 percent of buildings are ventilated in a natural manner.

In a considerable part of public utility buildings, offices, production and services building, natural ventilation is also used, as far as technological considerations or particular regulations do not require the use of mechanical ventilation.

In about 6 million apartments inhabitants use gas, both for heating as well as for hot water. It is estimated that in half of these apartments gas water heaters are used, burning fuel in an open chamber. In the last years in multifamily buildings there are used individual boilers for the heating of each apartment. Therefore in these types of apartments the use of mechanical exhaust ventilation is forbidden.

Mechanical ventilation is obligatorily used in such buildings, like those having over 9 stories. Because percentage wise there is not so many, and experiences in using mechanical ventilation is not always positive (frequent complaints about the excessive noise of the installation and the high consumption of energy by the fans), an interesting alternative could be hybrid ventilation systems. In Polish conditions it permits for an exceptionally effective combination expected by investors - the advantages of natural ventilation and the efficiency of the mechanical ventilation.

In apartment buildings in Poland, natural ventilation is used based on the guidelines of the Polish Standard, assuming the free inflow of air through windows and external doors that are not tight and the removal of air from the building through air exhausts located in kitchens, baths, toilets and rooms without windows. In practice, most apartments have 2 or 3 air exhausts ducts. In new buildings (constructed after the year 2000) apartments have individual ducts, whereas in old buildings common ducts are used, in which apartments are connected on every other story.

In practice, air intake takes place in an uncontrolled manner. In spite of the fact that it is mandatory to install elements that bring in air (air inlets) in buildings equipped with tide windows, in practice these recommendations generally are not practical. The obligatory legal system does not also put the direct obligation of approving the installation when the building is opened for use and during its exploitation. That is why in many cases, especially in new buildings and those that are modernized, there occurs defects in the working of the ventilation. The most frequent defects are the inadequate intensity in the exchange of air and the occurrence of back-drafts in the ducts.

The main criteria determining the intensity of ventilating in an apartment or house is the quantity of air removed by the ventilation ducts in each type of room (kitchens, baths, toilets and rooms without windows).

The scale of problems in the functioning of ventilation is not investigated statistically, but from experiences gained by the Polish Ventilation Association and companies working in the ventilation trade, it appears that the problem is serious.

According to our estimations there exists a large potential market, which can be used by delivering appropriate technical solutions in accordance to expectations and informing building owners about the role of the proper use of ventilation.

FIRST EXPERIENCES

The first attempts to introduce to the Polish market hybrid ventilation took place in the year 2003. The first extensive information about how hybrid ventilation works appeared at VENTILATION FORUM 2003, a national meeting of ventilation industry professionals. A seminar was prepared by the Reshyvent Group which enjoyed the exceptional interest of the listeners. Almost simultaneously, the Aereco company began intensive preparations to introduce to the market a VBP low-pressure fan. The VBP helps remove the air in the air exhaust ducts of the natural ventilation. The vacuum produced attains characteristics of natural ventilation. The device can work in a continuous manner or periodically to assist natural stuck effect in cooperation with sensors examining the prevalent conditions in the air exhaust ducts and in the environment of the building.

The fact that the idea of hybrid ventilation was well received could be seen the following year, at VENTILATION FORUM 2004, where Polish producers also presented their own hybrid ventilation solutions. The Darco company showed the Turbowent chimney cap. The hybrid chimney cap arose on the basis of the traditional Turbowent chimney cap, used for supporting natural stuck effect in air exhaust ducts by the means of the wind. In the Turbowent chimney cap is installed an electric engine synchronized with the main rotary element of the chimney cap. The sensor monitoring the parameters of the stuck effect causes the increase or decrease of motor rotations depending on the existing conditions.

The Uniwersal company designed the Fenko chimney cap. It is a chimney cap which after installing it on the end of the air exhaust ducts allows the ventilation to work in a natural manner. It is equipped with a fan that can be turned on by the user when conditions do not allow obtaining a natural stuck effect in the air exhaust ducts. Its efficiency is adapted to the amount of air removed from a typical apartment.

As usual in the case of new products, an important role is played by the possibility to practically check the use of the solution in Polish conditions. Aereco can be proud of their first accomplishments, as measurements were taken after the installation of the devices.
The investment was realized in the eastern part of Poland. Some buildings, in which commonly appeared draft disturbances in the air exhaust ducts, were modernized. Tenants complained about the lack of stuck or its reversal and the blowing of air through the grills of the air exhaust ducts. Low-pressure VBP fan were installed at the ends of the canals in building with 3 and 5 stories. The air to the apartments was brought in by humidity-controlled inlets in the windows - whose quantity was chosen with regards to the standards needed for air ventilation. Additionally, in the admission values to the air exhaust ducts were installed humidity-controlled air exhaust grills.

In summer conditions (August 2004) the first efficiency measurements were taken for the work effectiveness of the hybrid ventilation. The results of the measurements confirmed the efficiency of the solution used.

In consideration that the research was finished while this publication was being prepared for printing, a detailed description of the investment and the results obtained are on the CD prepared by the Polish Ventilation Association for conference participants.

POLISH VENTILATION ASSOCIATION

The Polish Ventilation Association is a group of professionals associated with the ventilation industry. It is founded by representatives of the Warsaw University of Technology and entrepreneurs dealing with manufacture, import and installation of ventilation systems for building industry.
The mission of the Association is to promote knowledge on modern and effective methods of ventilation for building industry as well as to increase the public awareness on the quality of the air in buildings through providing information on the consequences of invalid ventilation. At the same time, the Association is involved in activities meant for improving the legal system regulating the use of ventilation, and thus the quality of the polish building industry. The Association acts also to fit the ventilation industry for operation after Poland’s access to the European Community.

Our objective is to develop and promote initiatives, attitudes and activities encouraging development of ventilation industry. Particular information is available at www.wentylacja.org.pl

The Polish Ventilation Association has made an initiative to arrange a meeting of industry professionals - VENTILATION FORUM - to explore the issues of ventilation in the building industry and the operation of ventilation related businesses. The aim of FORUM is to enable exchange of experience and sharing legal and technical knowledge. Two-day cycle of training courses, seminars and discussions are accompanied by an exhibition presenting technologies available on the Polish market. During the FORUM in 2003 and 2004 the idea of hybrid ventilation was presented by the Reshyvent group. More information is available at www.forumwentylacja.pl

PERFORMANCE AND APPLICATIONS OF GOSSAMER WIND™ SOLAR POWERED CEILING FANS

M. Lubliner;[1] J. Douglass, PE;[2] D. Parker[3] and D. Chaser, PE[4]

[1 & 2] Washington State University Extension Energy Program, Olympia, WA 98502, USA
[3&4] Florida Solar Energy Center, Cocoa, FL 32826, USA

ABSTRACT
Research has shown that highly efficient solar powered ceiling fans improve thermal comfort and potentially provide health benefits when air conditioning or conventional ceiling fans are not available, such as during the 2003 summer heat waves in Europe, and in many undeveloped areas of the world. Ceiling fans can improve the spatial effectiveness of heating, ventilation and air conditioning (HVAC) systems. They can reduce air conditioning energy use if occupants increase thermostat set-points and reduce frequency of operation, and if waste heat from the fan motor is minimized.

This paper introduces a solar powered ceiling fan that utilizes Gossamer Wind™ improved blade technology and an efficient direct current (DC) motor. The Florida Solar Energy Center compared airflow and air velocity of Gossamer Wind Solar Powered (GWSP) fans. Three- and four-blade configurations were tested. GSWP fans were also connected to solar panels and tested. The potential uses of GWSP fans in dwellings, schools, warehouses, agricultural and livestock applications are discussed.

KEYWORDS
ceiling fans, air velocity, energy efficiency, thermal comfort

INTRODUCTION
Ceiling fans provide a cooling breeze, reduce temperature stratification and improve thermal comfort. Ceiling fans save energy in homes by improving thermal comfort, which results in changes to the thermostat set-point or reduced use of air conditioning.

Thermal Comfort
Since ceiling fans increase air velocity they can provide improved comfort to occupants. If the air is too hot and dry, however, such as in arid desert climates, increased air velocities can cause overheating. Research analysis based on Fanger's thermal comfort equation shows that at 60 percent relative humidity, 90 percent of people would be just as comfortable if the air dry bulb temperature were raised from 79.2^o to 82.5^o F (26.2 to 28.6 C) if air speed was also increased from still air to a velocity of 150 feet per minute (fpm), (0.76 meters per second m/s). At 80 percent relative humidity, 90 percent of people would also be as comfortable if set-points were raised from 77.9^o F to 81.8^o F (22.5 to 27.7 C) while similarly increasing air speeds. People can generally perceive air velocities over their skin of 0.3 m/s.

Gossamer Wind™ Blade Technology
In 1998, researchers at the Florida Solar Energy Center (FSEC) developed and tested new aerodynamically improved blade designs on alternating current (AC) powered residential and

commercial ceiling fans. These fans, manufactured by Hampton Bay, are now commercially available throughout the United States. The new blade design referred to as Gossamer Wind provides 40 percent higher airflows without increasing energy use. Waste heat from paddle blade type ceiling fan motors, contributes greatly to increases in air conditioner usage and are noisier when compared to Gossamer Wind ceiling fans.

Solar Powered DC Ceiling Fans

In 2002, Gossamer Wind technology was combined with efficient DC motors resulting in commercially available Gossamer Wind Solar Powered (GWSP) ceiling fans. Previous GWSP research by the authors compared preliminary bench test results for energy efficient AC and DC conventional and Gossamer blade ceiling fans, and looked at GWSP cost, energy savings and economics. The research confirmed GWSP performance over a typical residential 120 volt alternating current (VAC) "paddle-fan" blade design with typical AC motors providing 60-70 cubic feet per minute (CFM), (28-33 liters per second l/s), per watt on high speed and 100-200 CFM (47-94 l/sec) per watt on low speed.

GSWP technology connected directly to photovoltaic (PV) panels combine energy efficiency, simple engineering and variable control. When more solar energy is available, the fan produces higher airflow. GSWP fans connected directly to PV panels are well suited for schools, medical clinics, commercial and institutional buildings, beach cabanas and other daytime applications.

Battery-tied, direct DC systems eliminate inverter losses associated with AC ceiling fans, and allow for nighttime usage. GWSP technology is very cost-effective especially for off-grid PV structures, where the utility grid connection is too expensive or unavailable.

Since 1989, RCH Fanworks has sold thousands of DC powered ceiling fans using conventional paddle blades. These fans have been installed throughout the world predominately in off-grid applications in tropical climates. In the last two years more than 400 GWSP ceiling fans have been installed and RCH Fanworks' customers have noted a significant performance improvement over the DC paddle fans.

TEST DESCRIPTION

In 2004, the authors conducted GWSP fan testing at FSEC. Tests were conducted on a commercially available DC powered ceiling fan manufactured by RCH Fanworks, which employs Gossamer Wind technology. The fan blade span including the hub is 58 inches (147 centimeters cm).

The objectives of the tests were to evaluate rotations per minute (RPM), airflow and energy consumption at various voltages and fan blade configurations. Tests were conducted on the three- and four-blade fans using a 9 volt direct current (VDC), 14 VDC and 24 VDC power supplies. The three-blade Vari-Cyclone fan was also tested connected to 10 watt and 25 watt PV panels. The 25 watt PV panel is a prototype selected to better match the PV fan motor performance. These PV tests were conducted on sunny days at noon (965 watts per square meter W/m2) and late afternoon hours (350-375 W/m2), under typical June weather conditions for Florida. Commercially available testing equipment used included: a hot wire anemometer to measure air velocity, a hand-held laser RPM meter to measure fan rotation, a volt/amp meter to measure DC electricity, and solar pyranometers to measure solar insolation.

MEASUREMENT RESULTS:

Air velocity tests were conducted in accordance with American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 55-1981. Measurements were taken 53 inches (135 cm) from the fan and 43 inches (109 cm) above the floor. Measurements were taken three times at each station and averaged. Measurements were taken at nine points from directly under the hub to 48 inches (122 cm) away. Figure 1 provides the air velocity measurement at various stations for three- and four-blade fans with various power sources. The three-blade fan on a 24 volt power supply produced the highest velocities, in the 1.6 to 1.8 m/s range below the fan hub, with airflows still perceptible as far as 2.5 feet (76 cm) from the hub. The 12 volt and 9 volt power supplies provided the maximum velocities, in the range of 0.8-0.9 m/s, with perceived velocities within 1-1.75 feet (30-46 cm) from the hub.

Fig. 1 - Ceiling Fan Velocity Profile

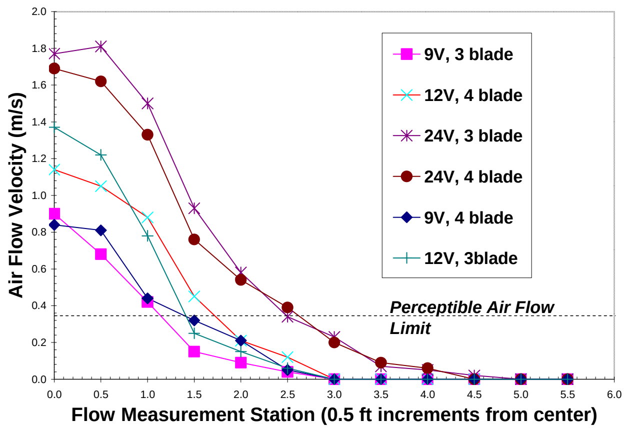


Table 1 provides the average and maximum velocity, total flow rates, watts and RPM for three- and four-blade models with 9, 12 and 24 volt power supplies. The average airflow presented is computed by averaging between the test points and computing the varying velocities across the positive flow zone created by the fan. The maximum velocity and RPM is highest for the three-blade fans, however the average velocity and computed CFM is higher on the four-blade configuration when the 9 and 12 volt power supplies are used. This indicates that the four-blade arrangement may provide better flow at lower power (smaller PV panel) and with larger PV systems under cloudy conditions.

Table 1
3 & 4 Blade Fan Performance with 9, 12 & 24 VDC Power Supply

Fan Type	**9V, 3 blade**	**9V, 4 blade**	**12V, 3 blade**	**12V, 4 blade**	**24V, 3 blade**	**24V, 4 blade**
Average Velocity (m/s)	0.19	0.22	0.32	0.32	0.61	0.56
Maximum Velocity (m/s)	0.90	0.84	1.37	1.14	1.81	1.69
Total CFM	852	1221	1476	1820	3925	3600
Total l/s	402	576	697	859	1853	1699
Total Watts	1.62	1.69	4.09	4.11	12.9	14.6
RPM	75	66	102	83	138	117

Table 2 shows the performance of the three-blade fan connected to the 25 watt and 10 watt PV panels. The panels were exposed to insolation at 5 p.m. and noon. The best fan performance was the 25 watt PV panel operating at noon, which provided 22.9 volts at 0.53 amps or 12.14 watts. Under this condition the fan ran at 135 RPM and provided a maximum velocity of 1.77 m/s directly below the hub. This configuration at 5 p.m. ran the fan at 123 RPM and provided a velocity of 1.4 m/s. The lowest fan performance was from the 10 watt PV panel running at 5 p.m., which provided 104 RPM and 1.3 m/s of maximum velocity.

Table 2
PV Powered Fan Performance

PV Watt Time-PM	Speed (RPM)	Power (Volts)	Current (Amps)	Energy (Watts)	Velocity (m/s)	RPM /Watt	m/s /Watt	Solar W/m2
10PV-12	108	16.2	0.35	5.67	1.45	19.05	0.26	965
25PV-12	135	22.9	0.53	12.14	1.77	11.12	0.15	965
10PV-5	104	14.3	0.31	4.43	1.3	23.46	0.29	351
25PV-5	123	18.7	0.42	7.85	1.4	15.66	0.18	351

Evaluation of Fan Laws:

The fan laws represent how performance varies when one of the operating conditions is changed. The following laws apply when the same fan in the same circumstances is operated at a different power level by changing the voltage applied. Eqns. 1 and 2 were applied to the maximum and minimum conditions. Applying Eqns. 1 and 2 to both RPM and velocity data yields comparable agreement:.

Eqn. 1: $$RPM_1/RPM_2 = Velocity_1/Velocity_2 = Q_1 / Q_2$$

Eqn 2: $$Power_1/Power_2 = (Watt_1 \cdot \eta_2)/(Watt_2 \cdot \eta_1) = (RPM_1/RPM_2)^3 = (Velocity_1/Velocity_2)^3 = (Q_1/Q_2)^3$$

Where: RPM = fan revolutions per minute
Velocity = air velocity
Power = motor shaft power
Watt = Electrical power at motor terminals
η = motor efficiency as loaded
Q = volumetric air flow rate
Subscript 1 designates baseline conditions at 24 volts applied to the motor terminals.
Subscript 2 designates different conditions when 9 volts applied to the motor terminals.

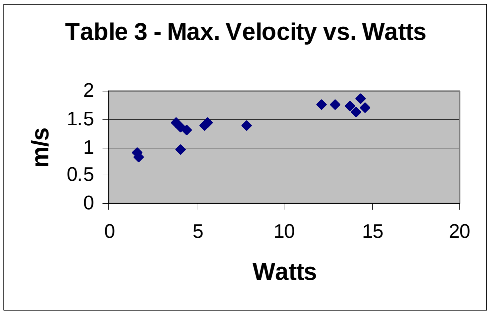
Eqn. 1:

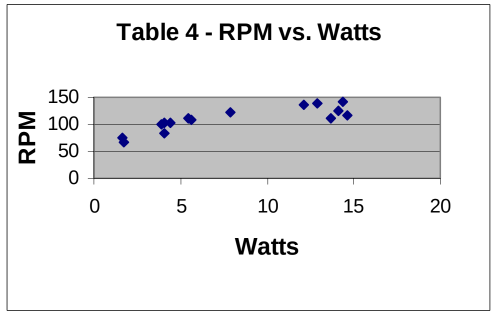
$$138\ RPM_{24v} / 66\ RPM_{9v} = 2.09$$
$$1.81 m/s_{24v} / .84\ m/s_{9v} = 2.15$$
$$2.09/2.15 = 97\%$$

Eqn. 2:

$$12.9W_{24v} / 1.69W_{9v} = 7.6$$
$$(138RPM_{24v}/66RPM_{9v})^3 = 9.1$$
$$7.6/9.14 = 83\%$$
$$12.9W_{24v} / 1.69W_{9v} = 7.6$$
$$(1.81\ m/s_{24v}/0.84\ m/s_{9v})^3 = 10.2$$
$$7.6/10.2 = 75\%$$

Eqn. 2 is applied to all tests shown in Table 1 and 2. Five additional “redundant” tests are not presented. A regression analysis was then conducted and presented in Table 3 and 4. The R-square values are comparable to the ratios in the examples above.





The fan laws would indicate that doubling the flow rate of a fan will increase the required shaft power by about eight times. For example, if flow was 1000 CFM (472 l/s) at 10 watts shaft power, the power expected to reach 2000 CFM (944 l/s) would be 2^**3** x 10 = 80 watts. In the data from the above test reports, velocity at 9 volts is reduced to 46.4 percent of the velocity at 24 volts. 46.4 percent cubed is 10 percent, so by the fan laws you would expect shaft power to drop to 10 percent. Shaft power was not measured but electrical power dropped to 13 percent. You would not expect electric power to drop quite as much as shaft power because motor efficiency is reduced at very low loads. The discrepancy here may be a result of the accuracy associated with the 0.19 amp measurement at 9 volts.

APPLICATIONS:

While GWSP ceiling fans have been used primarily in dwellings and schools to improve occupant comfort, these benefits may also apply in some warehouse applications. GWSP fans connected directly to PV panels are ideal in dwellings where ceiling fans are needed during daytime hours. GWSP ceiling fans benefits may include:

1) Reduced need for air conditioning, resulting in reduced greenhouse gas emissions;
2) Better ventilation and indoor air quality, due to increased mixing of outside air;
3) Health benefits during hot weather and reduced presence of insects that transmit disease;
4) Better air distribution and mixing of ducted HVAC systems;
5) Space heating energy savings, due to reduced temperature stratification.

New potential applications of GWSP ceiling fans for agriculture and livestock offer promise, provided air velocities are within acceptable ranges.

Livestock: The importance of air velocities is species and age dependent. Swine under 8 weeks of age experience slower weight gains and increased disease susceptibility when air velocity is increased from 25 fpm (0.13 m/s) to 50 fpm (0.25 m/s). Chickens benefit at air velocities up to 500 fpm (2.6 m/s) at temperatures from 75° F (24 C) to 95° F (35 C), however high-velocity air at a temperature above chicken feather temperature causes more not less heat stress.

Agriculture: Air speeds of 100 fpm (0.51 m/s) to 150 fpm (0.76 m/s) are considered suitable for plant growth. Greenhouse air circulation maintains suitable levels of carbon dioxide and humidity within the leaf canopy. Air speeds of 6 fpm to 20 fpm (0.03-0.10m/s) are needed to facilitate carbon dioxide uptake. Air speeds in excess of 200 fpm (1.02 m/s) can induce excessive transpiration, cause plant cells to close, reduce carbon dioxide uptake and inhibit plant growth.

CONCLUSIONS:

- Little difference was observed in RPM and velocity between the three- and four-blade fans. The three-blade fan costs less, while the four-blade may be slightly quieter, and provide better air moving performance with smaller PV arrays.
- The maximum performance was achieved at 138 RPM and 1.81 m/s maximum velocity with the 24 volt power supply providing 12.9 watts. The lowest performance was 66 RPM and maximum air velocity of 0.84 m/s, resulting from the 9 volt power supply providing 1.69 watts (8.9 volts at 0.19 amps).
- The 25 watt PV panel at noon under sunny conditions provided 12.14 watts (22.9 volts at 0.53 amps) and ran the fan at 135 RPM and 1.77 m/s.
- As expected, the GSWP fan connected directly to PV panels increased airflow and velocity in concert with solar availability, providing both comfort and energy benefits, assuming that sunshine and outdoor and/or indoor temperature, are related.

FUTURE RESEARCH:

- Demonstrate new applications discussed in this paper.
- Evaluate higher efficiency DC fan motors and PV panels to optimize performance.
- Assess cost effectiveness of optimum PV/motor packages in various applications.
- Evaluate PV powered non-ceiling fan designs in various building applications.

ACKNOWLEDGEMENTS:

This work is sponsored in large part by the U.S. Department of Energy Office of Building Technology's Building America Industrialized Housing program under cooperative agreement DE-FC36-99GO10478.

REFERENCES

The ACEEE Summer Study Grapevine (2002) *Technology Showcase*, Asilomar, CA, Aug. 2002.

ASHRAE 1997 Handbook of Fundamentals, chapters 8, 9 and 10.

Chandra, S. (1985). Fans to reduce cooling costs in the Southeast. FSEC-EN-13-85, Florida Solar Energy Center, Cape Canaveral, FL.

Fanger, P.O. (1982). Human requirements for the indoor climate of buildings. Paper presented at the International Passive and Low Energy Alternatives Conference, Biological Station for Research, Bermuda, Sept. 6.

The Gossamer Wind Series ceiling fan (2003) Home Depot www.fsec.ucf.edu/bldg/active/bdac/prototype/catalog.htm.

Hankins, F. (2004) Conversations with the author, RCH FanWorks, Colville, WA. USA.

James, P., Sonne J., Vieira R., Parker D., and Anello, M. (1996). Are energy savings due to ceiling fans just hot air? *Proceedings of the ACEEE Summer Study on Energy Efficiency in Buildings* **8**, 89-93.

Little, A.D. (1981). Energy savings resulting from the use of a Hunter ceiling fan: Phase II final report. Prepared for Ribbins and Meyers, Inc., Cambridge, MA.

Lubliner, M. et al (2003). Gossamer Wind Solar Powered ceiling fans. Paper presented at the American Solar Energy Society Conference, San Antonio, TX, July 2003.

Parker, D.S., Su, G.H. and Hibbs, B.D. (1998). High efficiency ceiling fan. Patent Application, Docket No. UCF-185.United States Patent Nr. 6,039,541, March 21, 2000.

Parker, D.S. et al (1999) Development of a high efficiency ceiling fan "The Gossamer Wind." Florida Solar Energy Center FSEC-CR-1059-99, Cocoa, FL.

Rohles, F.H., Konz, S.A. and Jones, B.W. (1983). Ceiling fan as extenders of the summer comfort envelope. *ASHRAE Transactions* **89:Pt. 1A,** 51.

Sonne, J.K. and Parker, D.S. (1998). Measured ceiling fan performance and usage patterns: Implications for efficiency and comfort improvements. *Proceedings of the ACEEE Summer Study on Energy Efficiency in Buildings* **1**, 335.

Energy consumption, thermal comfort and indoor air quality in schools

H. Hens[1], S. Muyldermans[1] and W. Saerens[1]

Laboratory of Building Physics, Department of Civil Engineering, K.U.Leuven
B-3001 Leuven, Belgium

ABSTRACT

School buildings in Flanders are quite old. They cause concern not only about energy efficiency but also about thermal comfort, indoor air quality, speech intelligibility and visual comfort. To evaluate the correctness of the concerns, energy consumption was monitored in 18 schools, while in each of them a classroom was selected for detailed measurements on comfort and indoor air quality. The results justify the concern. Energy consumption per pupil varies significantly, from low to really high. The reasons for that are quite clear: poor heating system control, hardly a nighttime and weekend setback, un-insulated buildings. CO_2 in almost all classrooms peaks at values far beyond 1500 ppm, which underlines that the air quality is a problem. Thermal and visual comfort anyhow did not pose many problems. The research resulted in a series of design guidelines for school buildings with low energy consumption, good comfort and excellent indoor air quality.

KEYWORDS

School buildings, energy consumption, thermal comfort, CO_2 measurements, indoor air quality, ventilation

INTRODUCTION

School buildings in Flanders are quite old. Of the eighteen schools that participated in the actual study, one dated from 1895. Six were built between 1918 and 1940; five between 1945 and 1975 while only six were rather recent, built between 1975 and 2002. The aging school building stock causes concern, not only about energy efficiency but also about thermal comfort, indoor air quality, speech intelligibility and visual comfort.

All countries that are confronted with aging school buildings, share that concern. Nielsen (1984) monitored the CO_2 concentration in eleven schools in Denmark. Norback et al. (1990, 1995) did the same in six schools in Sweden. Lee et al. (1999) looked to five classrooms in Hong Kong and Kolokotroni et al. (2002) analyzed four classrooms in the UK. They all had to conclude that even the average CO_2-concentrations were too high during teaching. Heath et al. (2002) searched for a relationship between the indoor environment and student performance. Daisy et al (2003) reported on a literature review on health, ventilation and indoor air quality in schools. Both concluded that students' activity suffers from bad air quality.

In Belgium, Vermeir et al. (2003) measured the speech transmission index and reverberation time in 47 classrooms. A too low value was recorded in 20 of them, indicating a net shortage in sound absorbing surfaces. Wouters (1989) evaluated indoor air quality a first time. The results were disappointing as peaks up to 5000 ppm were noted.

In the schools selected for the present study, energy consumption was analyzed while detailed measurements on thermal comfort, indoor air quality and visual comfort were performed in one classroom per school.

PERFORMANCE REQUIREMENTS

Requirements differ between countries. For thermal comfort for example, European countries use the same standard (EN ISO 7730) but they handle other criteria, table 1. The same holds for CO_2, table 2.

TABLE 1
Thermal comfort criteria

	Metabolism Seated people	Winter		Summer	
		I_{clo}	Operat. temp. °C	I_{clo}	Operat. temp. °C
Belgium			20-24		
The Netherlands	1.2 met	0.9 Clo	20-24	0.7 Clo	21-25
Germany	1.2 met	1.0 Clo	21±2.5	0.5 Clo	
France			20-21		

TABLE 2
Acceptable CO_2-concentration

	ppm
Belgium	-
The Netherlands	1200
Germany	1500
France	2000
EU	IDA 1 800 IDA 2 1000 IDA 3 1500

In the case being, no requirements could be imposed on energy as schools are not subjected to any legal performance in Flanders. Thermal comfort was judged using Fanger's approach: percentage of dissatisfied ≤ 10%, predicted mean vote ≤ |0.5|, operative temperature between 19 and 23°C, PD for draft<20% (Fanger, 1970). Indoor air focused on relative humidity between 30 and 70% and maximum $C0_2$-level not beyond 1500 ppm. Visual comfort was checked by looking to the illuminance on the black board (≥ 500 Lux), the illuminance on the desks (≥ 300 Lux), the illuminance uniformity and the daylight factor (≥ 3%)

SCHOOLS

The schools that participated in the research were quite different in size and number of scholars (table 1). Some are primary schools, other gymnasiums and technical schools or so called 'special' schools. Two follow 'alternative' didactics, most keep it 'traditional'.

MEASUREMENTS

Information on energy came from the analysis of the bills of the last two or three years. Thermal comfort was studied through (1) measuring air temperature and relative humidity from October 2003 to January 2004 on a 10' basis, using calibrated HOBO data loggers, (2) measuring the air temperature, the radiant temperature, the air velocity and the relative humidity during a 48 hours period using a calibrated B&K comfort meter the meter in the middle of the classroom and the sensors at head-height of the seated scholars, (3) conducting an enquiry between the scholars, based on the ASHRAE seven point scale. Indoor air quality was monitored indirectly, by measuring CO_2 on a 30" basis during 2 days with a Vaisala Carbocap sensor. The CO_2-meter stood near the comfort meter. CO_2 and partial inside water vapor pressure excess were used to evaluate ventilation. Illuminances finally were measured with a Testoterm Lux meter.

RESULTS AND DISCUSSION

Energy consumption

Table 3 gives the heating and primary energy consumed per scholar, standardized for the reference year. The differences between schools are striking. Some are quite efficient, see school 15, others demand huge amounts of energy, see school 3. No correlation exists between the primary energy consumed, the type of school, the number of scholars and the age of the building. On the contrary, the most recent schools (10 and 14) are not the most efficient ones! Likely reasons for the differences are: (1) a too simple control (see column 6 in table 3), (2) quite high temperatures in some classrooms, (3) differences in heated volume per scholar, (4) insulation quality of the envelope.

TABLE 3
Annual primary energy consumption per scholar

School	Age	Type	Number of scholars	Heating energy per scholar MJ/(a.scholar)	Nighttime and weekend setback?		Primary energy per scholar MJ/(a.scholar)
1	1975	Gymnasium	800	10110	YES	YES	12393
2	1950	Gymnasium	1050	3624	NO	NO	5126
3	1988	Technical	925	13781	NO	NO	21809
4	<1940	Primary	185	6204	?	YES	9609
6	1980	Gymnasium	320	7963	YES	YES	8427
7	1905	Gymnasium	2006	9902	NO	NO	13217
8	<1940	Special	183	9625	NO	NO	12365
10	2002	Special	288	3185	YES	YES	8668
11	1895	Primary	600	8309	NO	YES	10378
12	1985	Gym.+Tech.	661	3047	NO	YES	3887
13	<1940	Gymnasium	641	4293	NO	NO	6515
14	2002	Primary	240	10179	NO	NO	11908
15	<1940	Primary	207	3462	YES	YES	3874
16	1990	Primary	163	6613	NO	NO	9256
17	<1940	Gymnasium	1256	4316	YES	YES	5476
18	1962	Gym.+Spec.	510	8448	YES	YES	9230
			Average	7066			9509
			Standard dev.	3114			4215

Thermal comfort

The three evaluation methods gave opposite results, see figure 1 and 2. The two days check with the comfort meter and the long term measurement with the Hobo-loggers both show that on the average winter comfort during class hours is not a problem. The enquiries instead reflected quite some dissatisfaction with the thermal environment. That difference learns that when enquired, scholars and teachers react on the extremes they experienced during the past months, while the comfort meter and hobo results are calculated average votes over 2 days, respectively 3 months. Clearly, the information measurements and enquiry give is different.

This was not the case for draft. There the measured PD-value and the enquiry result both showed that the number of dissatisfied hardly passed 20%. Globally, winter comfort in classrooms does not seem to be an issue.

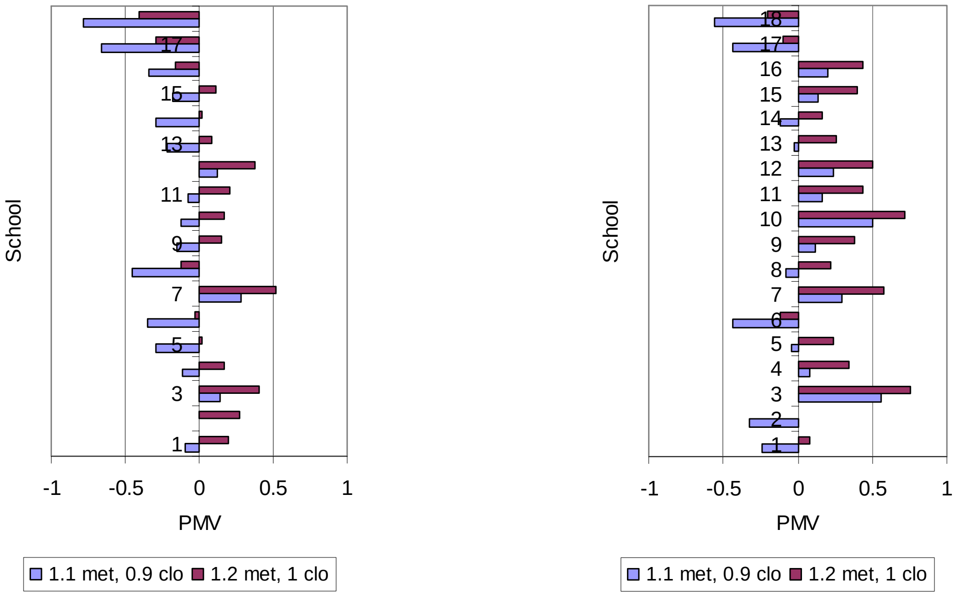


Figure 1: Two-days check (left) and long term measurement of wintertime thermal comfort in the 18 class rooms

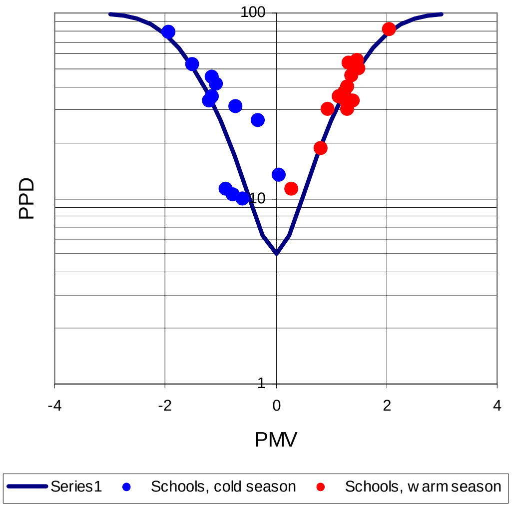


Figure 2: Comfort enquiry, scholars mean comfort vote for cold (blue) and warm days (red)

Indoor air quality

Figure 3 summarizes the results of the CO_2 measurements in 19 classrooms. In fact, in school 6, two classrooms, one with adventitious ventilation and the other with forced ventilation, were monitored. From the results, it appears that the air quality during class hours is not acceptable. In all classrooms except two, the CO_2 peak largely passes the 1500 ppm limit, while in nine classrooms, even the average goes beyond that limit.

The reason is straight forward. Eighteen classrooms (7 is the exception) are ventilated by opening windows. Hence, teaching with open windows is not an attractable choice: too much draft, too cold in winter, too noisy, paper that flies, etc. With closed windows, only infiltration is left, resulting in a dramatic drop in ventilation flow. A classroom has a volume of 170-200 m^3. The infiltration rates calculated from the CO_2 increments were as low as 0.5 h^{-1}. That brings the ventilation flow down to 85-100 m^3/h. Classes may be quite populated, 30 scholars is no exception. Included the teacher, only 2.7 to 3.2 m^3 fresh air per hour and per person is then delivered. For a metabolism of 1.2 met and a CO_2 maximum of 1500 ppm, a ventilation flow of $\approx$16 $m^3/(person.h)$ is needed, which means a total of 500 m^3/h during class hours. In the case being, that condition was only fulfilled in the classrooms 3, 8, 10 and 12. All others, i.e. 76% of the total, gave problems. See figure 4.

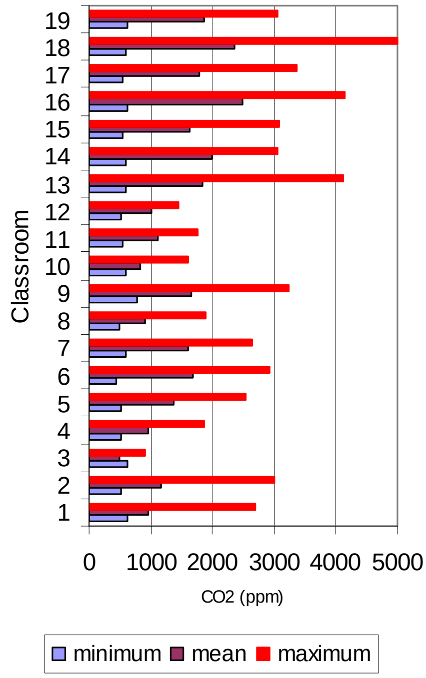


Figure 3: CO_2 concentrations in 19 classrooms during teaching, minimum, mean and maximum value measured

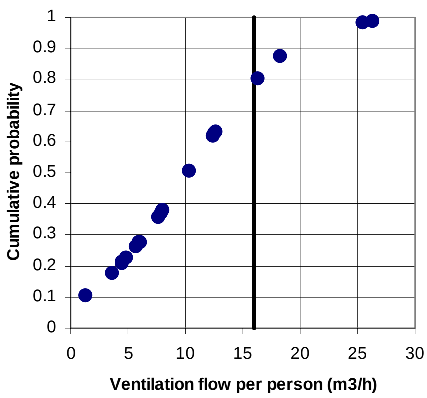


Figure 4: Measured ventilation flow per person in case the classrooms monitored are used by 30 scholars. Cumulative curve

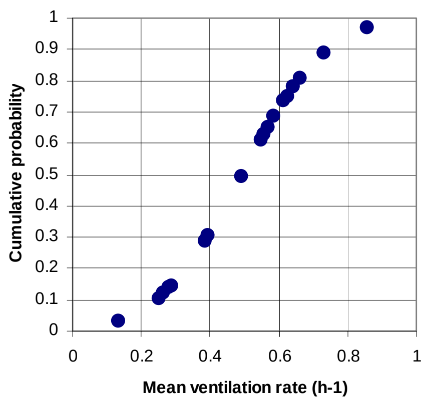


Figure 5: Mean ventilation rate in the 18 classrooms as deduced from the inside vapor pressure excess.

Looking to the poor ventilation, one could expect that relative humidity and vapor pressure also touch high values. This was not the case, mainly because the outside vapor pressure in a moderate, cool climate is quite low in winter and the vapor release by teacher and scholars remains restricted and block-wise. In fact, after each class hour of 50' tot 90', in most classrooms windows are opened during 10'. As a result, in nine of the eighteen classrooms, relative humidity even dropped periodically below 30%. The inside vapor pressure excess in turn was used to evaluate the average ventilation rate in the classrooms over the whole test period. The results are summarized in figure 5.

Visual comfort

The measurements showed that desk illuminance in most classrooms passed 300 Lux. In none of them however, a daylight factor even touching 3% was measured, while illuminance uniformity was worse than the 0.7 demanded between the minimum and the mean. Also blending could pose problems. Yet, despite these negative items, visual comfort was not perceived as a problem.

CONCLUSIONS

Eighteen schools were evaluated on energy consumption, thermal comfort, indoor air quality and visual comfort. The results confirm the concerns about high energy consumption and bad indoor air quality. Indeed, although quite some variation was noted, most schools do not use energy efficiently. Not a possible excessive ventilation, but a heating system with too simple controls, sometimes the quite high temperatures in classrooms, the large building volume per scholar and the absence of any insulation are the main reasons for that. Thermal and visual comfort is not an issue but indoor air quality is. The high CO_2-concentrations noted are a direct consequence of the absence of any designed ventilation system. Compared to the situation encountered by Wouters in 1988, nothing changed. Still, adventitious ventilation should but cannot deliver the fresh air needed during class hours.

REFERENCES

Daisey J, Angell W., Apte M. (2003), Indoor air quality, ventilation and health symptoms in schools: an analysis of existing information, Indoor Air, 13: 53-64

Fanger O.P. (1970), Thermal comfort: analysis and applications in environmental engineering, MacGraw-Hill, New York

Heath G., Mendell M. (2002) Do indoor environments in schools influence student performance? a review of literature, Proceedings Indoor Air 2002, p 882-907

Kolokotroni M., Katsoulas D., Ge Y. (2002), Monitoring and modeling iaq and ventilation in classrooms within purpose designed natural ventilated schools, Indoor and Built Environment, 11(6): 316-326

Lee S., Chang M. (1999), Indoor air quality investigations in five classrooms, Indoor Air, 9: 134-138

Muyldermans S, Sarens W. (2004), Inside climate and energy consumption in schools, Masters thesis K.U.Leuven (in Dutch)

Nielsen (1984), Quality of air and amount of fresh air in classrooms, Indoor Air 5:221-226

Norback D., Torgan M., Edling C. (1990), Volatile organic compoungs, respirable dust and personal factors related to prevalence and incidence of sick building syndrome in primary schools, Britisch Journal of Indian Medicine 47: 733-741

Norback D. (1995), Subjective indoor air quality in schools. The influence of high room temperature, carpeting, fleecy wall materials and volatile organic compounds, Indoor Air, 5:237-246

Vermeir G., Van den Bergh J. (2003), Classroom acoustics in Belgian schools: requirement, analysis, design, Research in Building Physics, Balkema Publishers, : 869-875

Wouters P. (1989), Belgian experiences concerning ventilation quality in buildings, WTCB-tijdschrift 2: 1-11 (in Dutch and in French)

INDOOR AIR QUALITY IN CLASSROOMS OF RENOVATED SCHOOL BUILDING IN LITHUANIA

Andrius Jurelionis, PhD
Faculty of Civil Engineering and Architecture, Kaunas University of Technology,
Studentu g. 48, LT-3031, Kaunas, Lithuania
E-mail: andrius.jurelionis@ktu.lt

ABSTRACT

The purpose of this study was to assess indoor air quality as well as actual ventilation in renovated school classrooms. A typical naturally ventilated school building was chosen to install different air inlet units in identical classrooms. Later measurements of carbon dioxide concentrations, temperature, relative humidity and air velocity were carried out. Actual measured values were compared with Lithuanian and European standards.
This study gives the evaluation of renovating process in the Lithuanian schools, which began in 1997. The aim of the mentioned process was the reduction of energy consumption in these buildings. Generally such works as modernization of heat substations, replacement of windows, additional thermal insulation of walls and roofs were usually performed. However, the proper attention to indoor air quality and ventilation of classrooms was not paid due to the low budget of these projects as well as underestimation of air quality impact on pupils' health. The results of indoor air analysis in classrooms show that renewal of ventilation systems must be considered more seriously when planning school renovation process in future.

KEYWORDS

School, classroom, ventilation, indoor, air, quality.

1. INTRODUCTION

Most Lithuanian schools are built under the standard projects of 70s and 80s. Great losses of thermal energy is typical of these buildings. In year 1997 "Sponsorship program of sanitary condition improvement in state and municipal educational institutions" was prepared and renovating process of schools started. The purpose was to reduce heating costs and to ensure parameters of thermal comfort in classrooms.
First significant research in evaluating quality of renovation was carried out in year 2001 – 2002. During the course of research some negative effects of renovation were noticed. One of them is insufficient ventilation in classrooms due to sealed windows [1]. Attempts to avoid this negative effect are being made while mounting air inlet units in sealed windows.
At present, valid Lithuanian construction regulations "Heating, ventilation and air conditioning" (STR 2.09.02:1998) [2] require that classrooms were supplied with 21.6 m^3/h (6 1/s) of outdoor air for one person. Fixed minimal quantity of outdoor air for one person is 14.4 m^3/h (4 1/s).
Although, in renovation projects it is stated that in case of window change air inlets should be mounted, specifications and characteristics of equipment are often not given. Insufficient number or type of air supply equipment is often chosen and the air extraction system is not being reconstructed at all due to financial retrenchment. Therefore, it is not known whether the means that projecting and constructional enterprises undertake are sufficient for the standard air circulation in the classroom.
Therefore, the aim of experimental research was to evaluate the effectiveness of typical ventilation systems that were mounted during school renovating process in Lithuania.

2. OBJECTIVE AND METHOD OF RESEARCH

Parameters' variation in time that characterizes the renovation effect on air circulation and classroom microclimate was analyzed in the process of experimental research. Room air temperature and relative humidity in different places of room, air velocity at 0.1 m, 1.1 m and 1.7 m high above the floor surface and the

concentration of CO_2 were investigated. The research of microclimate parameters was carried out following the standard of Hygiene of Lithuania “Microclimate of residential and public buildings” (HN 42:1999) [3].
In order to compare the effectiveness of ventilation equipment used, classrooms in which the research was carried out had to be similar (geometric similarity, similar width and the same orientation of windows, similar air tightness of partitions and thermal conductivity, similar age of schoolchildren and number of them in lessons etc.). Therefore, classrooms of the same school, on the same floor were chosen that fit all the requirements of similarity. Experiments were carried out in S.Neries secondary school in Vilkaviskis. There were 3 types of air supply equipment, 3 units of each type, mounted in classrooms: “Gecco 3” (“Gealan Clima Control”), “Aereco EMM707” and “Ducoplus 15000” (see figure 1). There were 22-27 schoolchildren in classrooms during lessons (8-10 years old).

a **b** **c**

Figure 1
Air supply equipment that was mounted in investigative school
(a – “Gecco 3”, b – “Aereco EMM707”, c – “Ducoplus 15000”)

“Gecco” and “Aereco” air inlets are fixed to the window frame and “Ducoplus” is the glazed-in air vents. “Aereco” air inlets regulate the supply airflow automatically, according to relative humidity of indoor air. “Gecco” and “Ducoplus” air inlets are controlled manually and have two positions: open and closed. “Aereco” air inlets were set on automatic position during the research. “Gecco” and ”Ducoplus” air inlets were open.
The throughput of mentioned air supply units is different. According to manufacturers information and area of cross-section, the largest amount of air can pass through “Ducoplus” air inlet and the smallest - through “Gecco” air inlet.
Systems of natural air extraction were mounted in classrooms during construction of the building, and were not reconstructed during the renovating process.

3. RESULTS OF THE RESEARCH

This section gives the results of measurement of CO_2 concentration, temperature, relative humidity and air velocity in standard classrooms, in which the above mentioned air inlets were mounted. The research was carried out in February – March of year 2004.

3.1. Results of measurement of CO_2 concentration

Despite the type of air supply equipment mounted in classrooms, CO_2 concentration heavily exceeds allowable limit (1000 ppm), as seen in figure 2. Results are very similar for classrooms with “Gecco” and “Aereco” air inlets (standard value was exceeded 3 times during the 4th lesson). Standard value was exceeded 2 times in typical classroom with “Duco” air inlets.

3.2. Results of measurement of relative humidity in the room

According to the previous research, carried out in year 2001 – 2002, relative humidity exceeded standard value in most renovated schools [1] (limits of relative humidity are 40-60%, as set by the standards of Hygiene of

Lithuania [3]). According to the research, relative humidity seldom exceeded 50% during lessons in this particular school. This partially explains the variation of CO_2 concentration in the classroom, in which “Aereco” air inlets are mounted. The humidity sensitive air inlets are adjusted to let in the maximum airflow, in case of 70% of relative humidity in the classroom. In this school this limit was not reached, therefore air inlets were only half open.
Using statistical methods, the existence of correlation between CO_2 concentration and relative humidity level in the classrooms was checked (correlation coefficient of Pearson applied). The results prove the existence of strong relation between these parameters; therefore, there is a linear dependence between them in classrooms.

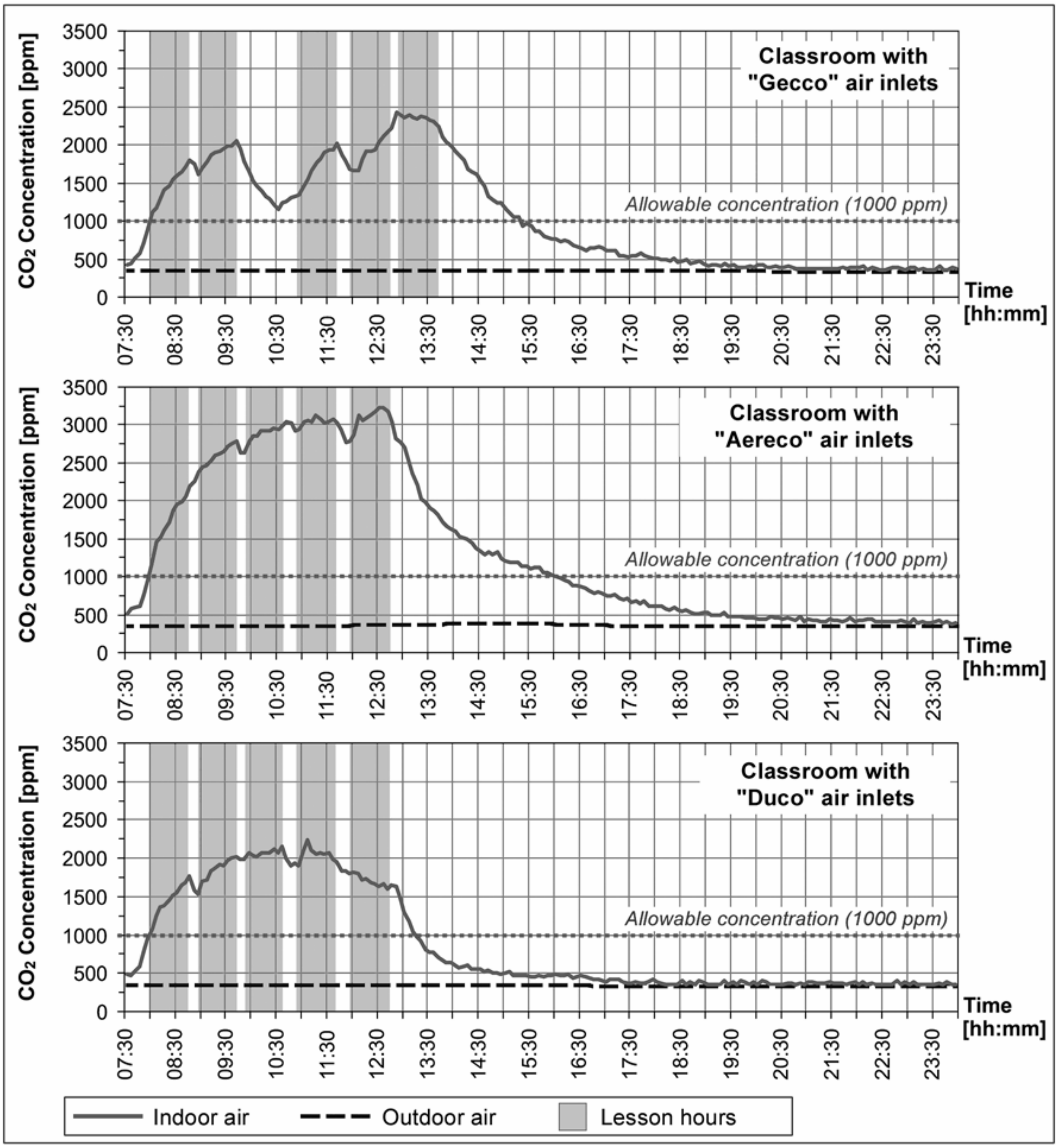


Figure 2
Variation of CO_2 concentration in the center of classrooms, 1.1 m high above the floor surface

3.3. Results of air temperature measurement

Figure 4 shows the variation of air temperature in classrooms. As shown in the figure, this parameter falls into recommended limits of comfort (21-24ºC according to Lithuanian and European standards) only when schoolchildren gather in classrooms. The research also shows that in some classrooms thermal comfort parameters practically are not ensured.

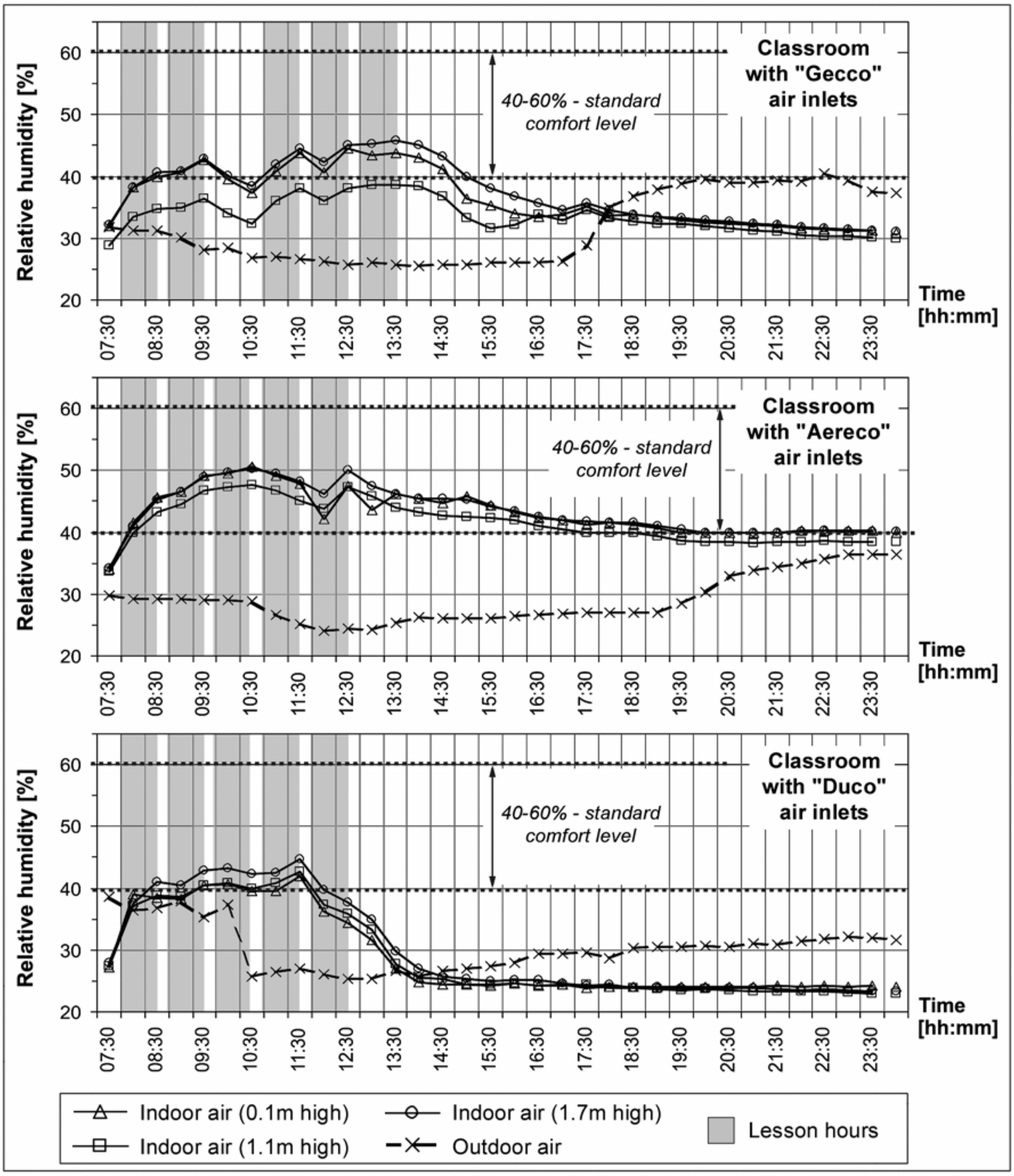


Figure 3
Variation of relative humidity of outdoor air and air in classrooms

3.4. Results of air velocity measurement

While measuring air speed at three different heights (0.1 m, 1.1 m, 1.7 m) of the room, the results were fixed at a one-minute interval. In case of natural ventilation, air velocity in the room is of pulsating nature. All the data was processed by the program of statistics, taking into account the recurrence of air velocity values that exceeds allowable limit (see figure 5). This limit, according to the standard of Hygiene of Lithuania HN 42:1999 [3], standard CR 1752:1998 [4] and standard ASHRAE 62-2001 [5] is set as 0.15 m/s.
According to the type of air supply equipment (i.e. to the airflow rate of supply air), the recurrence of values exceeding the standards is different. As seen in figure 5, supply airflow rate in classrooms influences air speed at lower level most. Air velocity at lower level (0.1 m high) is the slowest in classrooms with “Gecco” air inlets, which ensure the lowest airflow rate. Whereas in classrooms with “Ducoplus” air inlets, that have the highest air throughput of all air supply equipment investigated, air velocity at lower level is the highest and values that exceed the allowable limit recur even in 35,6% of cases.

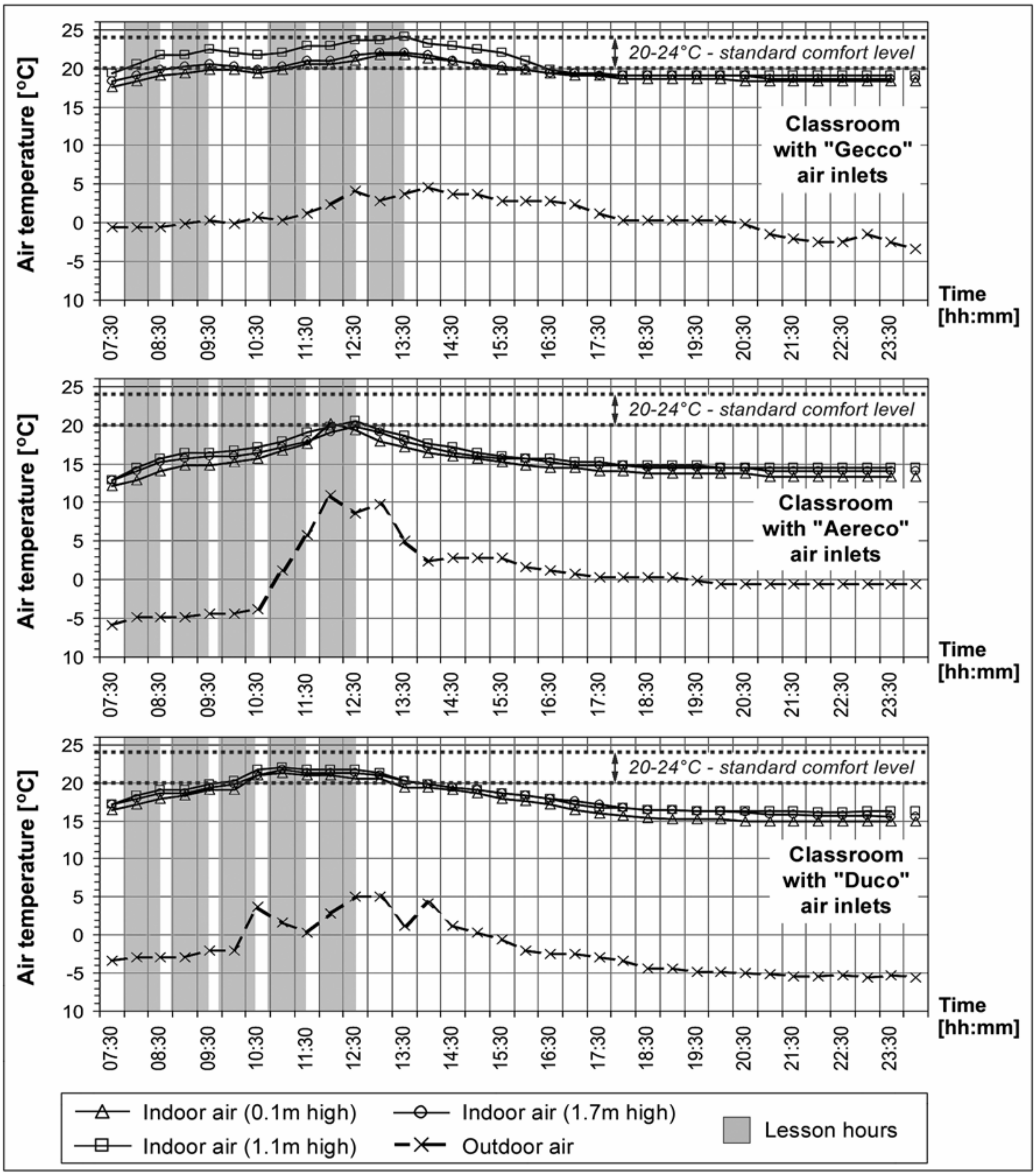


Figure 4
Variation of outdoor air temperature and air temperature in classrooms

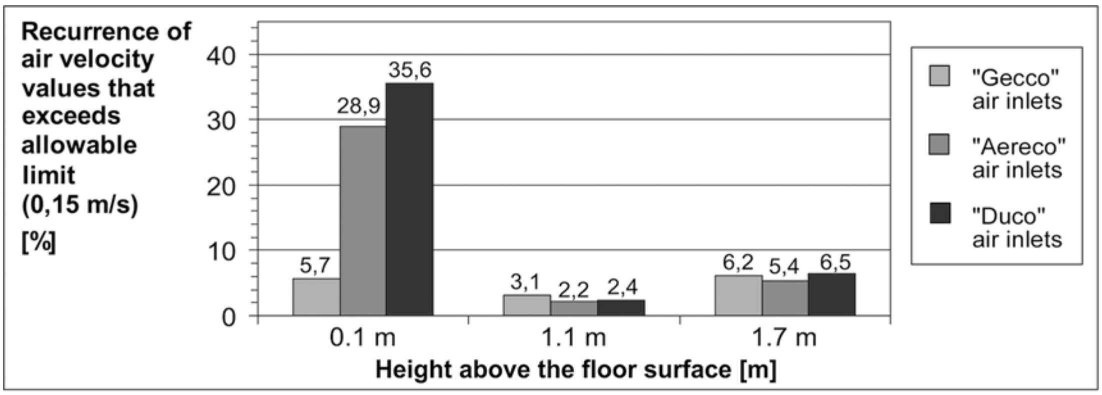


Figure 5

Percentage of a recurrence of air velocity values exceeding allowable limit in classrooms.

3.5. Indirect measurement of extraction airflow

Indirect measurements of extraction airflow were carried out in the investigative classrooms. Duct of a certain width of cross-section was fixed to the exhaust grille; extraction air velocity was measured in the center of the duct. The extraction airflow was counted according to the measured air velocity. This kind of research was possible only in the first floor classrooms, because the direction of air movement in the extraction duct was variable in upper floors, i.e. as outdoor conditions were changing, air was periodically blown inside through the exhaust grille. When calculations were carried out, it became clear that amount of air which is exhausted through the exhaust grilles is smaller than is required by the standards. In order to ensure standard air circulation in investigative classrooms, approximately 560 m^3/h of air should be exhausted [2]. However, passive stack air extraction system exhaust approximately 300 m^3/h (when outdoor temperature is ~0°C). This satisfies only 53% of standard air circulation in investigative classrooms or 79% of allowable air circulation.

4. CONCLUSIONS

In general, it is possible to say that constructional means applied to ensure the standard air circulation in renewable Lithuanian schools are insufficient. In classrooms where the air extraction system was not reconstructed, ventilation becomes insufficient and concentration of CO_2 is exceeded during the lessons. One of the reasons is that passive stack air extraction system do not ensure the standard air circulation in classrooms. In case the outdoor air temperature is ~0°C, the direction of air movement in the ducts of the upper floors is variable. Therefore it is essential to reconstruct air extraction systems while renovating schools.

As Lithuanian schools widely use the air inlets, which directly supply outdoor air to the classroom, the highest air velocity rates emerges at the lower part of the room (0.1 m high) in cold period. It has a pulsating nature (periodically exceeds standard values). The larger amount of supply air passes through the air inlets, the more often air velocity in the lower part of the room exceeds allowable level.

As after evaluating the correlation between CO_2 concentration and relative humidity in the classrooms their linear dependence was set, so ventilation systems with relative humidity sensors can be applied for airflow rate regulation of ventilation systems in school buildings. However, the sensitivity of these sensors must be adjusted for each particular case, taking into account variations of relative humidity in a day course.

In the course of research it was noticed that the air tightness of rooms (especially doors) and the situation of the room in the building layout (distance to staircase) influence air circulation in the classrooms. This must be taken into account while renovating ventilation systems of the classrooms (doors must be impermeable when closed).

References:

1. Ignatavičius, Č., Ignatavičius, G. and Tuomas, E. (2002). *Results of 1997-2000 school renovation.* Homo Liber, Vilnius, Lithuania.
2. STR (1998). *STR 2.09.02:1998, Heating, ventilation and air conditioning. Construction regulation.* Ministry of Environment, Vilnius, Lithuania
3. HN (1999). *Microclimate of residential and public buildings. Standard of Hygiene.* Ministry of Health, Vilnius, Lithuania
4. CEN Report (1998) *CR 1752:1998, Ventilation for Buildings – Design criteria for the indoor environment.* European Committee for Standartisation, Brussels, Belgium.
5. ASHRAE (2001). *ASHRAE Std. Ventilation for acceptable indoor air quality.* American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA.

EU RESHYVENT- INTERIM RESULTS

Peter Op ‘t Veld, Ad van der Aa

Cauberg-Huygen Consulting Engineers, the Netherlands

ABSTRACT
Within the EU RESHYVENT project four demand controlled ventilation systems have been developed, each one for a specific application field. The scientific support work for the industries has been reported in a number of documents. A number of these reports will be published as AIVC Technotes after completion of the project.

KEYWORDS

Demand Controlled Hybrid ventilation, Sensor Technologies

INTRODUCTION

In January 2002 the EU RESHYVENT project started, a three-year project within the EU Fifth Framework Programme on the investigation and development of demand controlled hybrid ventilation systems in residential buildings. The project is a clustering of four industrial consortia with a multi-disciplinary scientific consortium. Each of these industrial consortia has developed a working prototype of a hybrid ventilation system, each one for a specific climate. A scientific group with 12 partners from research institutes, consultants and universities will carry out the scientific research work for the development of these systems. This paper gives a summary and update of the work carried out and the interim results so far.

INTERIM RESULTS OF THE EU RESHYVENT PROJECT

The scientific research work is organised in a number of work packages. The industrial partners can consult the work packages. It is the task of their scientific coaches to structure these questions, to identify the relevant work package and to match the questions with the scope of the work programme and the objectives of the work packages.
RESHYVENT has following work packages:

WP 1 State of art review - WP leader NBI, Norway
Within this work package an extended database is collected on all available literature and research work in the field of advanced ventilation (www.byggforsk.no/prosjekter/Reshyvent/) At his moment this database is not public accessible due to copyright matters.

WP 2 Market Support Unit - WP leader SWP, Sweden
Domestic ventilation systems are very different from country to country. There are many reasons for this, differences in building codes, traditions, user preferences and climate. In northern Europe most new dwellings are equipped with mechanical ventilation systems, while southern countries often rely on window airing. More and more mechanical ventilation systems also include heat recovery. The starting point is therefore very different. In some countries simply installing a ventilation system is an improvement, and the reference installation cost is then very low. In countries with mechanical ventilation systems a certain installation cost for ventilation is expected and accepted, however there is often a tendency to install inexpensive systems. The benefit of LCC analysis is being discussed, but rarely applied

in real projects. In the countries where mechanical ventilation systems have become more and more common usually a building code that more or less requires mechanical ventilation has been developed e.g. in France, the Netherlands, Norway and Sweden. For the Netherlands and Sweden mechanical ventilation systems were required for apartment buildings for several years, but not any more. Common ventilation market driving forces on the European market are IAQ, health, comfort and energy (i.e. energy performance regulations).
The existing European housing stock has a variety of ventilation systems. Most countries, apart from France, the Netherlands and to some extent Norway and Sweden, have a pre-dominance of installed natural or passive stack ventilation systems.

WP 3 Renewables Integration Support Unit - WP leader Esbensen, Denmark
The integration of renewable energy technologies in the RESHYVENT project focuses and wind applications to substitute fossil fuel in the operation of hybrid ventilation systems. On the basis of existing renewable technologies this report gives an overview of the possibilities for integration of renewable into hybrid ventilation components. When integrating renewable in a system it is recommended that the Trias Energetica approach is followed to ensure that the use of conventional and renewable energy is optimised as much as possible. The method included tree steps: First the energy demand from the components is minimised as much as possible, secondly the remaining energy is supplied by renewable energy and third the remaining energy demand, if any, is supplied by conventional energy sources (fossil fuels). The third step includes optimisation of the efficiency of the conversion of fossil fuels. This report is focusing on step two the integration of renewable technology in hybrid ventilation systems. The following renewable applications have been described:
– Glazed balcony and sunspaces
– Solar air collector and solar wall
– PV systems
– PVT systems
– Wind cowls
– Wind turbines
– Solar chimneys
The described applications are all suitable in combination with a hybrid ventilation system, however whether the applications are feasible very much depends on the specific ventilation concept, location and urban environment. A rough overview of the characteristics, urban constraints and recommendations for the use of the different applications are shown in next table.

Concept	Description	Urban constraints	Recommendations
Glazed balconies	Existing or new balconies glazed for increase of the living area. Reduction of noise and for preheating of inlet air	Shadows and shelter in canyons	Recommend in open courtyards or at free exposed facades
Solar walls	Existing or new facades with glazing to improve the insulation level and for preheating of inlet air	Shadows and shelter in canyons	Recommend in open courtyards or at free exposed facades
Photovoltaics	Auxiliary energy for operation of fans and controls in a hybrid ventilation system	Very sensitive to shadows and shelter in canyons	Recommend in open courtyards, at free exposed facades facing south or at roofs
PVT systems	Integration in facade for production of auxiliary electricity and thermal energy for preheat of ventilation air	Very sensitive to shadows and shelter in canyons	Recommend in open courtyards or at free exposed facades

Wind cowls	Increase of wind induced flows in extracts	No constraints	Recommended at roofs
Wind turbines	Auxiliary electricity for fans and controls in the ventilation system	No constraints	Recommended at roofs
Solar chimneys	Increase of stack driven flows in extracts	No constraints	Recommended at roofs

WP 4 Standard and Regulations Support Unit - WP leader BBRI, Belgium
Work package 4 focuses on Standards and Regulations on Indoor Air Quality (task 4.1.) and Energy Performance (task 4.2.) in relation to ventilation. The general conclusions of WP4 task 4.1 are:
- Standards should determine test procedures / calculation methods without specifying requirements
- Regulations should determine requirements according to standardised test procedures / calculation methods
- Performance-oriented approaches instead of descriptive documents
- Standards on IAQ are no barriers for hybrid ventilation systems but have an impact on the conception of the components

The general conclusions of task 4.2. are:
- Calculation procedures can constitute a barrier to the application of hybrid ventilation systems.
- The specificity of such systems is not always taken into account in the standard calculation procedure (e.g. possibility to reduce the airflows).
- The evaluation of the benefits has to be determined by the so-called principle of equivalence. This requires an efficient and coherent framework allowing this assessment

WP5 Design parameters Support Unit - WP leader EMPA, Switzerland
Work package 5 has produced two reports: one Technical Report and a report on Parameters for Performance Assessment.
The Technical Report was originally aimed for the RESHYVENT participants, especially the participating industries but the information is of general interest for all manufacturers and designers of (hybrid) residential ventilation systems. The report gives detailed information on issues like wind pressure, thermal comfort evaluation by CFD simulation and input data, necessary to perform computer simulations for performance analyses of hybrid ventilation systems. This report will be published as an AIVC Technote.
The report on Parameters for Performance Assessment gives performance criteria, target levels and design constraints.

WP 6 Performance Assessment Support Unit - WP leader IDMEC, Portugal
The initial objective of this WP was to study the performance of different design options in hybrid ventilation systems for several climates, control strategies and occupancy schemes to support the industrial consortia (IC) with the development of their innovative systems. However, as the work started, the goals have been expanded to produce a tool that would evaluate new innovative ventilation products on the basis of the equivalence principle for satisfaction of regulations, norms and standards. This tool is an ideal platform, supported by scientists and industries, to assess and promote innovative energy efficient ventilation systems, necessary for the implementation of the EPD (Energy Performance of Buildings Directive. A graphical user interface tool has been developed to carry out simulations in Trnsys/Comis. A new subroutine type 101 for controllers has been written. Type 101 will allow the control of inlet grilles, exhaust valves and fans. It is possible to control 48 devices

(inlets, exhaust valves and fans). The inlet grids and exhaust valves can be regulated or auto regulated. If the inlet/valve is auto regulated the controller can have 1 to 4 levels of opening (besides closed) and reacts to one input signal, which can be for relative humidity, presence or CO2 concentration. There are two types of fan controller: ON/OFF fan ruled by a schedule that switches the fan position (0 or 1) or a proportional flow fan, (the fan speed rotation is a function of the inlet or exhaust airflow, depending on which is bigger).

WP 7 Control and Ventilation Strategies Support Unit - WP leader CSTB, France
The integration of natural ventilation and mechanical driving forces in a hybrid ventilation system requires development of new ventilation control strategies. The objective is to develop strategies for control of hybrid ventilation systems at any time and for a certain combination of internal pollutant, outdoor conditions and comfort requirements that ensure that the immediate demands to the indoor environment are fulfilled in the most energy efficient manner. The first work of the group showed that it was not possible to be exhaustive in the development of ventilation and control strategies. The final report draws up a panorama of the principles to take into consideration when developing ventilation and control strategies. The report contains three parts:
Part 1: Ventilation strategies for hybrid systems
Part 2: Hybrid ventilation control strategies
Part 3: Implementation of hybrid ventilation control strategies
The report gives a methodology to develop control strategies for hybrid ventilation together with examples of application. Particular strategies are developed with the Industrial Consortia who needed assistance. The work with the IC's is subjected to confidential reports.

WP 8 Specifications and ToR for components and systems - WP leader TNO, the Netherlands
All research work carried out in the different work packages as well as the developments for the four specific hybrid ventilation systems (within WP 9) will be "translated" to generic terms and specifications. Ventilation industries and designers for development of hybrid ventilation systems can use these specifications. It gives information on:
- specifications and terms of references: components, systems and building
- solutions for different climates: generic and specific
- price reduction by optimisation of design and by scale enlargement

WP 10 Urban impact - WP leader NKUA, Greece
The objective of this work package is to assess the impact of the urban environment on the hybrid ventilation air flow process through experimental and computational procedures performed at a number of different configurations that affect the performance of natural and
The main parameters affecting the performance of natural and hybrid ventilation systems in urban canyons have been identified. A full report has been prepared. The main problem is the estimation of the wind speed in canyons. Using data from RESHYVENT and the EU URBVENT project a methodology has been developed to calculate the wind speed in canyons.
A literature study on the potential of natural and hybrid ventilation in urban canyons has been carried out. Reports on the impact of noise in canyons as well as on the potential use of renewables have been prepared. An important scientific work performed under this task was the experimental validation of the methodology to estimate the wind speed in canyons.
A literature study on the potential of natural and hybrid ventilation in urban canyons has been carried out. Reports on the impact of noise in canyons as well as on the potential use of renewables have been prepared.

An important scientific work performed under this task was the experimental validation of the methodology to estimate the wind speed in canyons. The main configurations that affect natural and hybrid ventilation in canyons have been identified. Specific configurations have been selected in order to perform experimental investigations.
Full experiments have been performed in two canyons and three buildings in Athens during Summer 2002 to indicate the impact of the urban environment on the natural and hybrid ventilation air flow process in urban canyons. The observed air flow characteristics and mechanisms driving the airflow as well as the estimated air changes rates for applied ventilation systems, is presented for these canyons.

DEVELOPMENT OF A PROBABILISTIC APPROACH FOR PERFORMANCE ASSESSMENT OF INNOVATIVE VENTILATION SYSTEMS

The market uptake of innovative, energy efficient concepts in the building sector is to a large extent influenced by the stimuli found in building regulations. An increased number of countries and regions in Europe is implementing so-called Energy Performance Regulations (EPR). It is expected that more countries will follow this tendency. The new Energy Performance of Buildings Directive (EPBD) will surely enhance this development since it makes the application of an EPR mandatory for new buildings and for major renovations. If one is obliged to make an assessment of buildings in terms of energy performance, it is clear that one should be able to assess all kinds of building designs and of technologies. However, the present regulations clearly not cover all possible technologies. Among the technologies which are typically not covered by the standard procedures are innovative ventilation concepts, e.g. hybrid ventilation in dwellings.
Within the work packages 4, 5 6 and 7 a method for performance assessment of innovative ventilation systems is developed, based on a mixture of European measures and national actions, based on a probabilistic approach.

DEVELOPMENT OF FOUR HYBRID VENTILATION SYSTEMS

Within work package 9 the four industrial consortia actively participate with their scientific coaches on the development and construction of four hybrid ventilation concepts for four different European climate zones.

The Swedish concept
The Swedish concept addresses apartments in cold climates. As in these climates ventilation demand corresponds often with the heat demand the ventilation supply is integrated in a combined hybrid supply convector. Air collectors can preheat supply air.

Demo board of the Swedish hybrid ventilation system

Website of the Swedish system

Next to it, it is possible to preheat the air partly by a solar collector. The exhaust system is a fan assisted passive stack. Communication with the occupants via the internet about the energy performance of the system is one of the developments of the Swedish system.

The Dutch concept

The Dutch consortium is elaborating two concepts one for 2004 (ready at end of the project) and one for 2010. The 2004 concept is a fully hybrid demand controlled system with de-central supply from the facade and a coupled hybrid central mechanical extract. A characteristic development in this concept is an extreme low-resistance ductwork (< 2 Pa at 56 dm^3/s) based on the experiences and components developed within the EC TIPVENT project. A special fan is developed using 2 Watt at 56 dm^3/s at 20 Pa. This extreme low fan power is possible by a combination of the low pressure duct work and wind optimised cowls (<1 Pa at 56 dm^3s). Supply grilles are actively controlled with compensation for cross flow and infiltration. The advanced control system is being developed in close co-operation with WP7. The prototype is tested in 2003 in laboratory. In 2004 the system is build in a newly build test house at the by Brno University of Technology Czech Republic and will be extensively tested.

Demo board of the Dutch system

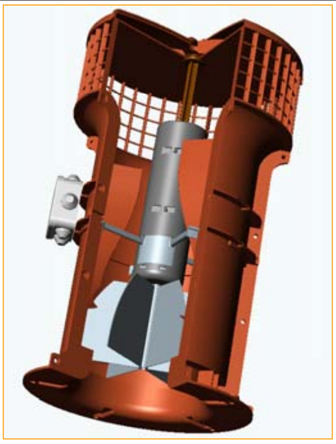
Exhaust chimney

Air inlets

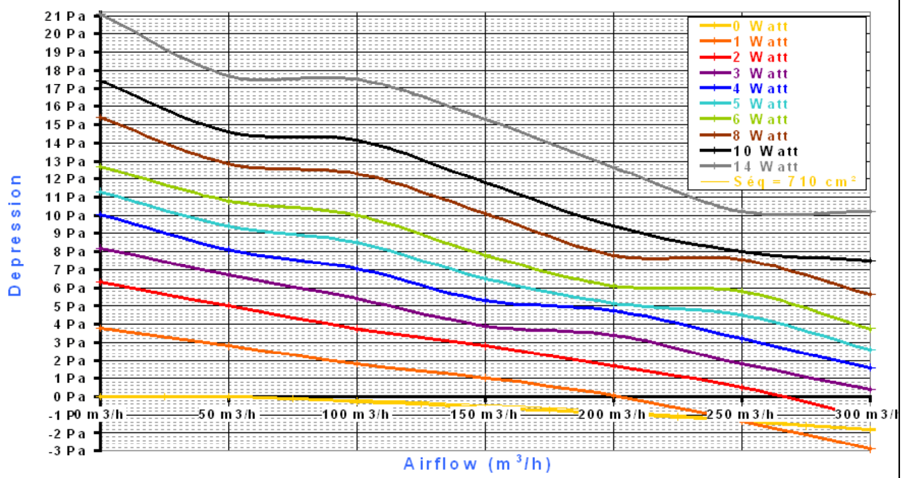
Demonstration house Brno Czech Republic

The French/Belgium concept

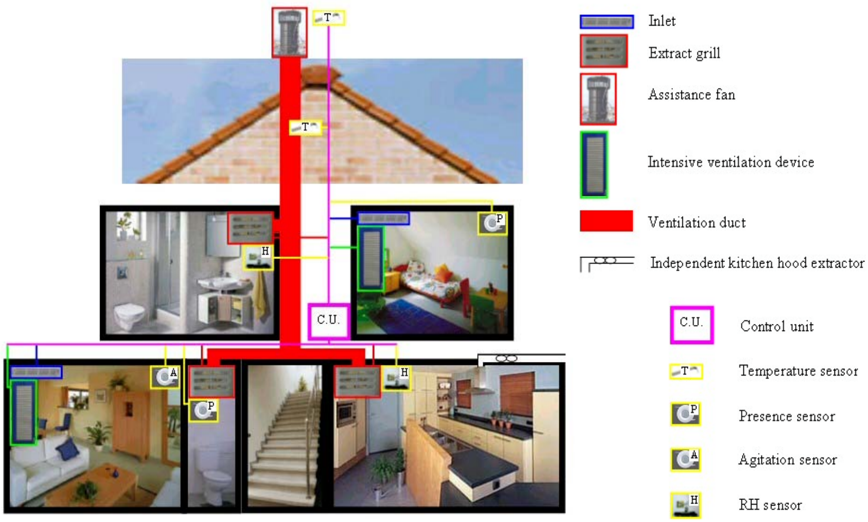
The French/Belgium consortium is working on the integration of renewables (i.e. PV application) in combination with hybrid ventilation. Like the Dutch concept, this concept is also based on a fully hybrid demand controlled system with de-central air supply from the facade and a coupled hybrid central mechanical extract. PV provides the auxiliary energy for the fan. There is special attention for the summer comfort en the application of free cooling during the night. A new development is a fan that can be used for combined natural and mechanical exhaust ventilation. The advanced controls for the system are being developed in close co-operation with WP7.



Fan for combined natural and mechanical exhaust. Power consumption 2W
No pressure losses when the fan is off.



Characteristics of the fan

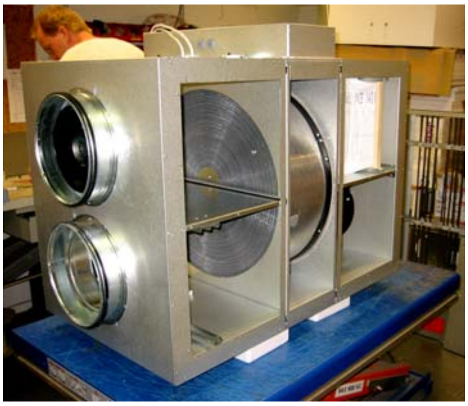


Various components of the ventilation system

The Norwegian concept

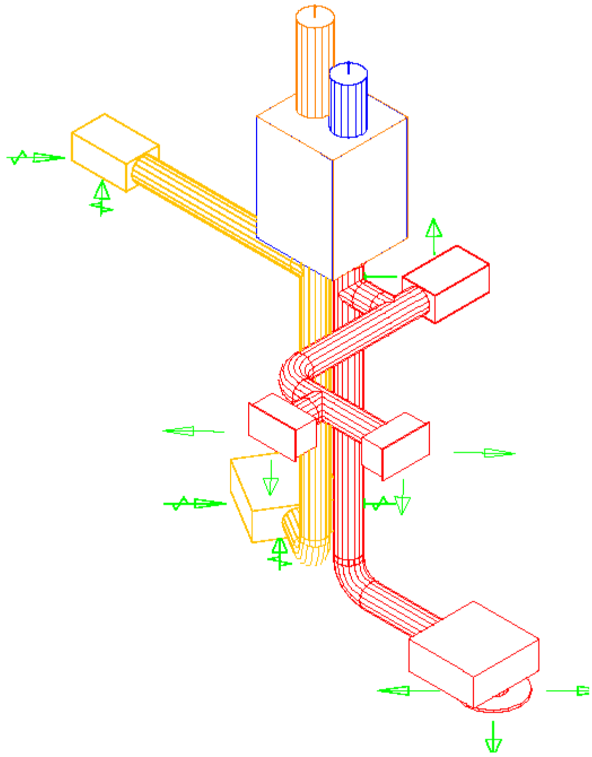
The Norwegian concept is being developed for extreme cold climates. For these conditions heat recovery is necessary for preheating and to recover energy.

The Norwegian concept is entirely different from the others. The combination of hybrid (natural) ventilation with heat recovery is innovative. A supply system with low-pressure ducts is used. The heat recovery system exists of a rotary heat exchanger. Special attention is being paid to develop and optimise the outlet with wind vane and the air inlet on top of the roof. The system can be equipped with CO_2-sensors as well as with R.H.-sensors. The system will be build in four demonstration houses in several configurations and will be extensively monitored and tested under occupied circumstances.



Prototype of the new developed hybrid ventilation unit with heat recovery.

Test houses with the Norwegian hybrid ventilation system.



Scheme of the optimised duct system

ACKNOWLEDGEMENTS

RESHYVENT is funded by the European Commission. This support is gratefully acknowledged.

REFERENCES

Blomsterberg A, (2004) Market report on hybrid ventilation systems
Antvorskov S. (2004) General information on renewable applications for auxiliary energy - suitable for use in hybrid ventilation systems
Wouters P., Heijmans N., Loncour X., Delmotte Ch, (2004), Standards and regulations concerning Indoor Air Quality and Summer Comfort
Wouters P., Heijmans N., Loncour X., Delmotte Ch, (2004), Standards and regulations concerning Energy performance of Buildings
Dorer V. (2004) Parameter for the design of demand controlled hybrid ventilation systems for residential buildings, Technical report
Dorer V. (2004) Parameter for the performance assessment of hybrid ventilation systems
Hussaunndee A, Jreijiry D., Millet J.R., Villenave J.G., (2004), Ventilation Control Strategies
Santamouris M., Niachou A., Inventory on the impact of the urban environment on hybrid ventilation
Santamouris M., Niachou A., State of the art and potential of hybrid ventilation in urban canyons
Santamouris M., Niachou A., Classification of configurations affecting hybrid ventilation in urban canyons
Santamouris M., Niachou A., Experimental research of hybrid ventilation in urban canyons
Santamouris M., Niachou A., Study of airflow characteristics at Ragavi urban canyon
Op 't Veld P., van der Aa A., (2003)RESHYVENT- a EU cluster project on Demand Controlled Hybrid Ventilation for Residential Buildings, AIVC 2003

DEMAND CONTROLLED HYBRID VENTILATION FOR COLD CLIMATES.

Åke Blomsterberg[1], Eje Sandberg[2] and Mikael Lönnberg[3]

[1]WSP Environmental, Slagthuset, S-21120 Malmö, Sweden
[2]Stigberget Driftteknik, Allévägen 37, S-19276 Sollentuna
[3]Systemair, S-73930 Skinskatteberg

ABSTRACT

The aim of the project is to study, develop, build (prototype system) and evaluate an energy efficient demand controlled hybrid ventilation system for dwellings in a cold climate. Hybrid ventilation in a cold climate means a ventilation system with low pressure drops, which result in a minimisation of the mechanical energy for ventilation, and that natural driving forces can play an important role. The project is included in the EC research project Reshyvent ”Cluster Project on Demand Controlled Hybrid Ventilation in Residential Buildings with specific emphasis on the Integration of Renewables”. Demand controlled hybrid ventilation is considered to be a promising system of ventilation for the future, where stringent requirements as to energy efficiency and air quality are to be fulfilled.

The ventilation concept is based on an exhaust air system with low pressures drops and a separate fan for each apartment. The fan has a built-in control system for a, according to desire adjustable, constant exhaust air flow independent of the boundary conditions. The desired air flow can be set from a panel in the apartment, but is also automatically controlled by humidity and outdoor air temperature. The outdoor air is preheated by a supply convector. Each apartment has individual control of indoor climate and individual metering of energy use. The system will result in a similar level of energy use for space heating as for a system with balanced ventilation with traditional heat recovery, but lower use of electricity, more user-friendly and improved indoor air quality.

KEYWORDS

Energy efficiency, demand controlled ventilation, dwellings, indoor air quality.

INTRODUCTION

The project is included in the EC research project Reshyvent ”Cluster Project on Demand Controlled Hybrid Ventilation in Residential Buildings with specific emphasis on the Integration of Renewables”. Demand controlled hybrid ventilation is considered to be a promising system of ventilation for the future, where stringent requirements as to energy efficiency and air quality are to be fulfilled.

The results from a technical procurement for demand controlled ventilation for new Swedish dwellings has been the starting point for the development of a demand controlled hybrid ventilation system for cold climates (Blomsterberg 2002). The work has been supported by Reshyvent work packages: market survey, integration of renewable energy, regulations and standards, design parameters, calculations and performance predictions, control strategies, terms of references for components and systems, and urban impact.

The development and expected performance of the prototype system and the system itself is described below.

GENERAL PHILOSOPHY AND ASSUMPTIONS

The task was to develop a concept for demand controlled hybrid ventilation for apartments in a cold climate. Today's ventilation systems, of which most are mechanical, in Sweden often have the following characteristics:

- Actual air flow rates deviate from design values due to deficiencies in system design, adjustment and uncontrolled influence of users (Sandberg 1994, Månsson 1998)
- The use of bathrooms have changed, increased moisture load due to increased shower frequencies and installation of washing machines (Gaunt 1985) with associated risks of moisture and mould problems.
- Mechanical ventilation in apartment buildings usually has an almost constant ventilation over time. Thus it is independent of variations in loads such as moisture, odours, cooking fumes, number of persons present, which results in excessive use of energy. There is a considerable energy savings potential in using demand controlled ventilation (Månsson 1992).
- Today's ventilation systems are often associated with draught problems (Engvall 1992, Andersson 1993). This is especially true for well insulated buildings, where the outdoor air enters behind the radiator.
- Ventilation systems fulfilling design air flow rates often create noise problems (Andersson 1993, Blomsterberg 1995).
- Many ventilation systems include the possibility of increasing the air flow in the kitchen when cooking. The odour capturing ability of fume hoods/fans are often not satisfactory and very often result in complaints concerning cooking odours according to questionnaires (Engvall 1992, Blomsterberg 1995).

A new type of ventilation system is needed, which can solve all or most of the above mentioned problems and which at the same time can reduce the energy use for ventilation (energy for operation and space heating). The most promising system to achieve these goals is demand controlled hybrid ventilation. Such a system should also include features such as individual control of heating and individual metering of energy use.

The first step in improving the performance of ventilation systems based on exhaust fan ventilation and at the same time lowering the energy use is adding demand control. This first step was taken for apartments in an ongoing Swedish technical procurement.

The ventilation concept was to be designed such that the user has the possibility to control the ventilation within the apartment. Nonetheless, the air flow shall automatically increase as needed, to the degree that the minimum environmental and health requirements are met. The varying airflow needs at different operational levels should be met e.g. forced ventilation in the kitchen and bathroom and minimum flow in an empty apartment etc. The ventilation system within the apartment shall be designed with regard to internal loads such as humidity, temperature and carbon dioxide. One desired feature is control of the airflow for each room within each apartment. However, the exhaust air flow for the apartment may only fall below the normal ventilation rate (usually 0.35 l/s(m² of floor area)) in the case of empty apartments.

The ventilation system shall be designed as an open solution; i.e. one that can be integrated with other systems and components from various manufacturers and that allows subsequent adaptations. The ventilation system shall be prepared for individual metering and customer billing. One desired feature is that the technical solutions are prepared for future integration with real property's technical systems and IT-systems for users e.g. time scheduling, internal messages, locking and security systems.

PERFORMANCE SPECIFICATIONS

Indoor climate:
The performance specifications below refer to the occupied zone.
- Outdoor air filtrated by filter class EU 5
- CO_2 < 1000 ppm (12 hour average) and the Reshyvent requirement of CO_2 > 1050 ppm max 500 kppmhours and CO_2 > 1750 ppm max 100 kppmhoursRH < 70 % within 8 hours (bathroom)
- Supply air to living room pre-heated to 5 °C – 30 °C by special convector which minimizes back draft, wind effects and night ventilation
- Indoor temperature 19 °C – 23 °C
- Air velocity < 0.15 m/s (winter) and < 0.25 m/s (summer)
- Outdoor air flow normal operation 0.35 $l/(sm^2)$, the ventilation rate to be based on the number of persons living in the apartment, which means that there are cases when the flow rate will be below 0.35 $l/(sm^2)$
- Outdoor air flow empty apartment 0.10 $l/(sm^2)$Air change efficiency > 40 %
- Cooker hood odour capturing ability > 75 %
- Thermal comfort, 90 % of the time < 10 % PPD
- Pressure difference indoor - outdoor < 15 Pa
- Sound pressure level from HVAC – Swedish class B: 26 dBA for rooms and 35 dBA for kitchen (agreed Reshyvent 35 dBA)Sound pressure level from outside – Swedish class B: 26 dBA for rooms and 35 dBA for kitchen (agreed Reshyvent 35 dBA)

Energy efficiency
- SFP exhaust system < 0.5 $kW/(m^3/s)$
- SFP balanced system < 1.0 $kW/(m^3/s)$
- SFP balanced system with heat recovery < 1.5 $kW/(m^3/s)$

System stability
- Ventilation system must tolerate window opening
- Demand controlled ventilation must not cause lasting changes in indoor air temperature
- Air flow stability 25 – 50 % (good)

System flexibility
- Open solution - allowing mixing of systems and components from different manufacturers

Operation and maintenance
- Individual metering of heating and electricity
- Accessibility for adjustment, cleaning, service
- Measurability of air flows
- Instructions and user friendliness

MAIN CHARACTERISTICS OF THE PROTOTYPE SYSTEM

The system is mainly developed for installation in new apartments, but can also be used for refurbishment.

General

- individual co-ordinated control of heating, indoor temperature and ventilation i.e. for each apartment
- individual metering of energy use, ventilation and indoor temperature, to motivate the users to operate their apartment in an energy efficient manner
- LON-based BEMS, enabling improved operations monitoring
- low pressure drops in ventilation system, to contribute to low use of electricity for ventilation
- control of humidity in bathrooms in order to avoid moisture damage to the building
- passive stack and wind (wind catcher) assisted exhaust fan ventilation, where the fan can be turned off e.g. when no one is at home.

Ventilation in apartments

- one self regulated flow constant volume flow EC fan per apartment
- exhaust air terminal devices in bathroom, lavatory and kitchen
- outdoor air inlets with back flow damper, in façade of bedroom and living room
- pre-adjusted normal ventilation as a function of number of persons, the number can be set by the user
- high efficiency cooker hood with manually forced ventilation with timer
- lowered ventilation when no one at home, manual or automatic (controlled by burglar lock of entrance door or pre-set timer) control. The fan can be turned off.
- lowered ventilation at night in living room, manual or automatic (pre-set timer) control
- relative humidity controlled ventilation in bathroom i.e. preventing lowered ventilation if high humidity level and no one at home.

Ventilation of common areas

- demand controlled ventilation of common areas like stairwell, bicycle storeroom, apartment storerooms, laundry room, technical rooms or central air-to-air heat recovery from exhaust air to supply air (to some of the common rooms)

Space heating apartments

- supply air to bedrooms pre-heated by supply air radiator
- bedrooms heated by radiator
- supply air to living room pre-heated to 18 °C by special convector with back draft damper
- living room heated by radiator and convector
- indoor temperature 19 °C – 23 °C
- the radiators are controlled as a function of outdoor and indoor temperature (thermostat)

EXPECTED PERFORMANCE

The performance of the supply convector, the fan and the control system have been thoroughly tested in a laboratory and proven to fulfil the performance specifications. However the characteristics and the built-in control of the fan should be further improved. CFD-simulations of the risk of draught from the supply convector shows a considerably lower risk than from traditional outdoor air inlets. A four-storey apartment building with the developed ventilation system has been simulated by the work package on calculations and performance predictions. The main goal has been to determine the influence, on infiltration, exfiltration, and air flows and spread of pollutants between apartments, of wind and stack effect coupled with fan operation (hybrid ventilation) for different air airtightness levels, control strategies and ventilation rates. Other goals have been to determine the energy use for heating and use of electricity for ventilation, as well as the indoor air quality. A comparison with a reference system will be made. Preliminary results from the predictions are promising.

The expected energy savings have been estimated by hand calculations to be 50% of the ventilation heat losses for an apartment with an floor area of 80 m^2 (see table 1). Savings which are not accounted for above are: individual metering, fan electricity, indoor temperature compensation of forward temperature. The specific fan power has been determined to be 0.2 kW/(m^3/s).

TABLE 1
Ventilation heat loss energy savings, for an apartment, thanks to demand controlled hybrid ventilation.

Measure	KWh/year
1. Basic adjustment according to number of persons saves on average 9 l/s. Varies with family size from 0 – 18 l/s. 8 h/day.	1 200
2. Night position (-20%) saves on average 4,2 l/s during 8 h , raises the air quality in the bedrooms	180
3. No one at home position (8 l/s during 8 h)	560
Total	1940

The expected energy savings will have a straight payback of 8 years (see table 2).

TABLE 2
Estimation of yearly energy savings, MWh for an existing apartment building.

Total measured for 72 apartments	890
of which domestic hot water	201
Savings thanks to demand control	140
Individual metering of space heating 10 %	55
Space heating control 10 %	49
Individual metering of domestic hot water 15 %	30
Total savings	274
Total savings per apartment	3.8
Payback assuming 1750 Euro additional cost and 0.06 Euro/kWh	8 years

The main demands and expectations of the customers (apartment building owners/developers) as regards ventilation systems are: low sound and draft level, good controllability, reliability, robust, aesthetic and easy to maintain and clean (Blomsterberg 2004). Noise and draught are common sources of complaints from occupants. The hybrid ventilation system being developed aims to meet these demands and expectations, and to be energy efficient.

The prototype system is designed to be more reliable, more user-friendly, better in operation and service than the existing ventilation systems. The overall performance is expected to be better. The ventilation system will be quieter than mechanical ventilation systems.

SUMMARY AND DISCUSSION

A prototype demand controlled hybrid ventilation system for cold climates has been designed, with low pressures drops and one constant volume air flow EC fan for each apartment. According to laboratory tests the main individual components fulfil the performance specifications. There is however potential for improving the characteristics and built-in regulation of the fan. The system will result in a similar level of energy use for space heating as for a system with balanced ventilation with traditional heat recovery, but lower use of electricity, more user-friendly and improved indoor air quality. The system incorporates individual metering of energy use, ventilation and indoor temperature to motivate the users to economize on energy. The main market is new construction of apartment buildings, but could also be retrofitting of existing dwellings (Blomsterberg 2004). The estimated investment cost of the ventilation system is lower than traditional balanced ventilation with heat recovery, but higher than exhaust fan only without heat recovery. Ideally a LCC analysis should be applied.

The next planned step, which is beyond the scope of Reshyvent, is a full-scale demonstration project in a real building. Useful results are expected from an ongoing demonstration project on demand controlled exhaust fan ventilation in 25 new apartments (Blomsterberg 2002).

REFERENCES

Andersson, K., Norlén, U., 1993. The indoor climate of the housing stock. ELIB-rapport 7, TN:30, The Swedish institute for building research, in Swedish.

Blomsterberg, Å., Carlsson, T., 1995. Air or radiator heating? Questionnaire and measuring survey of indoor climate and ventilation in modern one-family houses. SP rapport 1995:25, Swedish National Testing and Research Institute, in Swedish.

Blomsterberg, Å., et al, 2002. Technical Procurement of Demand Controlled Ventilation for Dwellings – Based on Performance Specifications. EPIC2002AIVC conference, Lyon, France.

Blomsterberg, Å., et al, 2004. Reshyvent WP2 Market survey. To be published January 2005.

Engvall, K., 1992. Perceived indoor climate in the housing stock of Stockholm. Utredningsrapport 1992:4, The office of investigation and statistics of Stockholm, in Swedish.

Gaunt, L., 1985. Occupants habits and energy. Meddelande M85:14, The Swedish institute for building research, in Swedish.

Månsson, L.-G., 1992. Demand Controlled Ventilating Systems – Source Book. IEA Annex 18, Swedish Council for building research, D2:1993.

Månsson, L.-G.,1998. Compulsory Ventilation Check – Technical Defects and Percentage Approved Ventilation Systems in Dwellings and Premises (in Swedish). Swedish National Board of Housing, Building and Planning, Karlskrona, Sweden.

Sandberg, E., Isaksson, H., 1994. Efficient ventilation saves on electricity. Swedish council for building research, T11:1994, in Swedish.

RESHYVENT
Hybrid Demand Controlled Ventilation System

Mild/Moderate Climate (IC3)

M. Jardinier, S. Berthin

Aereco S.A., 9 allée du Clos des Charmes, Collégien
F - 77615 MARNE LA VALLEE Cedex 3

ABSTRACT

The purpose of this system is to provide one improved ventilation system allowing significant good indoor air quality, heating (and cooling) energy savings and acceptable thermal comfort on summer, by using especially renewable energy.

This concept is based on sensors measuring relative humidity in bathroom and kitchen, occupancy in bedrooms and toilet, and agitation (i.e. the number of people) in the living room.

Driving forces are as much as possible natural ones (thermal stack effect, and wind induction), assisted with a photovoltaic supplied "roof cowl fan" whose speed is adapted to only compensate natural stack effect deficiency in the hotter times.

According to total ventilation forces evaluation, motorised inlets and extract grilles are driven in order to ensure suitable air renewal in each room, in correlation with need measurements.

In case of very hot times, a "night cooling" mode consist in an "over-ventilation" (maximum fan assistance) and in the opening of motorised windows, during summer nights, when outdoor temperature is colder than indoor.

KEYWORDS

Hybrid ventilation, presence & humidity control, communication, night cooling, renewals, strategy, motorised inlets/outlets, photovoltaic, experiments

CONCEPT FROM EU SAVE PHOTOVENT PROJECT

In 1999, a first collaboration between Aereco (French designer and manufacturer of modulated ventilation systems), Renson (Belgium market leader for natural ventilation) and the Belgium Building Research Institute has already led to the development of one improved controlled ventilation system, in the frame of the PHOTOVENT European project.

This system has been installed and tested in a "real" test house.

As shown next page (Figure 5), it was composed with :

- **Motorised Inlets :** they are placed in the "dry rooms". A motorised mechanism allows to open these inlets at wanted areas, so that airflows can be controlled in these rooms. They are PV supplied thanks to photovoltaic cells on their façade (plus one battery).

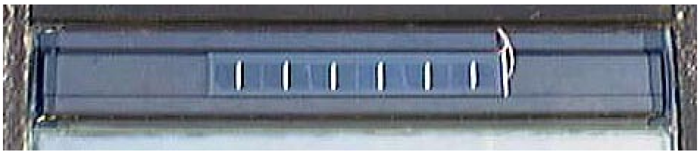


Figure 1 : PhotoVent PV inlet

- **Motorised extract grilles :** they are placed in the "wet rooms", where airflows can also be controlled. The energy supplying is ensured by non rechargeable batteries whose life time was close to two years.

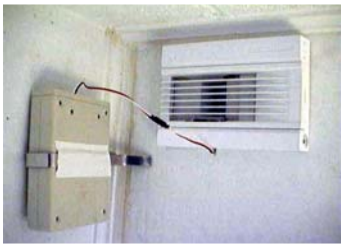


Figure 2 : PhotoVent Extract Grille

- **Presence sensors :** installed in the bedrooms and in the toilet, they tell the system whether these rooms are occupied or not. Non rechargeable batteries also ensure energy supplying.

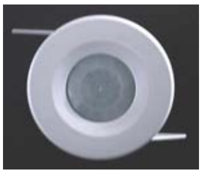


Figure 3 : PhotoVent Presence (or Agitation Sensor)

- **Agitation sensor :** this detector counts the number of movements in the living room, and consequently provides information about the number of people in this room.

- **Humidity sensors :** they measure relative humidity in the kitchen and in the bathroom.

Figure 4 : PhotoVent Humidity Sensor

This full mechanical sensor only required non rechargeable batteries for data communication.

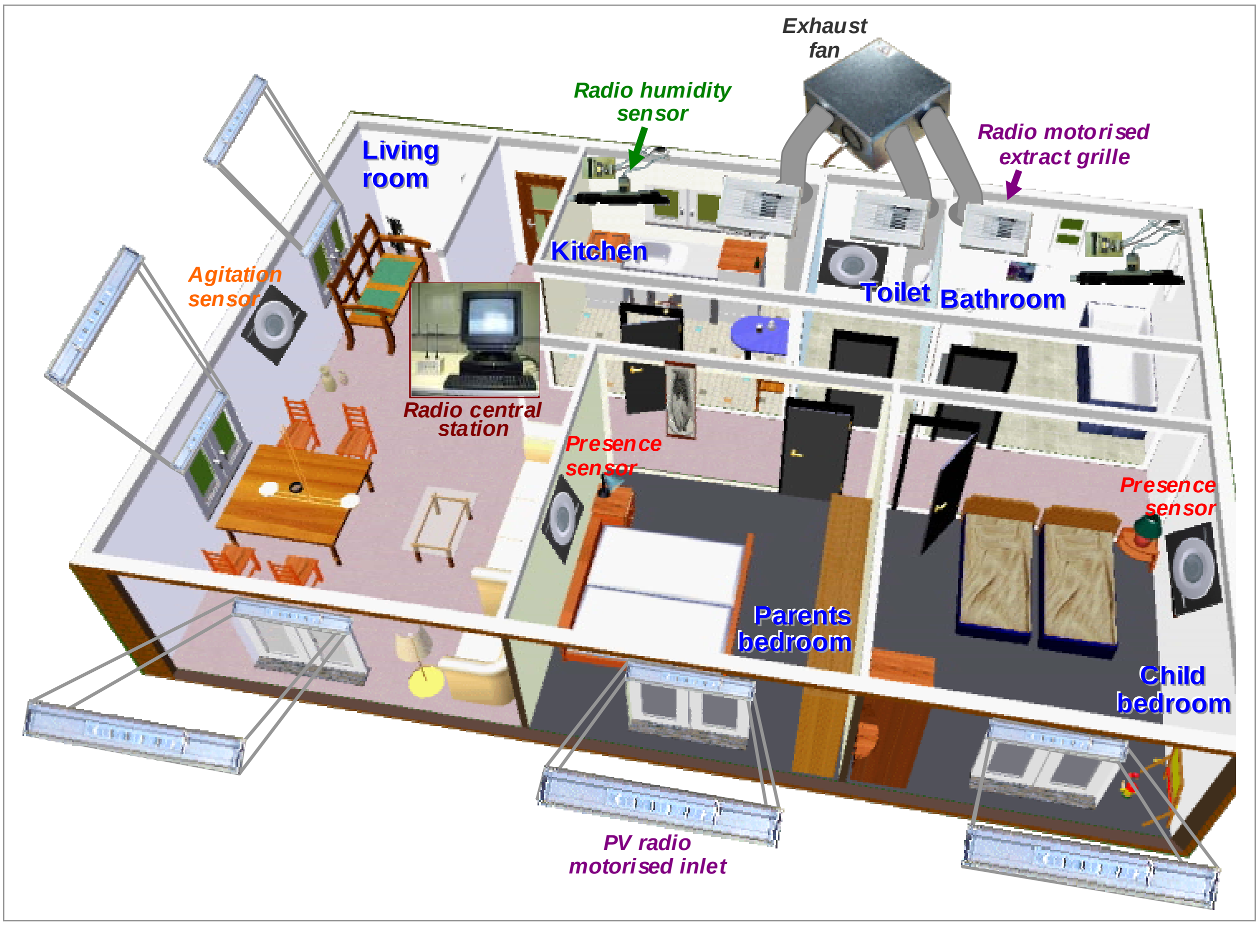


Figure 5 : Mechanical PhotoVent System

Ventilation force is ensured by **Mechanical Exhaust**. Since inlets are sized for natural air supplying, this system is based on the "C Belgium configuration".

A "Central Station" (PC / software) has been developed to apply one simple strategy.

Figure 6 : Central Station

Sensors measurements are sent to the Station every 5 minutes. According to the needs evaluated in every rooms, individual air renewal are calculated and balanced, so that "entering" airflows should be the same than "extracted" ones.
Then, every 15 minutes Inlets and Extracted grilles are driven to reach a suitable opening areas that allow individual expected airflows.
Opening areas calculations are very simple : given the mechanical exhaust, an almost constant 100 Pa depression is ensured by the fan ; since a 10 Pa depression is wanted inside the dwelling, it is easy to calculate both inlets and extract grille opening, to ensure each individual airflows.

(Low energy) communication between inlets/grilles/sensors and the Station was realised with 433 MHz **Radio Transmitters and Recievers**.

Figure 7 : Transmission/Reception Module

For several months, the system has been installed and tested in the BBRI Test House. Airflows have been measured in each room – thanks to gas tracer facilities – and the comparison with the calculated expected airflows (Figure 9) showed very impressive correlation, in spite of the air leakage and the crossing flows – due to wind – from one façade to another.

Figure 8 : BBRI Test House

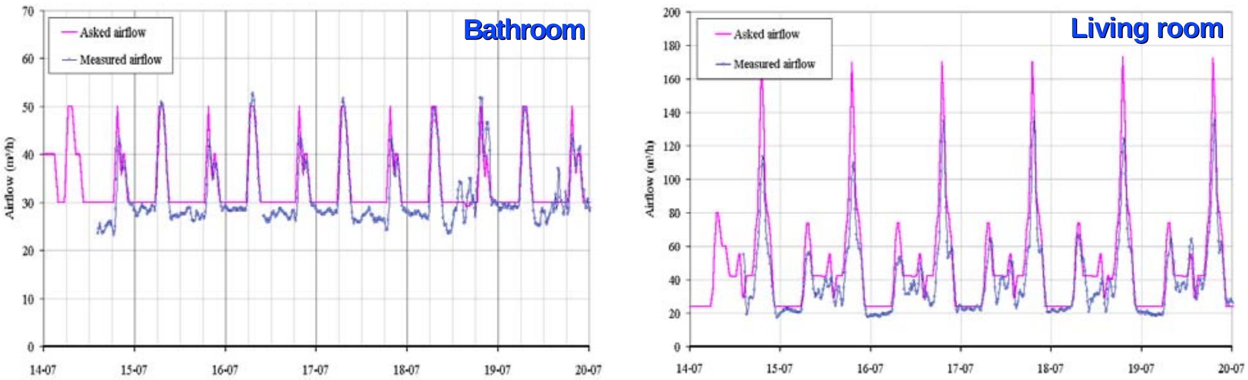


Figure 9 : Airflow measurements results

RESHYVENT PROJECT : HYBRID VENTILATION CONCEPT

Based on demand controlled ventilation, the PhotoVent concept allowed both air quality improvements and heating energy savings on winter (by the limitation of "cold entering" airflows at just useful levels).
One step further in **rational energy** using was to "optimise" natural ventilation – which is known as working correctly in cold times – and then use a mechanical assistance only when necessary.
The challenge was to develop a very low energy assistance, so that the *"unavoidable"* fan could be supplied with photovoltaic. Consequently, a Full Natural Modulated Ventilation working correctly all the year becomes possible.
Moreover, given the now importance of thermal comfort on summer, the use of a "boosted" assistance fan on night – associated to larger ventilation openings – allows to realise efficient Night Cooling, an alternative to cooling systems which require many energy.

DEVELOPMENT OF A HYBRID VENTILATION FAN

A fan fulfilling the objectives of the ReshyVent concept has been developed and improved during the first year of the project.

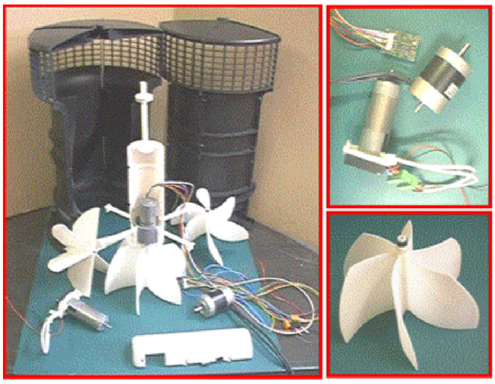


Figure 10 : Fan developments

Figure 11 : Installation on a building

The main characteristics of the fan are the following ones :

- Generation of very ***low depression*** (5~15 Pa), similar to level met in classical natural ventilation. The depression level can be adjusted in order to reach an "optimised" assistance, and to limit energy over expenditure.

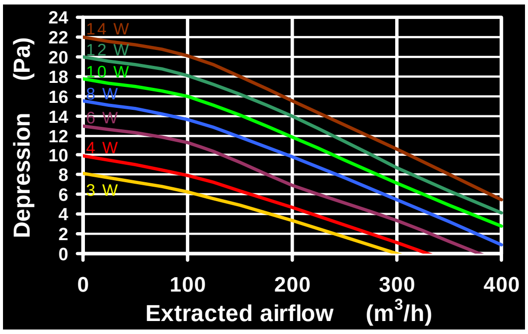


Figure 12 : Fan performance

- When natural ventilation alone is sufficient enough, the fan can be switch off. Since it is connected in the extraction part of the ventilation net, it must not brake the exhaust flow. This is why, when ***off***, the fan has a *very* ***low pressure drop*** (coefficient ξ***=0,9***).

- As shown Figure 11, the fan is installed as a traditional roof cowl. Therefore, the effect of the ***wind*** on the roof can be exploited to improve ventilation efficiency.

Many wind tunnel tests have been led to ensure good depression, even for significant extracted flows.

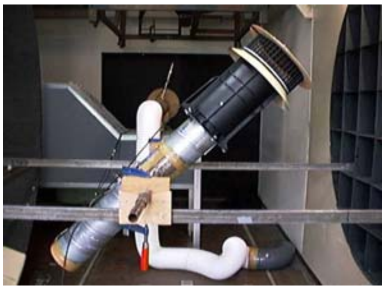


Figure 13 : Wind Tunnel Tests

- As shown Figure 12, ***very low energy power*** is required to run the fan (2 watt per dwelling on average), at low voltage (~12 Volt). Hence, ***photovoltaic*** supplying is quite suitable.

DEVELOPMENT OF IMPROVED COMPONENTS

Given the PhotoVent system was a concept prototype, industrialised components (i.e. "low costs" for the market) had to be developed and improved from the PhotoVent experience.

As shown Figure 14, most of ReshyVent components are similar to the PhotoVent ones, except Indoor and Outdoor temperature sensors, necessary for ReshyVent strategy appliance.

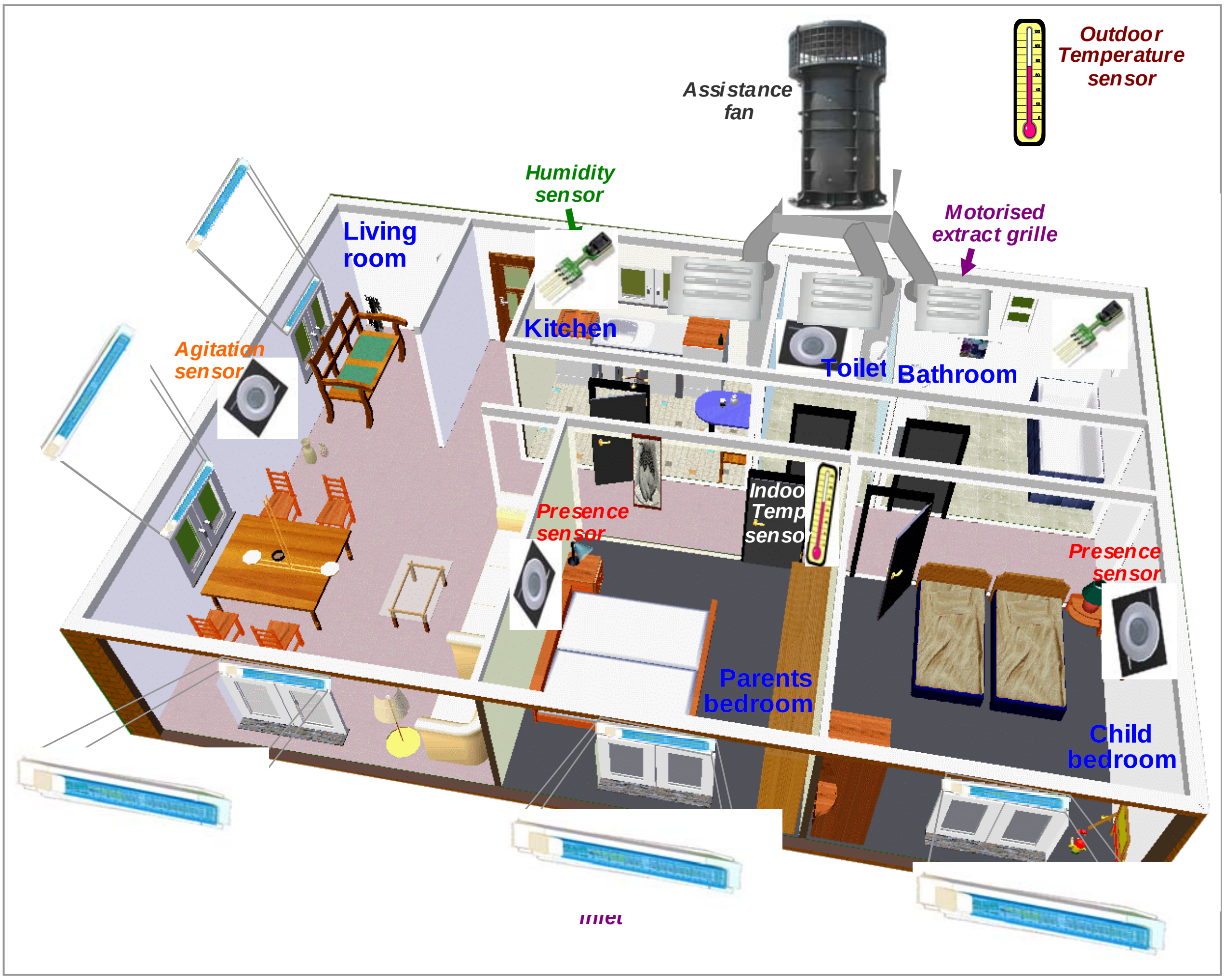


Figure 14 : Hybrid ReshyVent System

- **Motorised Inlets :** according to the (Belgium) market evolution, two types of standard natural inlets manufactured by Renson have been motorised, using a low cost stepper motor technology.

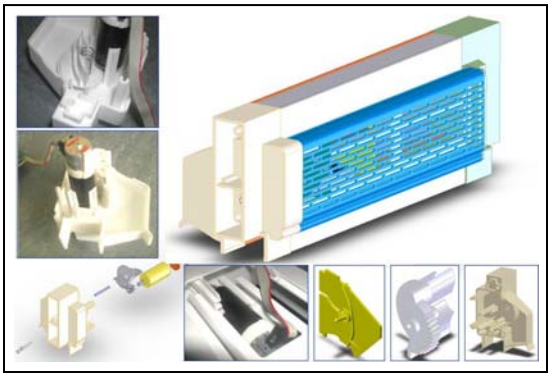


Figure 15 : THR-90 Inlet based

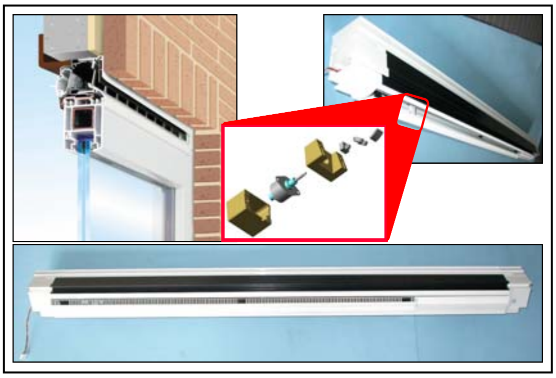


Figure 16 : INVISIVENT Inlet based

Eight accurate opening areas can be reached, from 0 cm² to 80 cm².

- **Motorised extract grilles :** as for inlets, extract grilles are standard Aereco natural grilles, motorised with low cost stepper motor. Eight accurate positions (from 10 cm² to 100 cm²) can also be reached.

Figure 17 : Motorised Extract Grille

- **Presence / Agitation sensors :** they are standard Aereco detectors, very reliable and low cost.

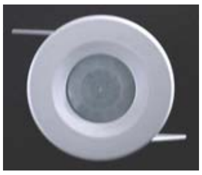


Figure 18 : ReshyVent Presence (or Agitation Sensor)

- **Temperature / Humidity sensors :** given the last technological evolutions of especially humidity sensors, "reliable and cheap enough" electronic sensors have been chosen.

COMMUNICATION DEVELOPMENTS

From the PhotoVent experience, radio communication between every system components seemed quite feasible. Radio modules that where expensive five years ago are now cheap enough, and energy consumption has significantly decreased. Except distance or transmission issues, the main problem is the presence of a "constant" interference sources (more powerful).

Focusing on a system more dedicated to new dwellings than to retrofitting – where cable installation is not a real barrier – very reliable wired solution has been developed (

Figure 19).

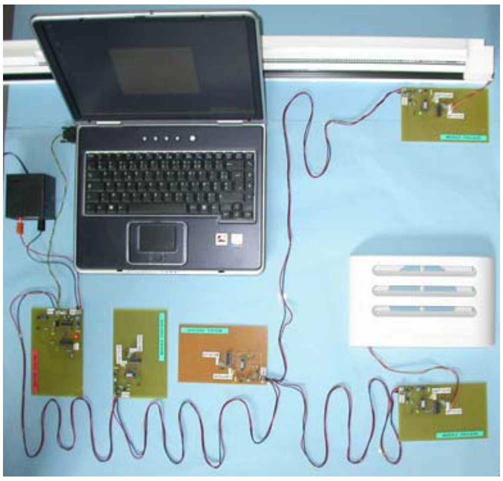


Figure 19 : Wired communication development

The developed solution is very simple for installation, since ***only two wires*** allow both energy supplying (low voltage) and data transmission for every components : the idea is to simply *"connect a black wire on the black connector of the component, and a red wire on the red connector"*. Inlets, grilles, sensors can consequently be linked in whatever order.

SYSTEM STRATEGY

An "improved" strategy had to be developed to make the system compensate natural forces deficiencies :

1. ***Determination of each individual airflow :*** given the need ("pollution level") measured in each room by sensors, first suitable airflows (for efficient air renewal) are calculated. In order to balance the total flow (global entering airflow has to be equal to global extracted airflow), some individual flows are increased.

   Then a total required flow is determined

   (**Ex. Figure 20 :** 160 m^3/h).

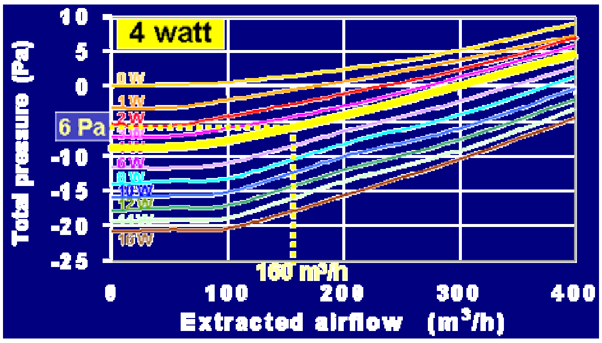


Figure 20 : Assistance calculation

2. ***Calculation of "optimum" assistance :*** according to Indoor and Outdoor temperature measurements, the natural thermal stack effect is evaluated. Then, if necessary, the fan is run to reach a ventilation depression level sufficient to ensure the expected airflows. (**Ex. Figure 20 :** fan power at 4 watt).

3. ***Calculation of extract grilles openings :*** knowing the total extracted flow and the running power of the fan (and the pressure drop level of the exhaust net), depression available at the extract grilles can be determined (**Ex. Figure 20 :** 6 Pa).
   Since a ***3 Pa depression*** is expected in the dwelling, grilles openings calculations (for kitchen, bathroom, toilet) can be done to reach the expected airflows (Figure 21).

4. ***Calculation of inlets openings :*** given that a 3 Pa depression is expected in the dwelling, inlets openings calculations (for bedrooms, living rooms) can also be done.

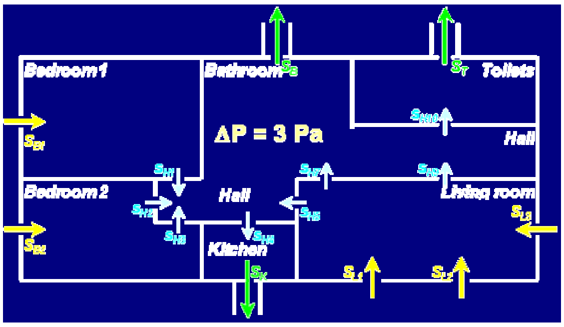
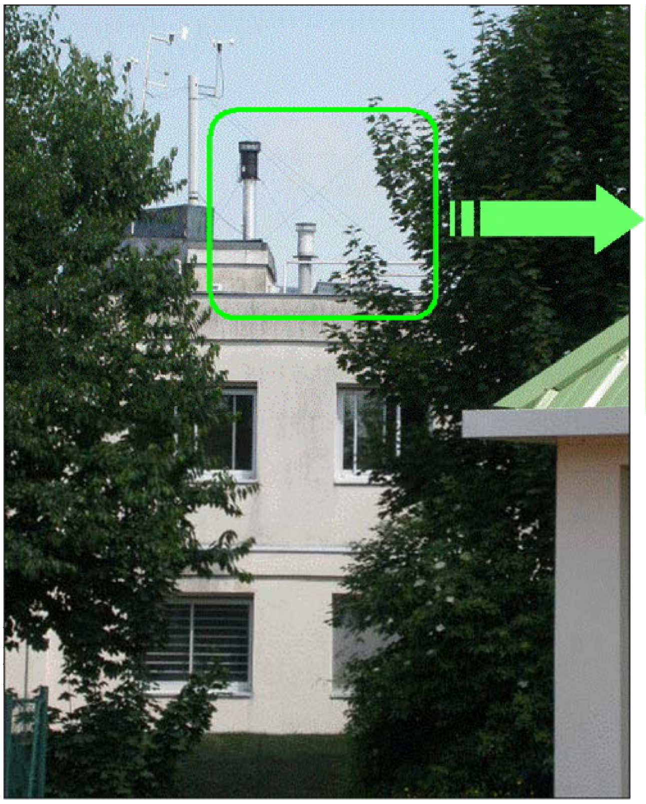


Figure 21 : Grilles opening calculation

5. ***Night cooling launching :*** based on a basic thermal model for dwellings, simplified criteria based on instantaneous indoor and outdoor temperatures, and also on outdoor average temperature on the last 24 hours, have been found to start "Night Cooling" on hotter times : the fan is run at its maximum speed (16 watt), inlets and grilles are fully opened, and motorized windows can also be opened.

CONCLUSIONS : WAITING FOR FIRST EXPERIMENTS RESULTS

Rough simulation showed that differences lower than ±15% from the "ideal" airflows had to be expected.
In order to test especially the system strategy reliability, the impact of outdoor conditions, and the solar supplying sizing, one experiment has just been launched in July 2004, in a Aereco building, close to Paris in France.



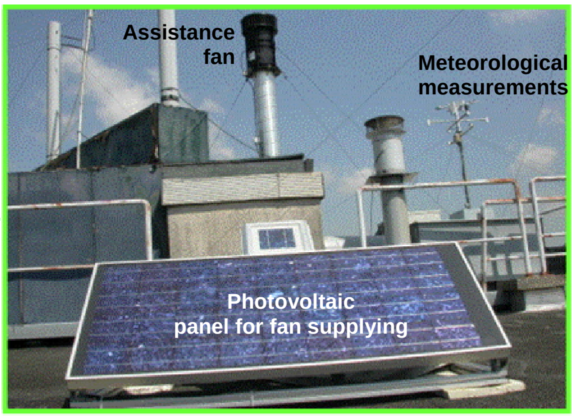


Figure 24 : system installation for experiment

INTRODUCTION TO INTEGRATION OF RENEWABLE ENERGY IN DEMAND CONTROLLED HYBRID VENTILATION SYSTEMS FOR RESIDENTIAL BUILDINGS

S. Antvorskov

Esbensen Consulting Engineers, Sukkertoppen Copenhagen,
Carl Jacobensens Vej 25 D, DK-2500 Valby, Denmark

ABSTRACT

In the scope of the EU supported project RESHYVENT, the possible integration of Renewable Energy Solutions (RES) into hybrid ventilation systems has been analysed. The focus has been on solar and wind applications to substitute the use of fossil fuel. The feasibility of the investigated options depends on the ventilation concept the RES is integrated into, the location of the building geographically, placement of the RES in the building and on the urban environment. This paper describes the different renewable technologies, options and constrains in connection with integration into hybrid ventilation systems.

KEYWORDS

Renewable energy integration, Solar, Wind, Urban environment restrains, Requirements to hybrid ventilation components.

INTRODUCTION

The RESHYVENT project (RESidential buildings HYbrid VENTilation) is a research project within the Fifth Framework Programme of the European Commission, which started in January 2002 and continues until December 2004. The aim of the RESHYVENT project is to research, develop, and construct demand controlled hybrid ventilation concepts for residential buildings with optimal use of renewable energies.

THE TRIAS ENERGETICA APPROACH

When integrating renewables in a hybrid ventilation system it is recommended that the Trias Energetica approach is followed. The trias energetica approach is a method to ensure that the use of conventional and renewable energy is optimised as much as possible. The method includes three steps: First the energy demand from the components is minimised as much as possible, secondly the energy demand is supplied by renewable energy and third the remaining energy demand, if any, is supplied by conventional energy sources (fossil fuels).

This means that before supplying the hybrid system with renewable energy, the energy demand of the system and individual components i.e. the fan, actuators, controls and sensors must be optimised and brought to the lowest possible level. When this is done, the evaluation and design of renewable energy options can be carried out. If it is not possible to fully supply the system with renewable energy, then conventional energy may be used. S. Antvorskov (2004)

POSSIBILITIES FOR RENEWABLE ENERGY FOR HYBRID VENTILATION SYSTEMS

For use and integration into a hybrid ventilation system six (6) general concepts have been identified on the basis of previous research work carried out in the framework of IEA and EU. The systems are the following:

- Photovoltaics (facade and roof integrated)
- Solar wall and solar air collector
- Glazed balcony
- Solar Chimney
- Wind turbine
- Wind cowl

Under the right circumstances and in the right combination these concepts can meet the demands of support energy in a hybrid ventilation system. However, in most cases it is realistic that only part of the system is supplied by renewable energy. Figure 1 shows the possible placements of the different renewable technologies.

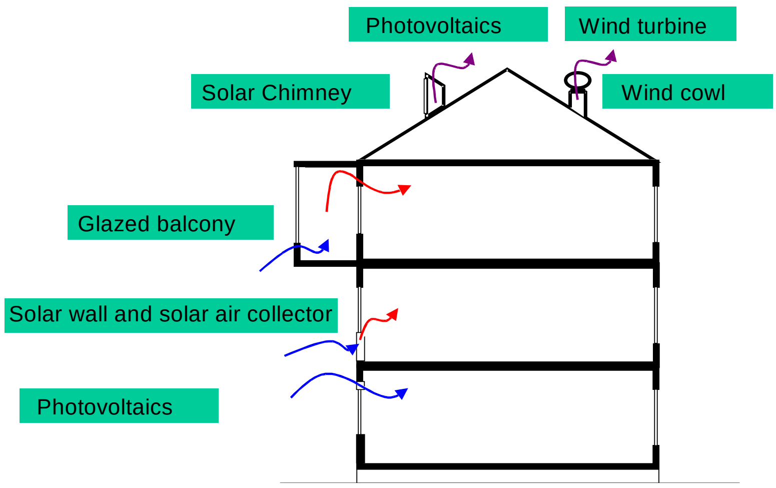


Figure 1: Concepts and placements of renewable energy solutions for hybrid ventilation systems.

INTEGRATION AND USE OF SOLAR ENERGY

Stand alone Photovoltaic Systems (PV systems)

A photovoltaic cell is a semiconductor device that produces electricity from photons (sunlight). A stand-alone PV system, suitable for use in a hybrid ventilation system, consists of a PV panel, an inverter and a battery. The battery is used as an energy storage for periods with low or no solar radiation, no other energy source is therefore needed. In combination with wireless control, all wiring to and from the different PV supplied components can be omitted, this makes the stand-alone PV solution very attractive especially in retrofit situations.

It is very difficult to generalise the required PV area and battery size for the different components in a hybrid system as this entirely depends on the energy use of the component, geographic location and placement in the building. A careful review of each component's energy consumption profile is required to establish the feasibility of economic and practical PV use. The parameters which need to be considered are illustrated in table 1.

TABLE 1
Design parameters for dimensioning and calculation of feasibility for a PV system

Main Item	**Sub Issues**	**Example**
Geography	Latitude	50° North (Brussels)
	Longitude	5° East
	Orientation	195° - 15° from south
	Tilt angle	90° - Vertical
Load profile	Input voltage range	6-12 Volt DC
	Power needed	2-6 Watts
	Time of consumption	6 Hours
	Period of consumption	Daily, summer and winter
	Consumption pattern	6-9 AM, 1-4 PM
Shadowing	Shadows occur	Yes / No
	Time of shadowing	Winter between 8-12 AM
Available area	PV	L_{max} = 900 mm, L_{min} = 400 mm
	Battery	H_{max} = 100 mm, L_{min} = 20 mm, W_{max} = 25 mm
	Control device	H_{max} = 100 mm, L_{min} = 80 mm, W_{max} = 50 mm
Wiring	Distance between battery and consumption	2 m
	Distance between PV location and battery	0,5 m
	Distance between PV location and controller	0,5 m
Weather Conditions	Average ambient temperature	Summer +22°C, Winter 2°C
	High / Low ambient temperature	-25°C to +42°C
	IP class needed for battery	IP 23
	IP class needed for controller	IP 65
Feasibility	Cost of kWh	0,13 Euro / kWh
	Price to power the component (AC transformer, cabling and installation cost, battery cost)	14 Euro
	Electrical maintenance cost	5 Euro per year
Integration	Possibility to integrate PV	Yes, front of inlet – 0,36 m^2
	Possibility to integrate battery	Yes, inside inlet – 20 cm^3
	Possibility to integrate controller	No
	Design requirements	"Black PV module look"

Under certain favourable conditions (low energy consumption and high solar gain) at least some components may be supplied with electricity through PV systems. Actuators are normally fit for supply by PV, as they have small energy demands and are close to the exterior. Probably most inlets can be supplied by rather small PV module and batteries. Fans have a larger energy use, and therefore need larger PV modules and a battery bank. However, fans are generally placed near the exterior, on the roof and there are usually more space available for mounting the PV.

The general design criteria for application of PV is a free horizon. This requirement may then exclude application of PV panels on facades in dense build environments as comprehensive shading on the facades typically will occur. PV operates best when facing south and with optimum tilt angle (mainly equal to latitude). S. Antvorskov (2004).

Solar Thermal Systems

There are different options for using solar thermal energy in a hybrid ventilation system. Glazed balconies, sunspaces, solar walls and solar air collectors can all be used.

Glazed balconies and sunspace are in principle the same technology. It consist of a glazed space located in front of the main building. The fresh ventilation air enters the closed space and is passively pre-heated by the sun and partly by transmission losses from the building. When designing a glazed balcony or sunspace it is important that the glazed elements are operable in order to prevent overheating in summer.

The advantages of using a glazed balcony or sunspace in connection with a hybrid ventilation system are:

- Passive use of solar energy to preheat the ventilation air,
- Reduction of transmission and ventilation losses,

Some of the more critical aspects are:

- Risk for overheating in summer,
- The high dependency of different user behaviour on the energy savings,
- Risk of condensation of moisture from the apartment on glazed elements

The price of a glazed balcony or sunspace depends on the building type, the size of the area that has to be glazed and specific features i.e. type of glass, frame etc. In general, a glazed balcony or sunspace is not cost-effective if it is considered only as a means to save energy and reduce maintenance. The additional added values connected to the integration must also be evaluated, such as: Increase in living space area, shorter heating season, reduction of outside noise and reduction in renovation cost. C. Boonstra et al (1997) (a) and (b).

A solar wall and solar air collector can also be used to preheat the ventilation air in a hybrid ventilation system. However, this is usually an active system where a fan is used to drive the air through the wall or collector, the energy to this fan can however easily come from a PV module (no battery backup are needed). S. Antvorskov (2004)

In a typical solar air system, fresh air is drawn across a heat absorbing south-facing wall or other sort of solar collector. The pre-heated air is then drawn into the building's primary heating system where it is further heated, then distributed throughout the building. J. Dalenbäck (1997).

Generally, the performance of a solar air system is in the range 50-250kWh/m^2 collector area in Nordic climates. The cost effectiveness is not possible to generalise as it is very dependant on the system, building and local climate. It must be noted that there are other benefits in addition to energy cost savings that can be gained by applying a solar system, e.g. environmental aspects and improved thermal comfort. C. Boonstra et al (1997) (b).

INTEGRATION AND USE OF WIND ENERGY

Wind Cowls

The expression wind cowls covers a large range of wind augmentation techniques, which are able to improve driving forces, eliminate dependency of wind directions and stabilise the air flow. Wind cowls are normally placed on the roof, to take advantage of the higher wind speeds, which are normally present on roofs. They are suited for natural ventilation systems as they can provide an extra driving force for the ventilation. In addition they can be used to avoid down draught in chimneys and exhaust outlets. Many different designs of wind cowls are on the market. Their efficiency is to date not very well documented. Test conducted over a two-year period by J.Orbesen show that the wind cowl produced by Nova-air shows quite good efficiencies with extraction rates ranging from 265 m^3/h to 2300 m^3/h depending on wind speed, air temperature and duct size, however tests conducted in the EU project Photo-Vent showed that the efficiency of the wind cowls was close to zero i.e. the wind cowls did not have any real effect compared to normal wind huts. S. Antvorskov (2004)

Small wind Turbines

Small wind turbines transform the kinetic energy in the wind to electricity or mechanical energy. They can be placed on rooftops, where the wind speed is normally higher than on street level. Some turbines can be placed in the middle of the roof to take advantage of the horizontal wind speeds and some are to be placed near the edge, to utilise the vertical wind speed. It is recommended to use a vertical axed wind turbine for integration in the build environment as this form is independent of the wind direction, and works efficiently in all horizontal wind directions. On rooftops the wind directions vary much and can change very quickly. A wide range of small-scale wind turbines are available on the market today, but is it still a market which it is under development. As is the case for the other RES, it is not possible to generalise the cost-effectiveness of a small scale wind turbine, as the energy production depends on a range of local factors, e.g. the speed and direction of the wind and the ventilation systems demand for electricity. S. Antvorskov (2004)

CONSTRAINTS OF THE URBAN ENVIRONMENT

The facades and roofs of buildings must be given special attention when integrating renewable energy into a hybrid ventilation system, the buildings' exposures to sun and wind often determine weather a system is feasible or not.

The dimensions and orientation of urban canyons vary greatly in the urban environment. As a result the sun/shade conditions vary equally much. Solar renewables are effected by shade from adjacent buildings and trees, it is therefore important to analyse the sun/shade conditions in each specific case before setting up a solar renewable technology.

PV systems are very sensitive to shadow. If only a small fraction of the PV panel is shaded the output of the entire string of panels will decrease drastically. Therefore, it is essential that shading of the panels is kept to an absolute minimum. If the panels are placed in an urban canyon, they should be mounted as high as possible to ensure that shade from other buildings is minimised as much as possible. This is especially important if the panels are facing east or west because the sun is at a low angle when rising in the east and setting in the west. If the panels are facing south it is easier to avoid shadow from other buildings because the sun is at a high angle over the horizon in the middle of the day, when the sun is to the south. It is not recommended that the panels are mounted facing north.

The wind conditions in the urban environment is greatly influenced by the layout of the buildings in the area, wind canyon effects can be created which is favourable or not favourable for applications of wind cowls or wind turbines. Therefore, the micro wind climate must be analysed for each individual case.

RECOMMENDATIONS FOR USE OF RENEWABLE ENERGY FOR DIFFERENT CLIMATE ZONES

When integrating renewables in a hybrid ventilation system it is recommended that the Trias Energetica approach is followed. This method ensures that the use of conventional and renewable energy is optimised as much as possible. Following this, dynamic computer simulations should be used to dimension and evaluate the RES in detail. A rough overview of the characteristics, urban constraints and recommendations for the use of the different renewable applications are shown in table 2.

TABLE 2
Overview of the different solar energy technologies, the constrains and recommendations

Concept	Description	Constraints	Recommendations
Photovoltaics	Auxiliary energy for operation of fans and controls in a hybrid ventilation system	Very sensitive to shadows and shelter in canyons	Recommended in open courtyards, at free exposed facades facing south or at roofs. Especially fit for supplying actuators in inlet grills. Can be applied in both warm and cold climates.
Glazed balconies	Existing or new balconies glazed for increase of the living area. Reduction of noise and for preheating of inlet air	Shadows, and building configuration	Recommended in retrofit situations for multifamily buildings. Mostly applicable for cold climates.
Solar walls	Existing or new facades with glazing to improve the insulation level and for preheating of inlet air	Shadows	Recommended in open courtyards or at free exposed facades. Mostly applicable for cold climates.
Wind cowls	Increase of wind induced flows in extracts	No technical constraints	Recommended at roofs. Can be applied in both warm and cold climates.
Wind turbines	Auxiliary electricity for fans and controls in the ventilation system	No technical constraints	Recommended at roofs, possible in connection with a PV module, creating a stand-alone hybrid solar and wind system. Can be applied in both warm and cold climates.

More detailed information on the integration possibilities for RES into hybrid ventilation systems is described in S. Antvorskov (2004), this document will be available at the end of the RESHYVENT project.

REFERENCES

- J. Dalenbäck (1997) Solar collectors in renovation projects. IEA, SHC programme task 20. James and James
- C. Boonstra, I. Thijssen (1997) (a) Solar Energy in Building Renovation. IEA, SHC programme task 20. James and James
- C. Boonstra, I. Thijssen and R. Vollebregt. (1997) (b) Glazed Balconies in Building Renovation. IEA, SHC programme task 20. James and James
- S. Antvorskov, (2004). General information on renewable applications for auxiliary energy - suitable for use in hybrid ventilation systems. EU project RESHYVENT, workpackage 3, deliverable 3.1.
- S. Robert Hastings and Ove Mørck, 2000 . Solar air systems – A Design Hand book. (James and James).

DESIGN PARAMETERS FOR THE PERFORMANCE ASSESSMENT OF HYBRID RESIDENTIAL VENTILATION SYSTEMS

Viktor Dorer and Andreas Weber

EMPA, Swiss Federal Laboratories for Materials Testing and Research
Energy Systems and Building Equipment Laboratory
CH-8600 Duebendorf, Switzerland

ABSTRACT

This paper summarizes the work within the EU RESHYVENT project in regard to design parameters for the performance assessment of hybrid ventilation systems. A framework for performance assessment based on simulation was developed. Performance criteria were defined for air flows, indoor air quality, thermal comfort, acoustics, energy, and emissions. These criteria were adapted to the time dependant performance of hybrid systems and were applied in the performance assessment of the systems developed within the project, together with a reference set of design constraints (boundary conditions) and building parameters. Probabilistic methods were evaluated and are proposed to account for uncertainties in the input parameters.

KEYWORDS

Hybrid ventilation, performance criteria, design parameter, probabilistic approach

INTRODUCTION

The assessment of the ventilation system is one aspect in a holistic building performance assessment task. In the frame of the EC Energy Performance of Buildings Directive (EPD) there are a number of standardisation activities in CEN, EOTA, and supporting projects. The aim is to achieve harmonized European assessment methods for various performances, including the assessment of (innovative) ventilation systems. While standardisation deals with calculation procedures, legislation sets the requirements, and handles the practical implementation.

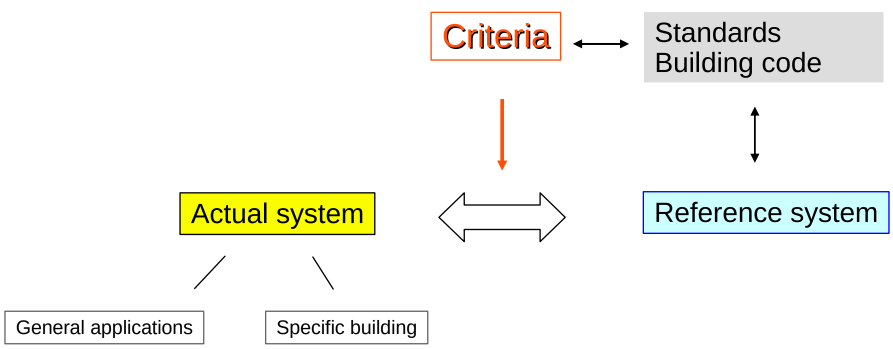


Figure 1: The Principle of Equivalence, applied to an innovative system by comparing the performance of the actual system with a reference system which is covered by the applicable standards and buildings codes

However, the assessment of systems with time dependant performance, like building automation, glazing, advanced cooling systems (tabs), adaptive materials and also hybrid ventilation, remains to be specified (Wouters 2000). In such cases, the Principle of Equivalence may be applied (Van der Aa 2002), comparing the system under consideration with a reference case which is covered by existing standards and regulation (figure 1).

DESIGN PARAMETER

Design parameters as used for the performance assessment can be differentiated into performance criteria and target values, design constraints (boundary conditions, assumptions), and building and ventilation system design variables (figure 2). Parameters can be defined on building, system and component level.

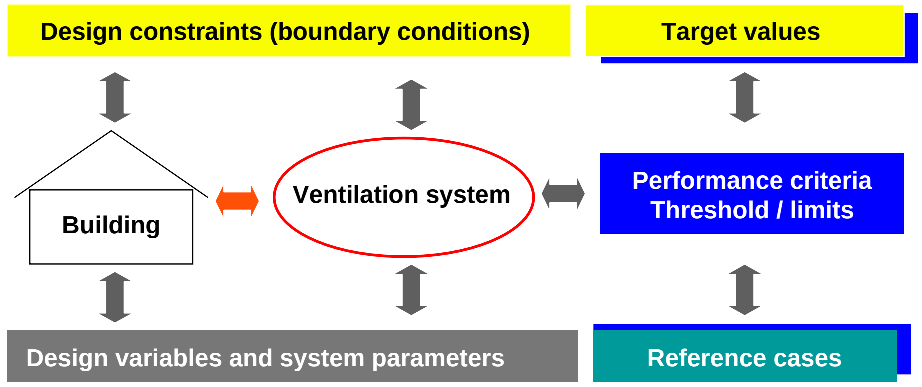


Figure 2: Design parameters for the performance assessment of ventilation systems

PERFORMANCE ASSESSMENT WITHIN RESHYVENT

Within the RESHYVENT project, a framework for performance assessment was proposed (Wouters 2004). This proposal is based on work performed in earlier projects such as IEA HYBVENT (Heiselberg 2002) and EU ENPER-TEBUC (ENPER 2003).

The performance assessment of the systems developed within the RESHYVENT project was based on dynamic thermal building and ventilation simulation using TRNSYS (TRNSYS 2000) and COMIS (COMIS 2001), or TRNFLOW (COMIS integrated into the TRNSYS building type) (Weber 2003).

For this performance assessment task, a comprehensive set of criteria and target values in regard to energy and indoor environment (indoor air quality, thermal comfort and acoustics) was defined (Dorer 2004).

The most relevant parameters were adapted to this simulation approach. Other criteria could not be assessed by building simulation, but were measured or qualitatively assessed by the industrial consortia.

PERFORMANCE ASSESSMENT CRITERIA

Performance assessment of systems with time dependant performance

For hybrid ventilation, it is obvious that any performance assessment has to be made over a certain time interval. Therefore, limits and required values outlined e.g. for steady state conditions are considered as thresholds, and the real performance criterion is whether these limits are exceeded, and for how much time.

The structure and the approach selected within RESHYVENT are outlined in the following example for the CO_2 concentration, as one of the parameters used for the characterisation of the indoor air quality. The performance is assessed transforming concentrations exceeding the threshold into an integral value (figure 3). The assessment can be room related or occupant related (dosis) (table1).

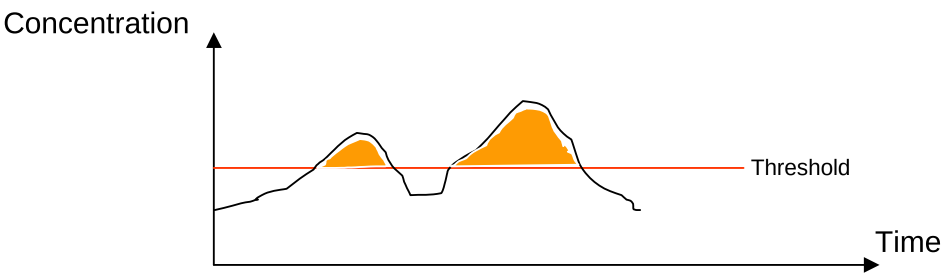


Figure 3: Performance in terms of concentrations is assessed by an integral value for the threshold exceeding

TABLE 1
Threshold and target values for the CO_2 concentration performance criteria

Threshold / limit:	700 ppm above outdoor level
Performance parameter: a) No of hours with concentrations above threshold value b) Hours times concentration exceeding (room related) c) Concentration exceeding exposure (occupant related)	 200 h 200 kppm.h 100 kppm.h

Performance criteria for air flows and air distribution

Direct outdoor air flow rates (habitable rooms) and exhaust air flow rates (wet rooms and kitchen) and the respective air flow stability are the key criteria. Pressure differences room – facade or room – ground are relevant for buildings with room placed stoves or gas appliances, and for buildings with risk of radon ingress.
Air exchange efficiencies can only be determined by CFD or by measurements for a specific point in time, but hardly for a prolonged period of time.

Performance criteria for indoor air quality

The parameters considered were: CO_2 concentrations (see above), low humidity (dryness feeling) and high room air humidity (risk of mould and house dust mite growth, condensation risk). The first two criteria are occupant related criteria. Pollutant spread from cooking, passive smoking and emissions from building and furniture materials may also be considered, but was not within RESHYVENT.

Performance criteria for thermal comfort

For thermal comfort evaluations, the steady state requirements set out in ISO (ISO 7730) and CEN (CR 1752) documents were adapted, considering values below and above the temperature or PPD limit values. The targets are expressed in terms of Kelvin-hours. Studies on adaptive thermal comfort show that thermal comfort may be dependant on elements such as expectations of the occupant in relation to how the indoor environment is established (naturally ventilated or air conditioned building), or adaptation of occupant to climate (Olesen 2002).

Draught risk can be evaluated by CFD simulation, but only for a specific configuration in terms of surface and air temperatures, and thus not over a prolonged time period.

Performance criteria for acoustic performance

As for other criteria, the acoustic indoor environment is a result of influences such as sound emitting sources, sound transport and respective attenuation measures, and outdoor noise levels.

Target values for ventilation systems are to be set in relation to the acoustic quality of the building, i.e. poor acoustic quality of ventilation systems in dwellings with high acoustic quality of partitions are to be avoided. Most important is the sound pressure level in the room, and the related system parameters are the sound power level of the ventilation system and the outdoor noise reduction capabilities of outdoor air transfer devices.

In multifamily buildings, sound attenuation between individual apartments is of great relevance. The ventilation system, especially ducts, may play an important role in sound transmission.

Performance criteria for energy and environmental impact

Criteria for energy are heat use of the building (heating power and heat demand), energy use for space cooling of the building (cooling demand), ventilation heat loss, electricity demand of the ventilation system, heat recovery performance factor and factor of renewable energy supply (mainly by system integrated photovoltaic panels).

DESIGN CONSTRAINTS

For the application of the Principle of Equivalence, the selection of the constraints is very crucial, as this selection must not lead to unjustified favouring or discrimination of a specific system under investigation. Some parameters may also be associated with high uncertainties.

For the performance assessment of the four systems developed within the RESHYVENT project, a set of reference or standard cases has been defined. Most of the design constraints were specifically related to the systems developed in this project, but reference was also made to the results of IEA A27 (Millet 2002, Månsson 2002), especially in regard to occupancy, occupant behaviour and indoor pollutant sources. In addition, procedures for the definition of probability distributions of the following parameters were proposed: Wind pressure coefficients, building envelope leakage distribution, occupancy, window opening behaviour.

INPUT DATA UNCERTAINTIES AND PROBABILISTIC METHODS

Especially in an early design stage of a building, many input data can be specified only within a certain bandwidth and/or with certain confidence levels. The effect of these uncertainties in the input on the resulting output must be considered.

Several methods can be applied: With the factorial design method, effects of the individual input parameters can be evaluated. The factorial design consists of choosing the simulation points at the edge of the multi-dimensional domain defined by the input parameter ranges. The simulation results are fitted to an appropriate polynomial function corresponding to a Taylor series of the analyzed model. For more information on the application of these methods, see results of the IEA Annex 23 (Fürbringer 1995 and 1999).

The effect of uncertainties in the input on the resulting output can also be determined by probabilistic methods, as e.g. the Monte-Carlo technique (Rubinstein1981), where for each simulation run random values for the input parameters (according to the probability distribution) are used and a probability distribution profile for each of the output parameters is determined (figure 4).

Probabilistic methods may be especially applied for the evaluation of the influence of design constraints which have a high degree of randomness. This applies e.g. to occupancy and occupant related release of moisture and other pollutants, or to wind pressures (Heijmans 2002). However, to get realistic results, correlations with time dependent parameter (e.g. outdoor temperature) and inter-correlations between the probability distributions of the individual parameters (e.g. the individual wind pressure coefficient values) must be considered.

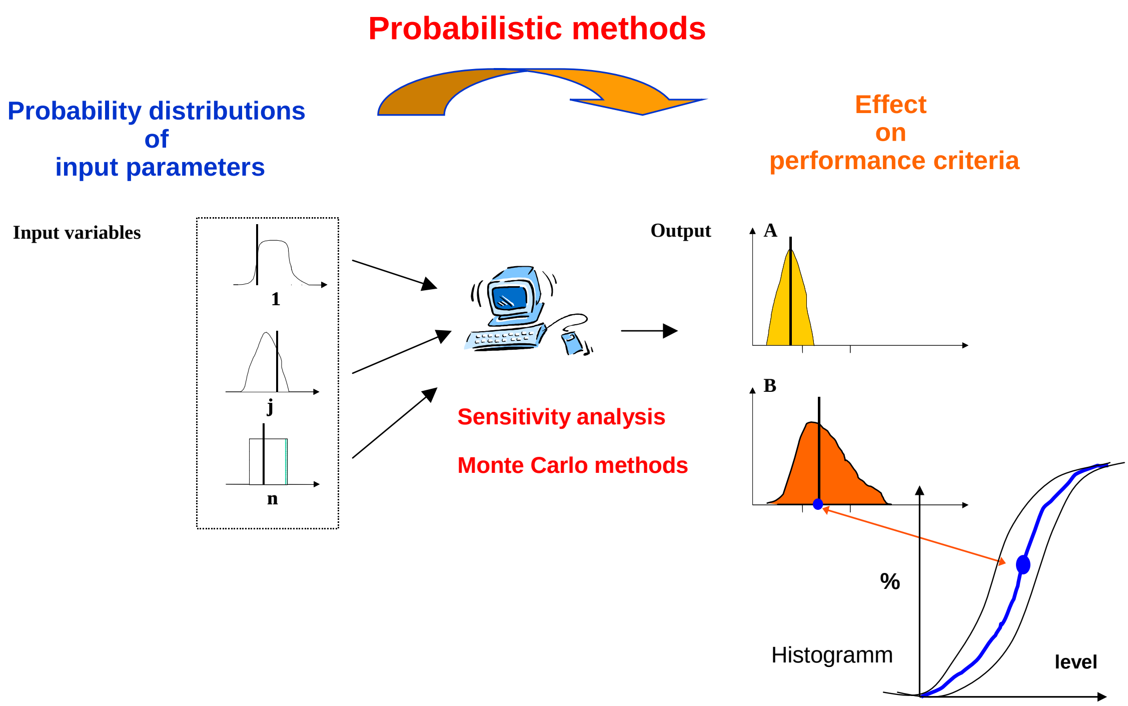


Figure 4: Probabilistic performance assessment approach based on Monte-Carlo techniques, with probability distributions for certain input parameters and for the result parameters

ACKNOWLEDEMENTS

This project is partially funded by the Swiss Federal Office for Education and Science (contract 01.0046, based on the EU contract ENK6-CT2001-00533 RESHYVENT).

REFERENCES

CR 1752 (1998). CEN Report 1752. Ventilation for building – Design criteria for the indoor environment.

COMIS (2001). COMIS 3.1 . Program for modelling of multizone airflow and pollutant transport in buildings. EMPA Dübendorf

Dorer V., Weber A. (2004). Parameter for the performance assessment of hybrid ventilation systems - Performance criteria, target levels and design constraints. RESHYVENT Report WP5, to be published on the RESHYVENT CD.

ENPER (2003). Report B2 Energy Performance of Buildings - Assessment of innovative technologies. See www.enper.org

Fürbringer J.M., Roulet C.A. (1995). Comparison and combination of factorial and Monte-Carlo designs in sensitivity analysis. Building and Environment 30 No 4 pp 505-519

Fürbringer J.M., Roulet C.A. (1999). Confidence of simulation results: put a sensitivity analysis module in your model. The IEA-ECBCS Annex 23 experience of model evaluation. Energy and Buildings 30 (1999) pp 61–71.

Heijmans N.; Wouters P. (2002). Impact of uncertainty of wind pressures on the prediction of thermal comfort performances. Technical report of IEA Annex 35 HybVent. BBRI.

Heiselberg P. (ed.) (2002). Principles of Hybrid Ventilation. Aalborg, Aalborg University, Hybrid Ventilation Centre, ISSN 1395-7953 R0207

ISO 7730 (1994). Moderate thermal environments -- Determination of the PMV and PPD indices and specification of the conditions for thermal comfort.

Månsson, L.-G.(ed.) (2002). IEA ECBCS Annex 27 Handbook. FaberMaunsell Ltd.

Millet J.-R. et al. (2002). IEA Annex 27 Evaluation and Demonstration of Domestic Ventilation Systems. Volume 2. Indoor Air Quality. CSTB ENEA/CVA-02.015R.

Olesen, B. W., Parsons, K. C. (2002). Introduction to thermal comfort standards and to the proposed new version of EN ISO 7730. Energy and Buildings. 34 No 6 pp 537-548

Rubinstein, R.Y. (1981). Simulation and the Monte-Carlo Method. Wiley, New York

TRNSYS (2000). TRNSYS 15, Transient System Simulation Program, Solar Energy Laboratory (SEL). University of Wisconsin Madison, USA

Van der Aa A., Opt'Veld P. (2002). Assessment of energy performance targets in standards and regulations. Proceedings of the EPIC Conference, Lyon 2002

Weber, A., et. al. (2003) TRNFLOW, a new tool for the modelling of heat, air and pollutant transport in buildings within TRNSYS. In: Building Simulation 2003, Proceedings of the IBPSA Conference. Eindhoven, August 2003.

Wouters P. (2000). Quality in relation to indoor climate and energy efficiency – An analysis of trends, achievements and remaining challenges. PhD thesis. Université Catholique de Louvain. Belgium.

Wouters, P., Heijmans, N., de Gids, W., Van der Aa, A., Guarracino, G.; Aggerholm, S. (2002). IEA Annex 35 WP A2 Source book - Performance assessment of advanced ventilation systems in the framework of energy and IAQ regulations: Critical issues, challenges and recommendations.

Wouters P., Heijmans N., Loncour X.: (2004) Proposal for a framework for a methodology for the assessment of innovative ventilation systems. BBRI. RESHYVENT report.

VENTILATION SYSTEMS WITH LONGITUDINAL COUNTERFLOW SPIRAL RECUPERATORS

M. Adamski

Department of Heat Engineering, Technical University
15-351 Białystok, Poland

ABSTRACT

This paper presents ventilation systems with longitudinal counterflow spiral recuperators. Heat transfer losses in ventilation system can be reduced by increasing the length of the recuperator, but in this case pressure drops increase. These two losses determine exploitation costs.
Taking into consideration the results of measurements and calculations the costs for capital expenditure and exploitation of ventilation systems are minimized.

KEYWORDS

ventilation system, counterflow spiral recuperator

LONGITUDINAL COUNTERFLOW SPIRAL RECUPERATORS

Counterflow ventilation heat exchangers are the most important parts of energy recovery systems, see Figure 1. The ventilating central stations with heat recovery consist of:

- diaphragmatic heat exchanger,
- two ventilators,
- two filters,
- electric switching-board and controller.

Apart from the standard equipment the central station can include:

- air heater
- by-pass (one or two, open in summer)
- sprinkling chambers and humidifiers,
- noise silencers,
- cooling.

The special plate design makes the spiral recuperators a preferable choice for many applications. The plates are usually made of raw or epoxy coated aluminium. The fact that the exchangers are fully produced of aluminium makes them withstand winter conditions, which ensures a longer life time.
Spiral-tube heat exchanger is made of metal sheets which are wound with constant distance between subsequent windings, see Figures 2 and 3. Owing to their advantages, spiral recuperators with the longitudinal countercurrent flow should be widely utilized for ventilation heat recuperation. In comparison with cross-flow heat exchangers, they obtain greater efficiency ε for the same value of the parameter Ntu. Furthermore, spiral recuperators have also more uniform thermal field in each transverse sections of the air stream. As a result, they are more resistant to outdropping of moisture from the air-cooled stream and the effect of

frosting practically does not occur. In order to drain condensed water vapour effectively it is beneficial that they should be installed almost horizontally or vertically so that the condensate flows to the waste pipe. The recovery of ventilation heat in highly efficient recuperator is always accompanied by outdropping of water vapour, which must be drained in the most reliable way to the sewage system.

Use:
- industrial institutions and halls,
- buildings of public utilities (banks, offices, show rooms, cinemas, etc.),
- single-family and multi-family buildings,
- halls and sports buildings: swimming-pools, water parks,
- schools, universities, laboratories, hospitals and clinics,
- shops, market-halls, supermarkets, restaurants, hotels, banqueting halls, discos.

Free choice of installation place: cellar, attic, boiler room, outside building, etc.

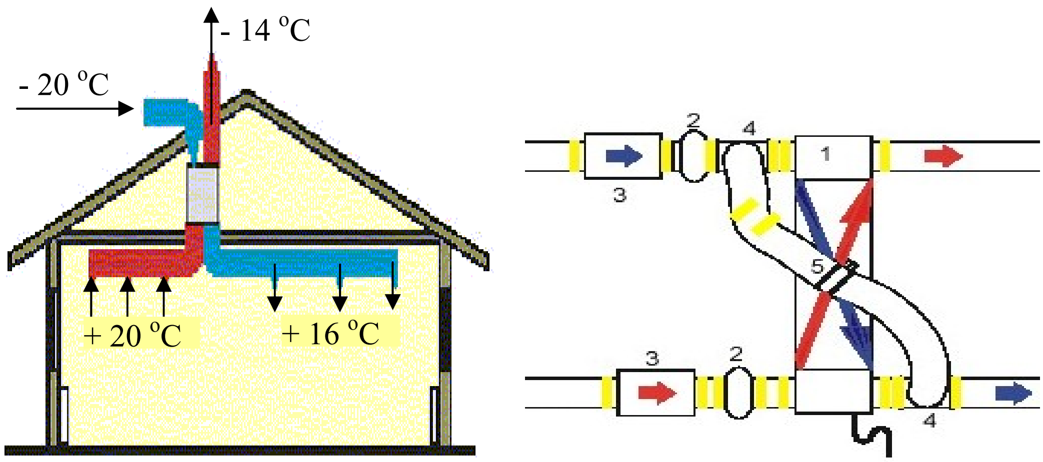


Figure 1: Examples of a heat recovery system, 1 - longitudinal spiral recuperator, 2 – ventilator, 3 – air filter, 4-5-4 – by-pass (open in summer), 5 - valve

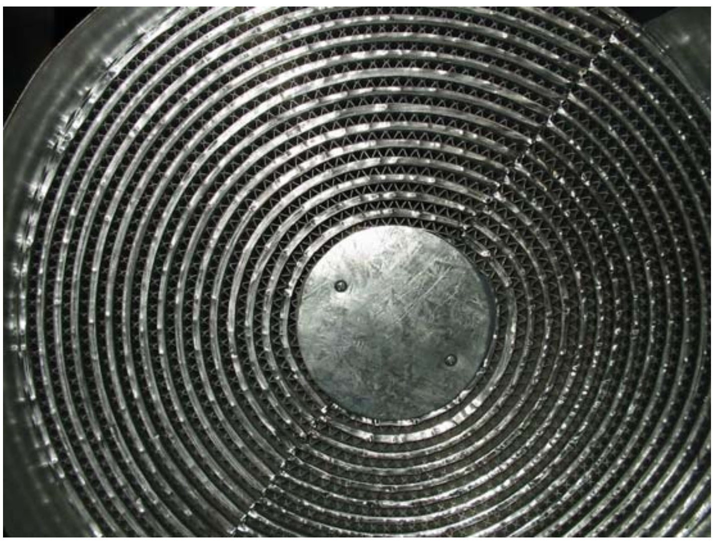


Figure 2: Inlet and outlet side of the longitudinal counterflow spiral type recuperator

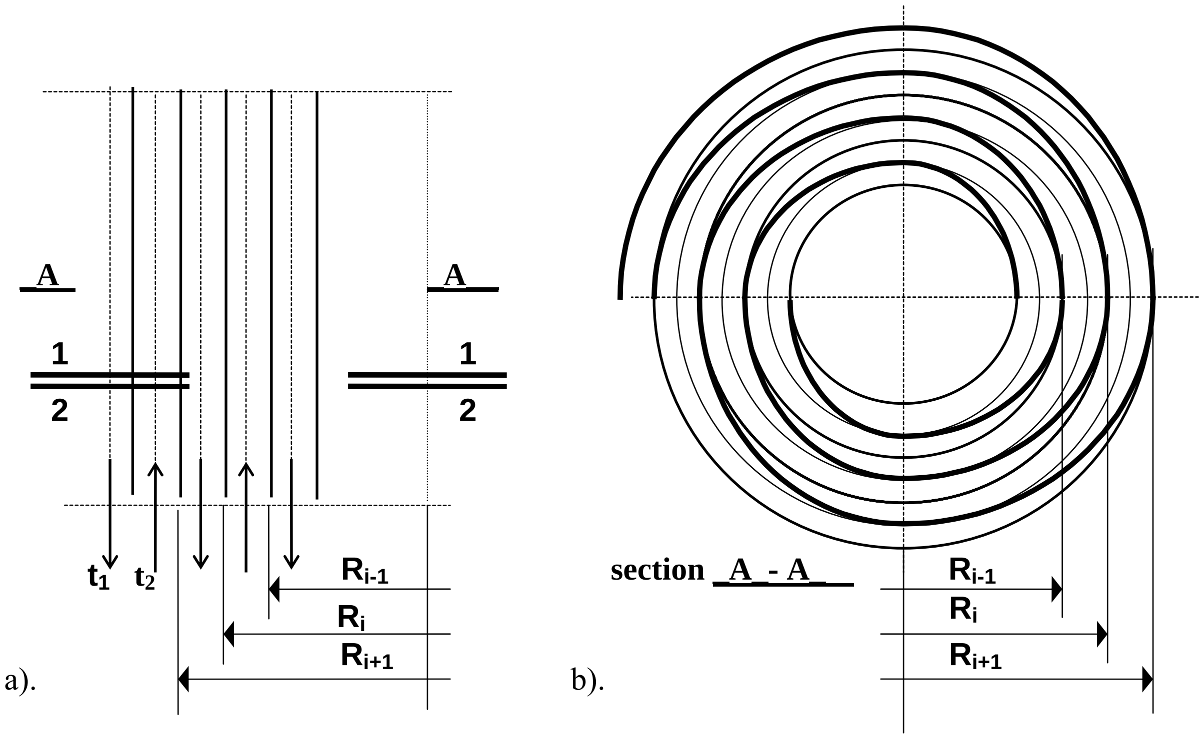


Figure 3: Longitudinal counterflow spiral type recuperator
a) longitudinal section, b) cross- section

FORMULATION OF THE OPTIMIZATION PROBLEM

The optimum length L_{opt} of the spiral recuperator could be determined using two opposite criteria [1, 2]:

- minimum heat transfer losses:

$$\dot{Q}_{outflow}(L) = \dot{Q}_{\max} - \dot{Q} = (1 - \varepsilon(L))\dot{Q}_{\max}$$

- minimum pressure drops in the channels $\Delta H_{1,2} = a_{1,2} v^n$, which induced energy losses:

$$\dot{E}_{1,2}(L) = A_C v \Delta H_{1,2} = a_{1,2} A_C v^{1+n} L\,.$$

Let's define general function as

$$N(L) = \frac{\dot{Q}_{outflow}(L) + \varphi\left(\dot{E}_1(L) + \dot{E}_2(L)\right)}{\dot{Q}_{\max}},$$

where

$$\varphi = \frac{K_R + K_{W1} + K_{W2} + 24 N_D \dfrac{c_e}{\eta}\left(\dot{E}_1 + \dot{E}_2\right)}{24 N_D c_c\left(\dot{E}_1 + \dot{E}_2\right)}$$

for minimum of the construction and exploitation costs of the recuperator.

Taking into consideration the heat exchanger effectiveness:

$$\varepsilon(L)=\frac{NTU(L)}{NTU(L)+1}\text{, where } NTU(L)=\frac{UA(L)}{C}=\frac{4U}{D_H v\rho c}L\text{,}$$

we obtain the general function:

$$N(L)=\frac{1}{\frac{4U}{D_H v\rho c}L+1}+\varphi\frac{(a_1+a_2)A_C v^{1+n}L}{c\rho(T_{1,i}-T_{2,i})}=N_{\Delta T}(L)+\varphi N_{\Delta p}(L)$$

where a_1, a_2, n, U – are determined experimentally [3].

SOLUTION OF THE OPTIMIZATION PROBLEM

The general function $N(L)$ reaches its extreme value, if an equation $\frac{\partial N(l)}{\partial l}=0$ is satisfied, hence the optimum length of recuperator is

$$L_{opt}=\left(\sqrt{\frac{D_H(T_{1i}-T_{2i})}{4A_C U\varphi(a_1+a_2)v^n}}-\frac{D_H v}{4U}\right)\rho c$$

and:

$$N_{\min}=N(L_{opt})=1-\left(\left(\frac{A_C D_H\varphi(a_1+a_2)v^{2+n}}{4U(T_{1i}-T_{2i})}\right)^{0,5}-1\right)^2$$

Model exchangers are calculated, see Figure 4.

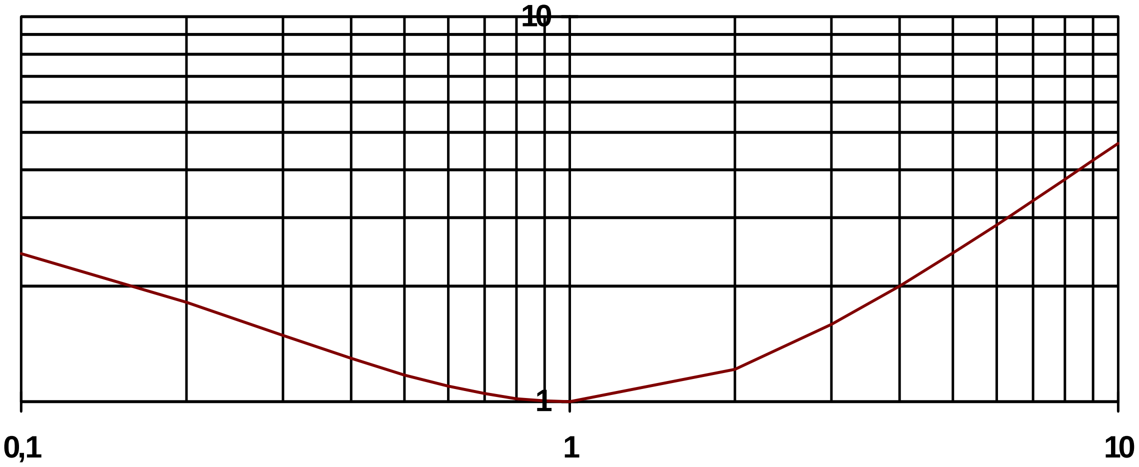


Fig. 4. Relative variation of the investment and exploitation costs N(L)/N(L_{opt}) as the function of dimensionless length of the recuperator L/L_{opt}.

The produced exchangers have the constant length, optimum flow velocities are used which the optimum diameter of recuperator D corresponds to for defined volumetric flow rate, see Figure 5.

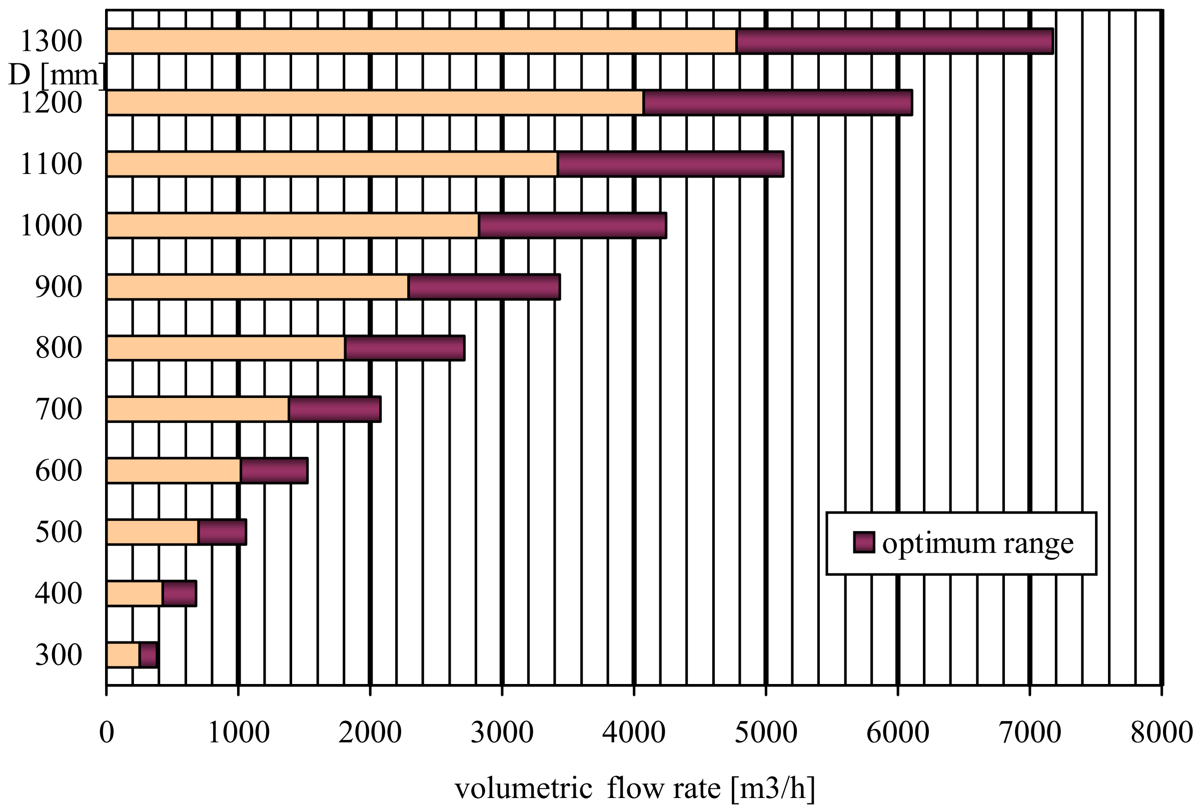


Figure 5: The optimum outside diameter of the spiral recuperator in relation to volumetric air flow rate

CONCLUSIONS

The aim of the heat recovery ventilation is to provide fresh air in the way in which the thermal comfort as well as energy saving are maintained, using a recuperator with the heat recovery from the removed air. In particular, heat recovery should be used in offices, gastronomic institutions, industrial institutions.

Taking into consideration the results of measurements and calculations the costs for capital expenditure and exploitation of ventilation systems with longitudinal counterflow spiral recuperators are minimized.

Ventilation system with spiral recuperators refunds the capital expenditure within one or two years' time.

NOMENCLATURE

A – heat transfer area, m^2,

A_C – area of duct cross – sectional, m^2,

c – specific heat at constant pressure, J/(kg K),

$C = mc = \rho A_C v c$ - capacity flow rate, W/K,

c_c, c_e – unit cost of heat energy, of electrical energy, respectively, zł/Wh,
D, L – diameter, length of exchanger, respectively, m,
D_H – hydraulic diameter of channel, m,
K – cost, zł,
N_D – number of exploitation days
T – temperature, °C,
U – overall heat transfer coefficient, W/(m^2 K),
$V = A_C v$ -volumetric flow rate, m^3/s,

Greek symbols

ρ – mean density of fluid in duct, kg/m^3,
v – velocity, m/s,
ΔH – pressure drop, Pa,

Subscripts

min, opt - minimum, optimum,
R, W– exchanger, ventilator,
1, 2 – cooled, heated air,
i, o – inlet, outlet,

REFERENCES

[1] Adamski M. (2002). Optimization of counterflow plate type ventilation heat exchangers, *IX Międzynarodowe Sympozjum: „Wymiana Ciepła i Odnawialne Źródła Energii”*,
[2] Adamski M. (2002). Obliczenia oraz optymalizacja spiralnych rekuperatorów o wzdłużnym przepływie przeciwprądowym, *X International Conference: Air Conditioning, Protection & District Heating,* pp. 17–22.
[3] Bujwicki, Sobiech, Cybulko (2001). Ekologiczne systemy wetylacji i klimatyzacji z odzyskiem ciepla, Firma Bartosz, Białystok.
[4] www.bartosz.com.pl

HIGH ACCURACY MANOMETER FOR IN-SITU MEASUREMENTS

Siret, F. and Jardinier, M.

Aereco S.A., 9 allée du Clos des Charmes, Collégien
F - 77615 MARNE LA VALLEE Cedex 3

ABSTRACT

Our commitment to improve both air quality and energy savings in existing dwellings involves scope measurements campaigns. Constraints linked to the use of measurements material in these conditions, the keeping of their reliability all project long and their costs prompted industry to develop special devices for this kind of application. It is the case of this high accuracy manometer required for the wide demonstration project called HR-VENT (Nangis – France). This monitoring carried out during almost 2 years aims in particular at characterizing the running of a hybrid ventilation system in place of an existing passive stack ventilation system. All in all, more than 160 manometers are installed to measure pressure differences near extract units and gas appliances. Small pressure differences, such as those measured in passive stack ventilation and the required accuracy lead Aereco to design a powerful device with a reasonable cost.

KEYWORDS

Manometer, high accuracy, measurements, pressure, passive stack ventilation, hybrid ventilation, HR-VENT

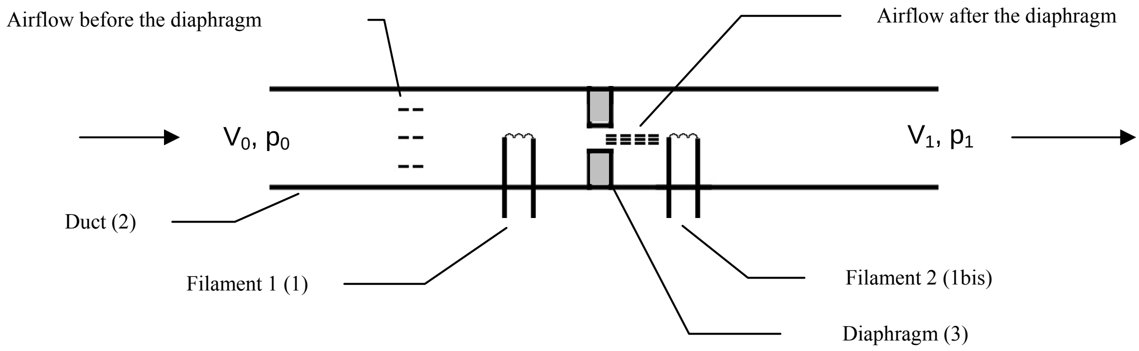
INNOVATIVE PRINCIPLES

Currently, there are a lot of manometers able to measure an absolute pressure or a pressure difference with a high accuracy. However these devices are often very complex and expensive.

Moreover, the hot-wire technology used by this manometer is well known; but usually, to measure air flow speed. It consists of an electrically heated, fine metal wire which is immersed into the airflow; the cooling effect on the wire electrode causing its electrical resistance to change. However, this technology requires frequent calibrations to maintain a high accuracy, especially at low pressures.

Specially designed to run into low pressure ranges (commonly met in passive stack and hybrid ventilation), this manometer aims at releasing these drawbacks.

Next scheme illustrates the theoretical principle of this manometer.



Component and process	Function
Duct (2)	Connection of the volumes V_0 and V_1
Diaphragm (3)	Canalization and acceleration of the airflow
Voltage Measurements of the 2 filaments at 1 mA	Fixing of the zero point to control drift over time
Voltage Measurements of the 2 filaments at 32 mA	Determination of the flow direction and the pressure difference between the volumes V_0 and V_1

Figure 1 : theoretical principle

DESIGN ASPECTS

Concretely, this high accuracy manometer measures the low pressure difference between two air volumes divided by a diaphragm setting out in a duct. When crossed by an airflow, the duct is then subjected to very different fields of speeds here and there of its extremities.

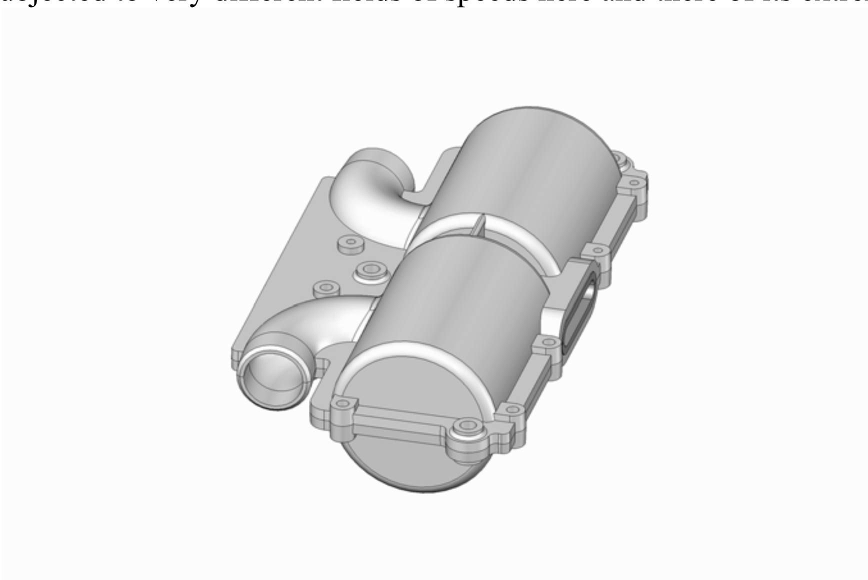


Figure 2 : Enclosure box of the manometer

Next scheme shows constitutive elements of the device and their arrangement

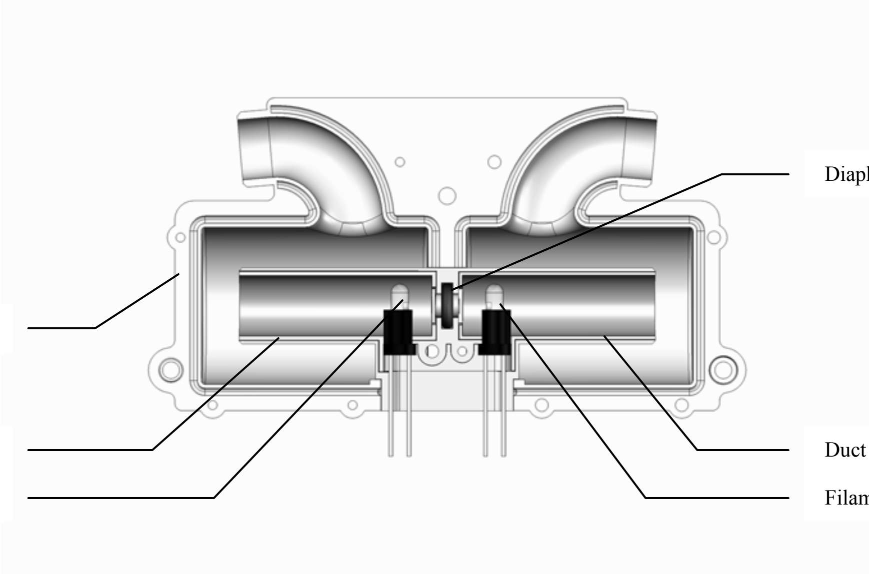


Figure 3 : Cross-section of the manometer

The device shown on figure 3 consists in a duct (2) running in 2 volumes (V_0 and V_1) at respective pressure P_0 and P_1. A cylindrical diaphragm (3) is placed into the duct (2). Here and there this diaphragm (3), the filaments F_1 and F_2 (1 and 1bis), are both placed along the axis of the duct. Made from electrical lamps these hot-wires are powered by a current and their resistance varies with the temperature.

When the air flows from the V_0 volume to the V_1 volume, the diaphragm (3) ensures the canalization and the acceleration of this flow. For example, when the diameter of the diaphragm is the quarter of the diameter of the duct, the air velocity will be sixteen times more important after than before the diaphragm. So, the filament after will be cooled faster than the other. Consequently, the resistances changes of each filament make it possible to show a pressure difference between the two volumes, the direction of the flow and then to determinate the value of the accurate pressure difference. For these reasons, filaments characterized by a big surface of contact and a small inertia are well appropriate to measure such values.

The duct (2) and the filaments F_1 and F_2 are placed in an enclosure box (4) whose inner sides are coated with grease (5). In the same way, the external surface of the duct (2) is coated. This constitutes a filtration of the majority of impurity like dust flowing between the volumes.

MEASUREMENT PROCESS

Next figure shows the measurement process which leads to the results as accurate as mentioned above.

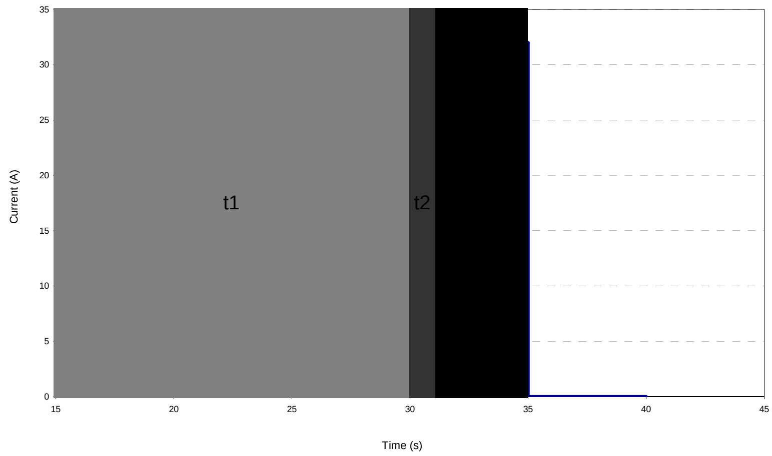


Figure 4 : measurements cycle

During a period t_1, about 30 to 120 seconds, F_1 and F_2 filaments are not powered.

During a first period t_2, about 1 second, filaments are powered with a low current (about 1 mA). This first resistance measurement of the F_1 and F_2 filaments is carried out at the ambient temperature and makes it so possible to fix the response. It should be noted that the warm up of the filaments F1 and F2 is so low that the cooling effect, caused by the airflow, is completely negligible.

During a second time (t_3), long enough to reach the heat balance of the F1 and F2 filaments (generally, between and 10 seconds), these hot-wires are powered by an electric current whose intensity is between about 15 and 45 mA. So, F_1 and F_2 hot-wires are heated at a temperature which not have to exceed 100°C. Then, the new resistances of F_1 and F_2 hot-wires are measured again.

First, airflow has been filtered before; then, the temperature of hot-wires has been increased at a pretty low value. So, thanks to diagrams showing the evolution of the hot-wires resistances as a function of the pressure difference, it is possible to determinate the pressure difference between the V_0 and V_1 environments. At the end, this process can follow an iterative method.

The voltage of the hot-wire is given by :

$$U = I \times R_0 \times (1 - \alpha \times (T_f - T_0))$$

With T_f : temperature of the hot-wire
$(R_0 ; T_0)$: R_0 is the tungsten filament resistance at a T_0 temperature
α : constant of tungsten
I = current

With a given I current :

$$U = f(T)$$

i.e. $$U = f(\Delta p, T_a)$$

With Δp : pressure difference

T_a : ambient temperature

Then it is possible to draw 2 pressure calibration curves (negative et positive) showing the response of a filament at 32 mA (cf. Figure 5 :)

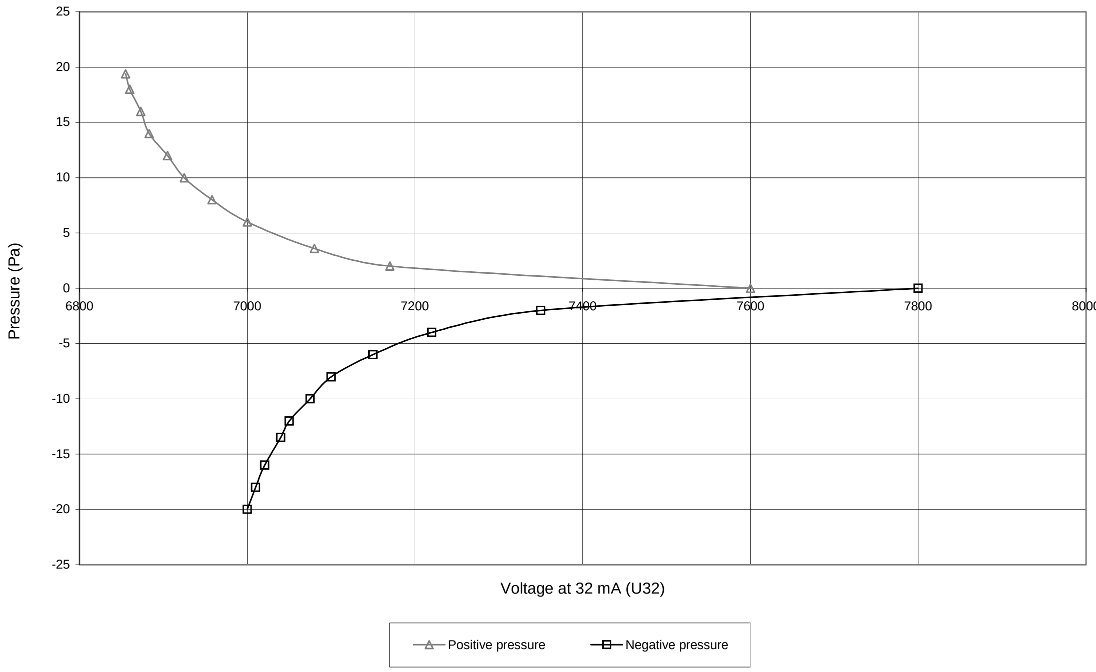


Figure 5 : pressure calibration curves of a manometer

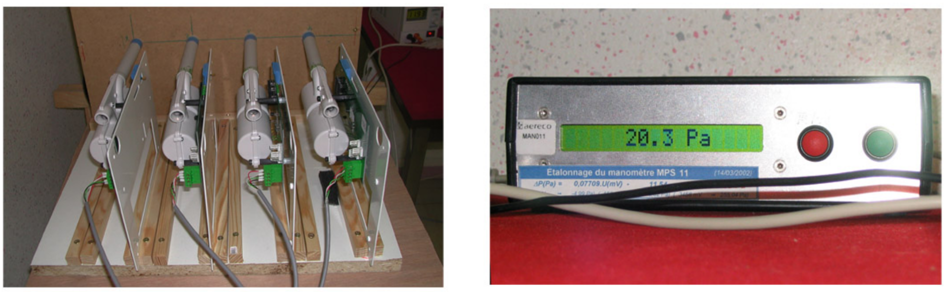
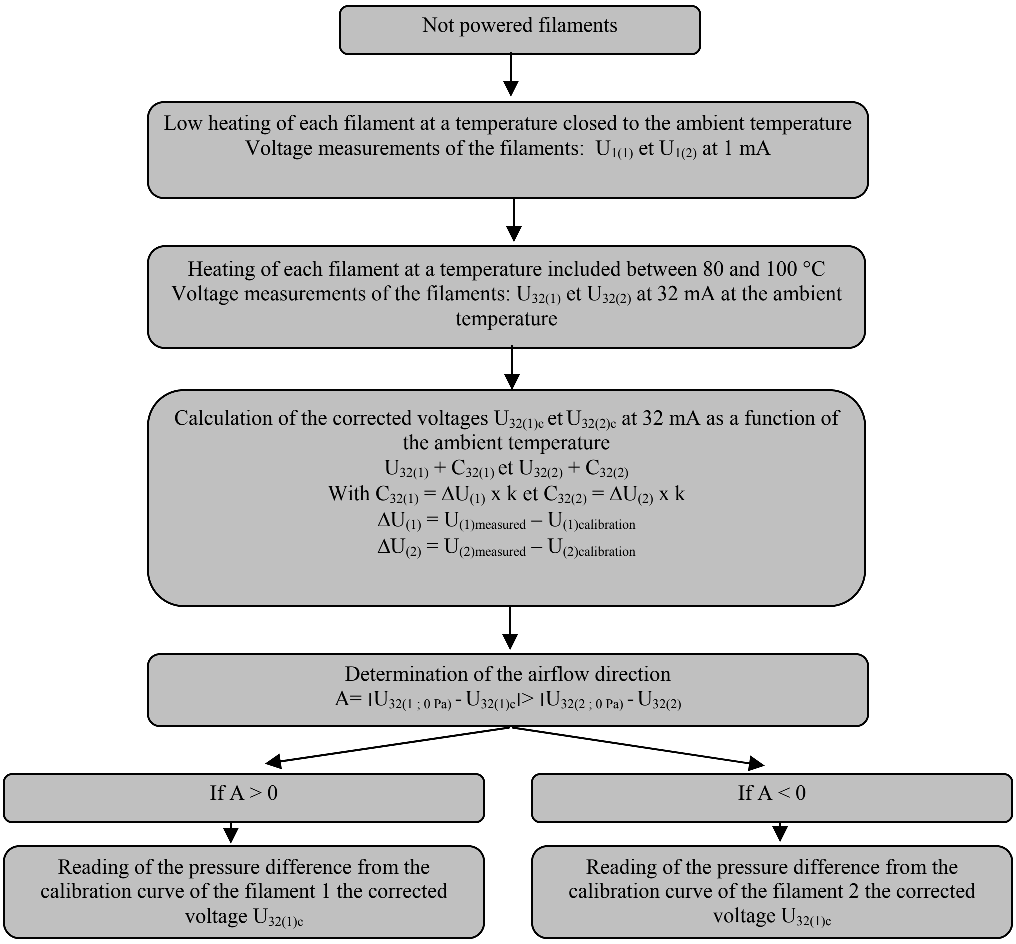


Figure 6 : calibration equipment

Next diagram summaries the methodological approach which leads to the determination of the pressure difference between two environments.



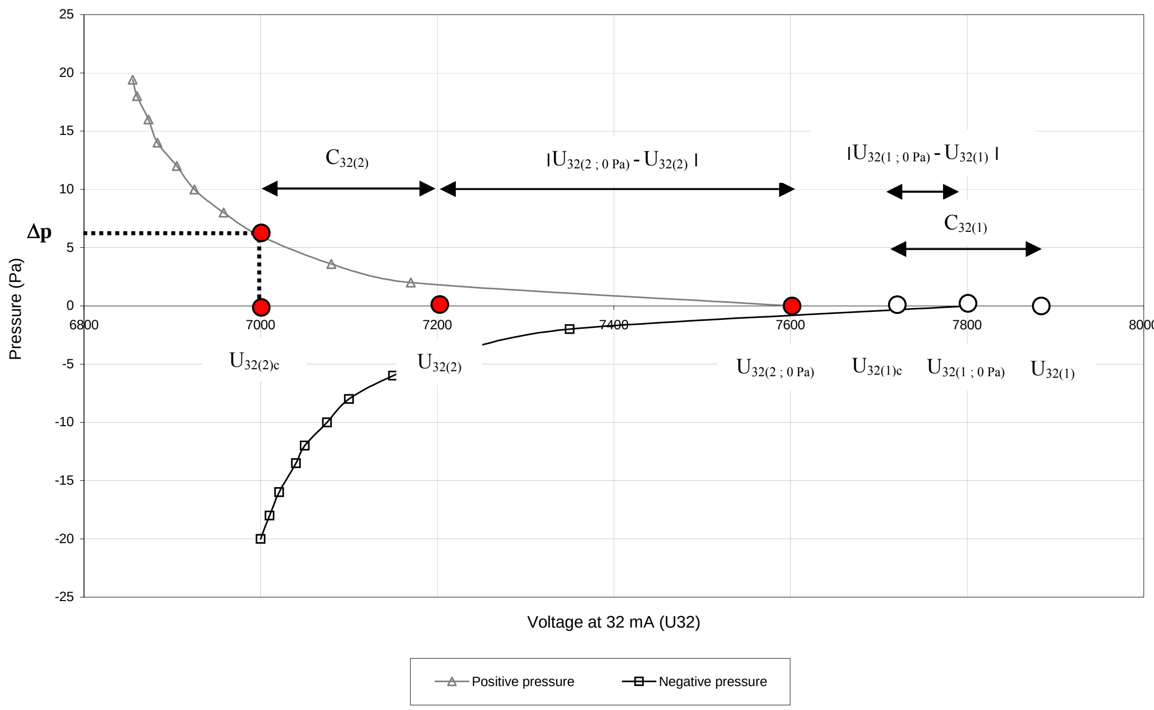


Figure 7 : Graphical method to determinate the pressure difference Δp

APPLICATIONS

Especially designed to measure very low pressure, this patented manometer guarantees an accuracy of about ±10% between -20 and 20 Pa. Moreover, its manufacturing cost is affordable in comparison with the similar products of the market. This makes it possible to consider a widening of its applications. Its first use took place in HR-VENT, the French Aereco monitoring where about 160 manometers have been installed. Next figure illustrates its simple integration in a box behind a humidity sensitive extract grille for passive stack ventilation.

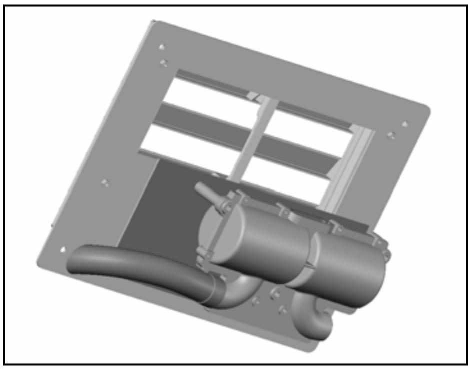
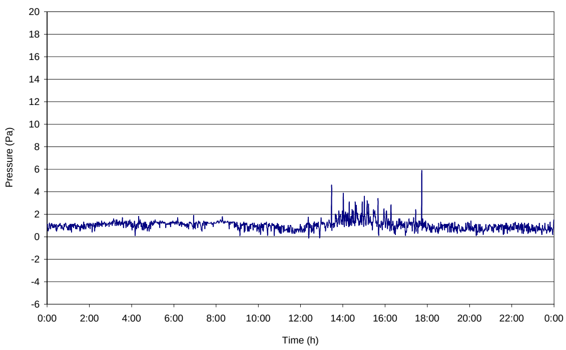
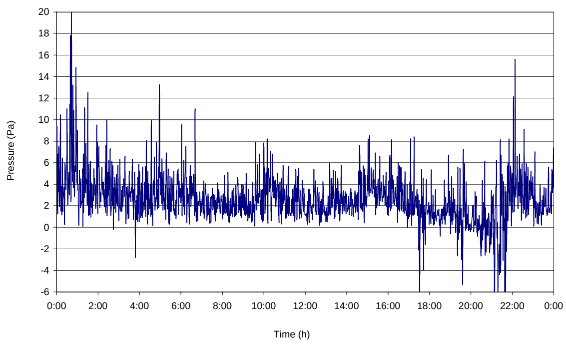


Figure 8 : Humidity sensitive extract grille with high accuracy manometer

Linked to an electronic card of power supply and data acquisition which defines measurements cycles, minute per minute, this manometer shows a true reliability.



February 15th 2004
Average air velocity : 1.5 m/s



February 20th 2004
Average air velocity : 4.2 m/s

Figure 9 : Comparison between 2 days with different wind conditions

CONCLUSION

The innovative technology shown before, naturally, leads manufacturer to patent this manometer. Measurements of low pressures with a high accuracy are now possible not only in laboratory but also in-situ. Moreover, the process makes it possible to get results independent from the ambient temperature and with controlled drift over time. With a cost about ten times cheaper than common products of the market, it is reasonable to believe that this device can extend its application.

REFERENCES

Siret, F., Savin, J.L., Jardinier, M. and Berthin, S. (2004). " Monitoring on HR-VENT hybrid ventilation project - first results." *25th AIVC conference.*

Savin, J.L., Jardinier, M. and Siret, F. (2004). "In-situ performances measurement of an innovative hybrid ventilation system in collective social housing retrofitting". *25th AIVC conference.*

DRAFT RISK SIMULATION IN A ROOM WITH AIR TRANSFER DEVICE

Marek Scholler[1], Jaroslav Katolický[1], Miroslav Jícha[1]

[1]*Department of Thermomechanics and Environmental Engineering, Brno University of Technology, Technicka 2, 616 69 Brno, Czech Republic*

ABSTRACT

The article describes the influence of the supply air devices that are part of hybrid ventilation system which is being developed within a EU funded project RESHYVENT as a part of this project, on thermal comfort in living-room of a three-bedroom apartment. The supply air radiator and the supply air convector are compared. The fresh air is sucked through a supply air convector and supply air radiator respectively and the air leakage through the facade is assumed too. 2 variants, which cover different outdoor temperature and supply air temperature for each device, have been solved. The main difference between them is the direction of the incoming air. Supply air radiator is like a classical radiator, outdoor air comes through the radiator, warms up and enters the room vertically. Supply air convector is stand-alone device with heat exchanger to preheat the entering air and with a back draft damper and a wind damper. In this case the outdoor air enters the room horizontally. The CFD model of the room was created and solved using the commercial code STAR-CD. Based on temperature and velocity fields, draft risk was calculated according prEN 13799:2003_01 in the occupation zone as a parameter for thermal comfort specification.

KEYWORDS

ventilation, CFD, thermal comfort, draft risk

INTRODUCTION

More and more people suffer from allergy and asthma due to the bad indoor air. The problem is especially big in schools, offices and other working places. But with increasing time people spend at home, the problem concerns also residential buildings. The rooms where we spend long hours must have a well working ventilation system, which is effective also after being used for many years and which doesn't gather dust and germs. Air supply convectors, also called outdoor air transfer devices (ATD) are part of such a system. Supply air devices takes in the outdoor air through a wall of the room and uses the heat exchanger connected to the radiator heat system to preheat the supply air. It's also possible to have an individual hot water system for supply air devices. These devices are also equipped with a back flow damper and wind damper to prevent back-draughts and with a filter which clear the supply air. The best ventilation effect is achieved when the ATD device is placed low down, since the outlet air vents are mostly positioned opposite and at a high level.

ATD devices that have been used in this case are Supply Air Convector (designed by Thermopanel, Sweden, Fig 1.) and Supply Air Radiator (designed by Purmo, Sweden, Fig. 2.). Supply Air Convector is a stand alone device with heat exchanger and thermostat system so it’s easy to control the temperature of supply air. The plume from supply air convector has a horizontal direction. Supply Air Radiator is improved standard radiator (see Fig. 2.) The supply air comes through the wall to the radiator and warms up. The plume from supply air radiator has vertical direction. Temperature of the supply air depends on a thermal load of the radiator and can’t be controlled exactly.

Fig 1. Supply Air Convector

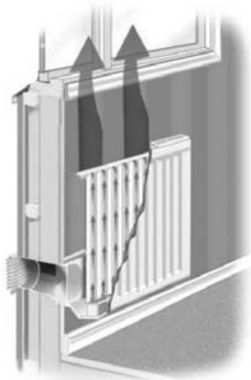


Fig 2. Suply Air Radiator

DESCRIPTION OF THE ROOM WITH SUPPLY AIR DEVICE AND SOLUTION PROCEDURE

The room in which the air flow was studied is a living room in a three-bed room – see the outside 3D view (Fig. 3.). Floor area of this room is 29,4m^2. Bedrooms, bathroom, closet and WC weren’t considered in the model. The room contains kitchen unit with cooker and cooker hood. Cooker hood wasn’t considered in the model because of its irregular work. Main exhaust outlet which was the only outlet in the model is pos. 8 in Fig. 3. Exhaust outlets in WC, closet and bath room were ignored too. The outdoor air enters the living room through a Supply Air Convector, model TK35 or a Supply Air Radiator. Air leakage is assumed too. Air leakage is assumed to occur in the joint between the exterior wall (walls where windows pos. 1, 3, 6 in Fig. 3. are situated) and floor, the joint between the exterior wall and ceiling and the windows (pos 1,3,6 in Fig. 3.). Pos. 7 in Fig. 3. is balcony door. The convector Thermopanel TK-35 (supply air radiator) is situated under the window (see Fig. 3. pos. 4).Supply Air Radiator has the same position as the TK-35. Positions 2 and 5 indicate standard flat radiators.

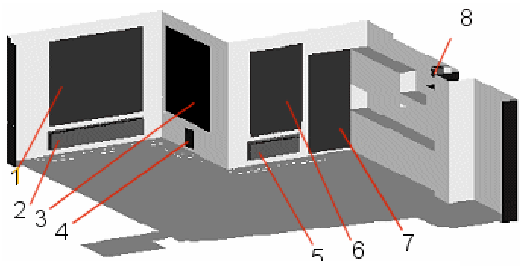


Fig. 3. 3D view of the room

The following U-values were assumed for the room:

- Exterior walls 0.25W/m²K
- Windows 1.8 W/m²K

There are no heat losses or gains to the neighbouring apartments. The heating system is a low temperature system with nominal setting at 60/40 °C. However, the thermal load of radiators has been adjusted according to scenario in order to keep the room air temperature

at the desired value. For each supply air device 2 combinations of outdoor temperatures were studied.
Next Tables 1 and 2, show the summary of solved variants.

TABLE 1
Boundary conditions for 2 variants when supply air convector is installed

Variant	Te	Ti	Tc	vk	vi	q
1	-10	22	18	16.2	6	650
2	0	22	18	16.2	6	510

TABLE 2
Boundary conditions for 2 variants when supply air radiator is installed

Variant	Te	Ti	Tsar	vk	vi	q
1r	-10	22	0	16.2	6	770
2r	0	22	8	16.2	6	585

Te –outdoor temperature (° C)
Ti – indoor temperature (° C)
Tc – temperature of preheated air from convector (° C)
Tsar – temperature of preheated air from radiator (°C)
vk –air volume flow through the convector and radiator, respectively ($l.s^{-1}$)
vi – air volume flow through the façade ($l.s^{-1}$)
q – specific thermal load of radiators ($W.m^{-2}$)

The problem was solved using a set of equations for incompressible, transient turbulent 3D flow with standard *k-ε* model of turbulence. The equation for a general variable ϕ has the well-known form:

$$\frac{\partial}{\partial t}(\rho\varphi)+\frac{\partial}{\partial x_i}(\rho u_i\varphi)=\frac{\partial}{\partial x_i}\left(\Gamma\frac{\partial\varphi}{\partial x_i}\right)+S_\varphi \qquad (1)$$

where the variable ϕ substitutes velocity components *u, v, w*, temperature *T* and kinetic energy of turbulence *k* and its rate of dissipation *ε*. The set of equations was solved using the control volume method and CFD code StarCD. Solution domain contains in total 450000 control volumes.

RESULTS AND THEIR DISCUSSION

Results of the modeling are presented in the form of draft risk DR, which corresponds with percentage of dissatisfied persons PPD. Draft risk is one of the several criteria, with which thermal comfort is evaluated. A well-accepted method to evaluate the predicted PPD concerning draft is the following equation, according to prEN 13799:2003_01

$$DR=(34-T_i).(v-0.05)^{0.62}.(3.14+0.37v.Tu) \qquad (2)$$

where T_i is local temperature, *v* is local air velocity, *Tu* is intensity of turbulence. Draft risk determined with eq.(2) gives a percentage of dissatisfied persons on the basis of an insulation value of clothes clo=0.75 and an activity met=1.2. Intensity of turbulence was assumed 0.4. Velocity and temperature were taken from the appropriate predicted fields in the locations of interest. Results of simulation are presented in vertical plane and horizontal plane (0,1 m above the floor), see Fig 4.

Variants with different supply air device have been solved (supply air convector- SAC, and supply air radiator SAR). Supply air temperatures are 0°C, 8°C respectively when the SAR is installed. These temperatures was calculated assuming that radiator which works as a supply air device gives 25% of its thermal load to the incoming air which flows through. These low temperatures have a significant influence on DR nearby the supply air radiator. Infiltration also affects the DR distribution negatively. The air leakage is assumed to occur in the joint between the exterior wall and the floor, the joint between the exterior wall and the ceiling and the windows, 1/3 evenly distributed at each location.

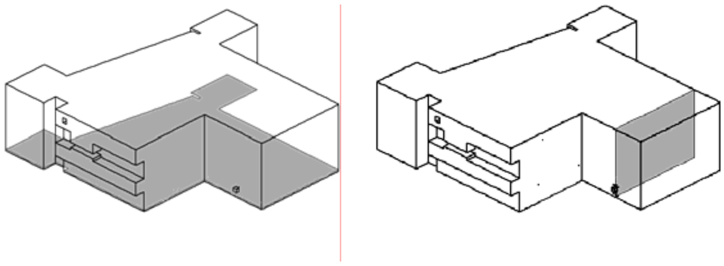


Fig. 4. Planes where PPD is discussed

Outdoor temperature: -10°C 0°C

Supply air temperature: 0 °C 8 °C

Variant 1r Variant 2r

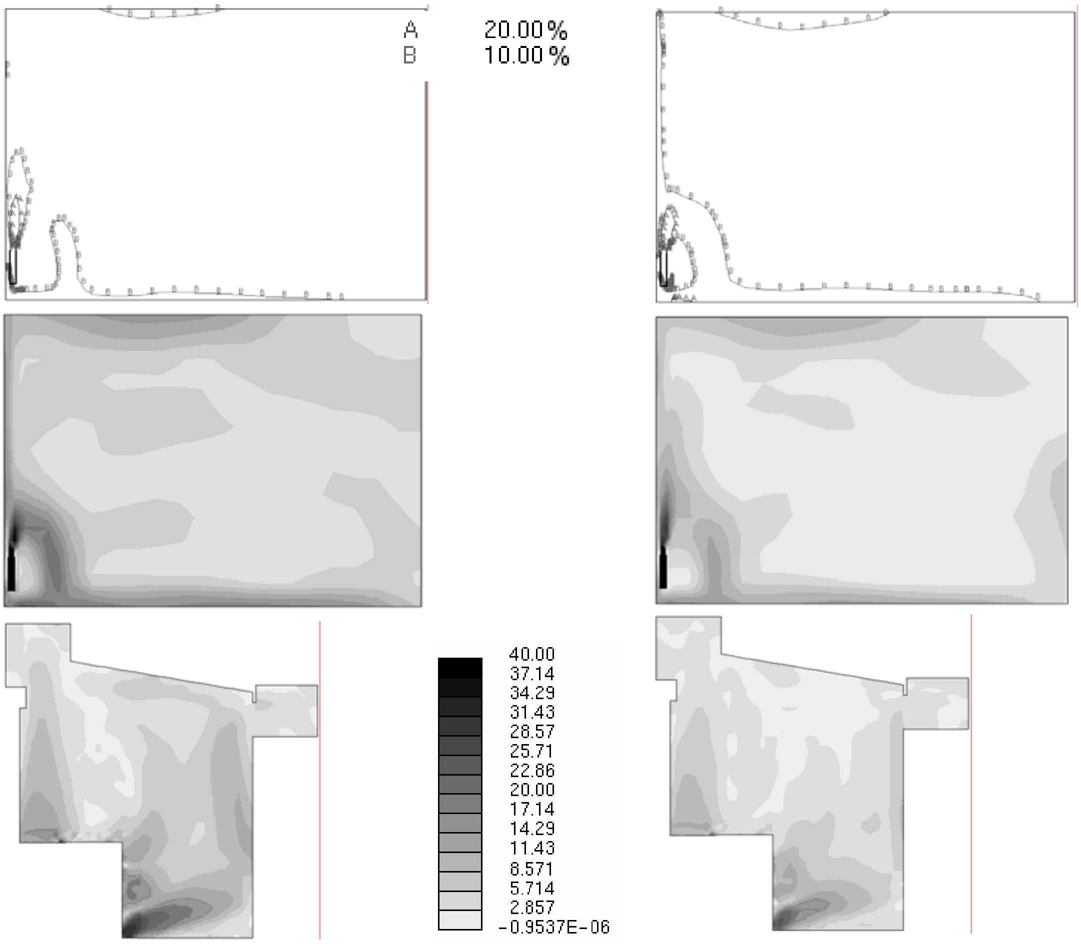


Fig.5 PPD values for variants with Supply Air Radiator

Simulations show that there are very high PPD values nearby the supply air radiator. The cold air turns down to the floor, so the PPD values exceed recommended value of 10 % in this area (see Fig. 5). When supply air convector is installed (see Fig. 6), there is different distribution of PPD in front of the device. As we can see the highest PPD are cumulating in the zones between floor and the distance 0.1m above the floor and under the ceiling (these zones are due to infiltration through air leakage which brings in a very cold air at the temperature of –10°C) and along window. Above the level of 0.1m from the floor, PPD are below 10%, in most cases below 5%. We clearly see that other cold area is located in front of the balcony door and in the small space between wall with convector and the opposite partition between living room and bedrooms. The highest PPD can be found just in this space where values of PPD reach up to25% We can expect that if a table is placed in this space, people could feel a cold draft close to the floor. In case of the balcony door, the value of PPD 10% extends along the kitchen unit and we can expect certain dissatisfaction of those who cook. The higher values of PPD along the kitchen unit can be observed in all cases that were modeled.

Outdoor temperature: -10°C 0°C
Supply air temperature: 18 °C 18 °C

Variant 1 Variant 2

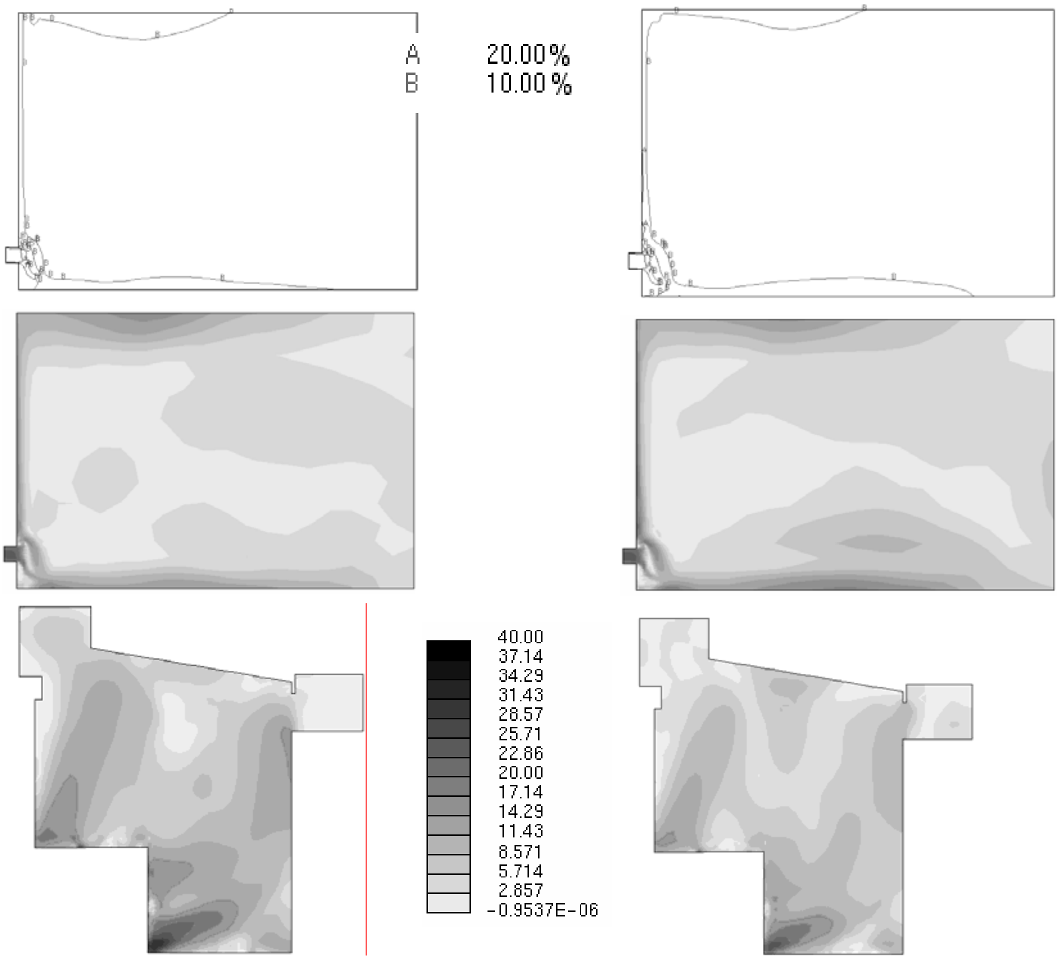


Fig.6 PPD values for variants with Supply Air Convector

CONCLUSIONS

Draft risk was evaluated based on CFD modeling of velocity and temperature fields in a living room of a 3 bedroom apartment in a multifamily house. Results of modeling show that supply air radiator doesn't have sufficient thermal load to heat up outdoor air to a satisfactory temperature in light of PPD (in case of low outdoor temperatures). Outdoor air comes through and turns down to the floor so the PPD values rises up to 20% in front of the radiator. When supply air convector is installed, PPD values are affected by infiltration. Close to the floor, the PPD values are higher just due to air leakage in both variants of supply air device. The PPD values of up to 20% can be met in the area of a cavity formed with exterior walls (walls where windows 1 and 3 are located - Fig 3) and namely in front of the balcony door along the kitchen unit.

To lower PPD values in critical areas, air leakage should be avoided, convector should direct the preheated air partly downward and the supply air radiator should be more powerful.

ACKNOWLEDGMENT

Financial support from Brno University Research Plan No. MSM26210001 funded by the Czech Ministry of Education, Research Fund of Faculty of Mechanical Engineerig No. BD 134 3036 and 5.FP EU project RESHYVENT are gratefully acknowledged.

REFERENCES

1. Awbi, H. (2002). Ventilation of Buildings, Spon Press, London, U.K.
2. Dorer, V., Pfeiffer, A., Weber, A. (2003). RESHYVENT REPORT – WP5-TR-5-Version 3, Switzerland

BLOWER DOOR TESTS (EN 13829) FOR QUALITY ASSURANCE: GETTING AIR-TIGHT BUILDINGS IN RETROFITTING, TOO

Sigrid Dorschky

BlowerDoor GmbH, Energie- und Umweltzentrum, D-31832 Springe, Germany

ABSTRACT

For retrofitting as well as for new buildings a good airtightness is an important issue. In Germany, Austria and Switzerland about 1000 persons conduct blower door tests according to EN 13829 in order to characterize the air permeability of buildings. Also, preliminary measurements of the air barrier are made, often by the craftsmen themselves. Early measurements allow to repair leakages more easily than when the building is completed.
In this lecture typical faults and the resulting problems as well as good solutions are introduced at planning and execution with two attic storey developments:

(1) In an appartment building thick insulation layers were built in during the attic storey development in the eighties. The subject airtightness was not considered. Consequence: The rooms lying to the east didn't get warm sufficiently.

(2) At the attic development in an one-family house of 1928 the airtight layer was planned in detail and checked with the blower door during the construction.

In the course of further redevelopment measures the n_{50} value of the complete building was improved from 5 h^{-1} to less than 2 h^{-1} and a ventilation system (central exhaust ventilator) was installed.

Different test methods were used: Zonal Pressure Measurement, Opening A Door, Guard Zone Measurement.

KEYWORDS

Airtightness, EN 13829, Blower Door Test, Retrofitting, Attic Storey Development, Quality Assurance

INTRODUCTION

The additional attic storey development is probably the most difficult retrofitting task with respect to the airtightness: Here meet solid and timber structure on each other, on the one hand. On the other hand, there are restrictions by the available construction and instructions of the authorities. And for the end an insulation must be carried out for the noise, fire and smoke protection also to the building part lying under this.

Visibly high-quality development is often planned primarily under architectural points of view. However, a high energetic standard only can be reached if an energy diagnosis is made in advance. And first of all a professional planning of the thermal bridges and airtightness details and ventilation technology must be carried out. Many different crafts must moreover cooperate.

An accompanying quality assurance with the blower door and a proof according to EN 13829 are the only guarantee to avoid problems later and to secure that the ventilation system works as planned. And the leakage locating already before a retrofitting during the energy diagnosis motivates the owners to take steps to improve airtightness and insulation.

It is above all in the attic that poor airtightness creates a problem for both the construction of the building and for human health: if the attic storey is inadequately sealed, the thermal buoyancy created within the building will cause air to flow up from the lower storeys, bringing noise, smells and also pollutants from the old ceiling construction into the new living space. If there is ever a fire, the smoke and flames can spread rapidly. Air will flow continuously, particularly at cold times of the year, through leaks in the new envelope from the inside to the outside. This can cause water vapor to condense out of the moist warm air onto structural elements. Structural damage and fungal growth may be the result.

TABLE 1
A good airtightness is important for

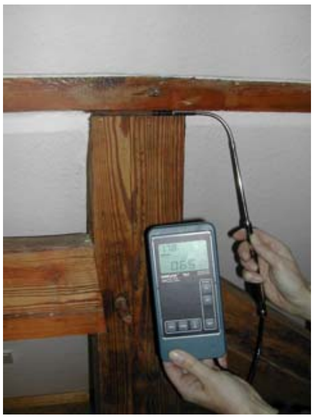
- reduction of energy consumption
- securing of demand-controlled ventilation
- providing a good indoor air quality
- protection against pollution (Radon from the ground, mould and odours from the cellar, odours from neighboring dwellings)
- protection against airborne noise (from the staircase, between dwellings, traffic noise)
- efficient smoke and fire protection
- increase of comfort and cosiness
- disclaiming of timber preservative

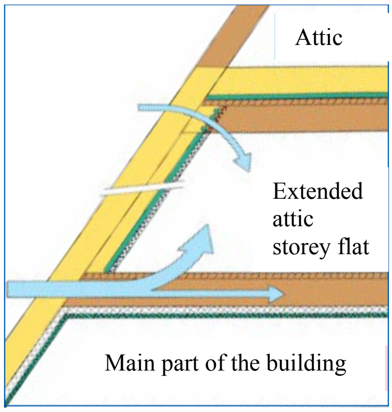
1st EXAMPLE: THE ROOF EXTENSION WILL NOT BE PROPERLY SEALED UNLESS AIRTIGHTNESS IS PLANNED

The first measurements of airtightness on an old German building (1920) were carried out as early as 1989 at the energy and environmental center e-u-z, Springe. The faults that we know to be typical were observed: During the development of a large attic storey apartment at the beginning of the 1980s, an insulation thickness of 200 mm and more was installed. At the time, this was revolutionary, but the creation of airtight joints was not given any consideration. The result was that the occupants complained about the difficulty of keeping their rooms warm when the cold, east winter wind blew against the broad side of the house. When the wind was strong, granulated cork trickled out of the beam sealing; when the weather was particularly cold, condensed water dripped into the bathroom and kitchen from the surrounds of the skylight windows. The radiator against the jamb wall of the house once froze. The thawed snow always made it very easy to see from the outside how warm air was flowing out along the joints to the beam ceiling and the interior walls. With 50 Pascal pressurization, artificial fog emerged from exactly these points.

Figures 1+2: Thawed snow and the appearance of fog at 50 Pa pressurization show how air is flowing at the internal walls, beam ceilings and attic areas, and that there are energy losses in spite of the 200 mm insulation thickness.

The overall airtightness of the extended attic storey apartment could not be measured, since an adequate differential pressure could not be reached: With an open BlowerDoor fan with a flow capacity of approx. 8000 m³/h [3], and with an apartment volume of approx. 500 m³, this means that n_{50} is greater than 16 h^{-1}. By comparison, the limit value for buildings with window ventilation in the Hessian Promotion Program for Low-Energy Houses [4] was $n_{50} \leq 3\ h^{-1}$. The reason for this extremely high value is to be found on the one hand in the absence of an airtightness concept for the attic storey, and on the other in the leaks to the main part of the building underneath. Both of these types of leakage are typical for attic storey extensions, even today.





Figures 3,4,5: Draughts at the joint between post and center purlin (0.65 m/s); flow through the ceiling (air flow rate at the ceiling opening 3.4 m/s) due to incomplete airtight layer at the ceiling joint

Typical leaks to the parts of the building situated underneath / to the main building

When the attic storey is developed above an existing ceiling, it is popularly assumed that this ceiling is already airtight, and that no particular steps need be taken other than for the new access door. Unfortunately, however, in most cases various leaks are already present, and the modification work creates yet more. Only when the extension is being carried out in order to extend the living space available inside a one-family house it is possible that these leaks may be negligible. When a new, self-contained living unit is being created, as in the case of the e-u-z, they can lead to significant problems. Consequences of these leaks – driven by the thermal pressures within the building, are:

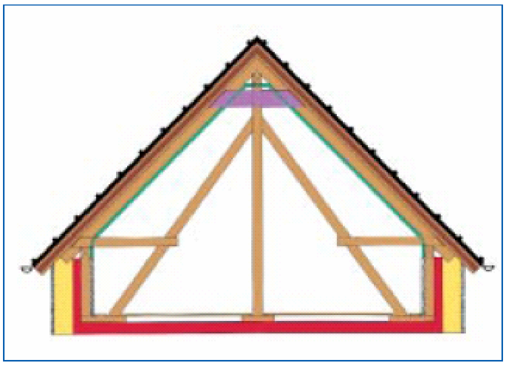
- poor airborne sound insulation (in both directions),
- the spread of smells from below to above (food, cigarette smoke) and out of storage rooms,
- possible ingress of pollutants from the ceiling into the new apartment consisting, for instance, of building material or of fungal spores resulting from earlier condensation out of the lower rooms,
- in the event of fire, first the smoke and then the flames will pass upwards through these channels.

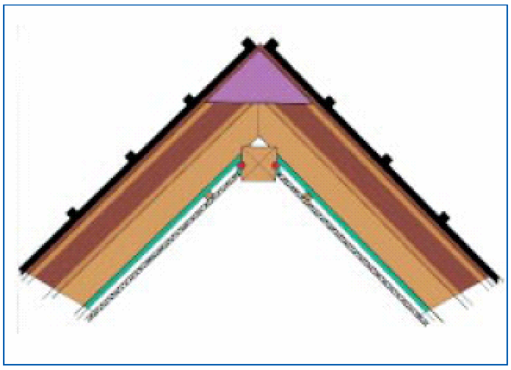
A high proportion of these leaks are not confined to wooden ceilings, but also occur with solid ceilings.

2nd EXAMPLE: HOW TO MAKE THE SEAL – INCLUDE THE AIRTIGHT LAYER AT THE DESIGN AND STATIC CALCULATION STAGE!

In old roof woodwork often a large number of beams hinder an optimal airtightness. Achieving permanent sealing in accordance with technical regulations always implies avoiding, or at least minimizing, penetration of the wooden beams. For this reason in the second example – having learned from the experience of the first – it was decided at the initial design stage not to attach to the pillars and braces (altogether 8 items), but to join up to the seal of the diagonals to the ridge purlin along the existing cracks.

The static engineer almost made nonsense of this plan again: due to the planned doubling of the rafters (Agepan webbed beam AS 160), each pair of rafters was to be reinforced in the center by two shackles nailed to the side - this would have resulted in 36 new holes! This imposition was discovered just in time before obtaining the quotation. The solution was to fasten the Agepan beams above the ridge purlin by means of triangular boards - without penetration.





Figures 5+6: Original design offered by the static engineer to reinforce the ridge purlin for the rafters: penetrating shackles which cannot be easily, economically and permanently sealed … and the alternative that was built: triangles at the tips of the locking rafters outside the airtight layer, attached along the ridge purlin

Penetration to the existing main building

Although it is true that this is not a separate apartment, attention was paid to achieving the most airtight possible implementation for the following reasons:

- the very poor sound insulation in the original two-family house should at the very least be improved in the newly extended area.
- the new ventilation equipment should operate separately on each floor, since the thermal buoyancy in a 2.5-floor building that is not adequately sealed can overpower the suction generated by the ventilation equipment [4]
- it was also desirable to avoid drawing moist warm air through the largely unheated stairway
- and, last but not least, even the existing, solid separating wall from the main building with its ventilated cavity layer and the solid ceiling were not airtight to the outside.

Successful strategies for attic extensions

The problems could be solved in these ways:

- the roof is improved right up to the ridge, leaving the ridge purlin partly visible. In this way – as well as avoiding penetrations – the architectonic unity of the wood construction is displayed.
- there is room for the electrical installation in the additional insulation under the rafters between the supporting battens of the internal lining.
- installations are avoided in the new, single-skin gable wall.
- attachments are made, or lath work is put in place, at the joints between the solid ceiling and the jamb wall and between the jamb wall and the purlin before plastering.
- the internal walls are assembled inside the airtight layer and are screwed to the plasterboard internal skin of the sloping roof. A separating cut is included to improve sound insulation to the bathroom. Windproof sockets (such as those manufactured by Kaiser) are used to avoid the ingress of insulating material.

BlowerDoor measurements for quality assurance and as final evidence of airtightness

An extremely good BlowerDoor result was, of course, demanded in the building contract itself for this attic storey extension: a target of $n_{50} \leq 0.6\ h^{-1}$ (passive house limit value [6]) was set for the renovated part of the building. The builders therefore knew what they were taking on, and took the topic of airtightness seriously. At the detailed planning stage, the details of the leaks (and therefore also of avoiding thermal bridges) were optimized. As the work proceeded, the design plans had to be modified from time to time – the reason for this lay, on the one hand, with sloppy measurement and lack of a capacity for spatial visualization on the part of the designers, and, on the other hand, the selection of extremely new materials and unconventional methods by the client.

The BlowerDoor was used several times during the work: this was to achieve quality assurance while the vapor barrier was still visible. Unfortunately events could not proceed as desired in this relatively small building area, where the work of the various trades overlapped heavily.

The total airtightness was finally assessed using different methods. The original measurement had been $n_{50} = 5.2\ h^{-1}$. The size of the building as a whole was not identical with its size before the conversion, because the attic floor of the extension was enlarged, as was the stairway. For this reason, the improved result of $n_{50} = 2.4\ h^{-1}$ is not meaningful. A number of additional methods were therefore used in order to determine the airtightness of the separate parts of the building.

For the zone measurements using the "Opening-a-Door" method [7], the doors of the ground floor and the upper floor apartments were opened, and a depressurization measurement taken in each case. Using the volumetric flows from several series of measurements, a mean n_{50} of $1.2\ h^{-1}$ with a scatter of 20% was estimated.

Using Guard Zone (or Deduction) Measurements with two BlowerDoor systems, of which one was mounted in an external door and the second was mounted in the apartment doors, it was possible after several series of measurements to confirm an n_{50} value of $1.2\ h^{-1}$, with a scatter of 10%. In a further Guard Zone Measurements with three BlowerDoor systems built into the external door and into a window in each apartment, it was finally possible to determine a value of about $1\ h^{-1}$ for the extension. A great success, even if the ambitious target was not entirely reached!

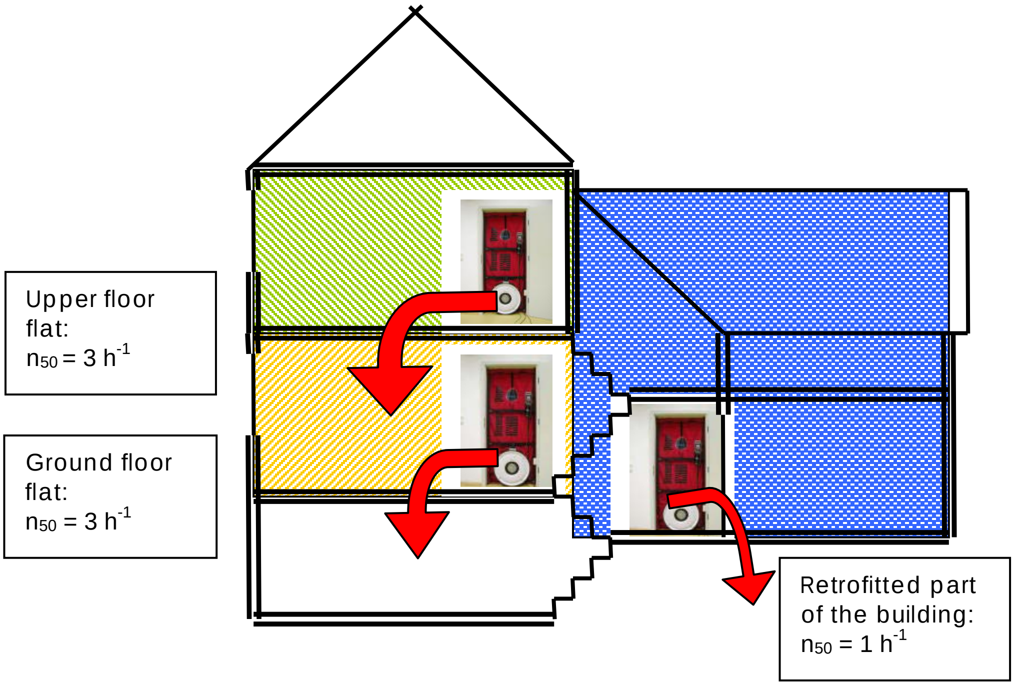


Figure 7: Guard Zone Measurement with 3 BlowerDoor systems to determine the air permeability of the improved part of the building (and at the same time for the unchanged part of the building, consisting of two apartments)

The BlowerDoor result was further improved through sealing done between the ground floor and the cellar. A replacement for the old trap-door is planned on the first floor. The cavity in the wall has since been blown in with SLS 20, reducing the leakage to the wood joist ceiling: $n_{50} = 1.5\ h^{-1}$ for the entire building!

CONCLUSIONS

A good n_{50} value can even be achieved when improving the attic storey of existing buildings, provided the airtight layer is explicitly designed and subject to quality assurance. The factors for success are assessment of the existing building using BlowerDoor measurements at the energy diagnosis stage, inclusion of the target value for n_{50} in the building contract, and the location of leaks using depressurization during the construction phase.

The complexity of existing roof woodwork means that a great deal of prior experience in the field of airtightness is necessary. Bringing in someone with an understanding of the BlowerDoor has been found valuable.

REFERENCES

[1] Robert Borsch-Laaks: Das Süddach - Dämmung des Dachgeschosses; Dachdämmung ohne Hinterlüftung. In: Rundbrief 8. Jahrgang Nr. 25, Energie- und Umweltzentrum am Deister, Springe-Eldagsen 1988.
[2] Normenausschuss Bauwesen (NABau) im DIN Deutsches Institut für Normung e.V.: DIN EN 13829: Wärmetechnisches Verhalten von Gebäuden. Bestimmung der Luftdurchlässigkeit von Gebäuden. Differenzdruckverfahren (ISO 9972 modifiziert). Deutsche Fassung EN 13829:2000. Berlin 2001.
[3] The Energy Conservatory / BlowerDoor GmbH: Manual/Handbuch Minneapolis BlowerDoor. Minneapolis/Springe-Eldagsen 1988-2004.
[4] Johannes Werner, Ulrich Rochard, Joachim Zeller, Matthias Laidig: Messtechnische Überprüfung und Dokumentation von Wohnungslüftungsanlagen in hessischen Niedrigenergiehäusern. Studie im Auftrag des Institut Wohnen und Umwelt, Darmstadt. Hessischer Minister für Umwelt, Energie und Bundesangelegenheiten, Wiesbaden (Hrsg.) 1995.
[5] Sigrid Dorschky: Systeme und Spezialelemente für luftdichtes Bauen. Eine Positiv-Auswahl und Erfahrungen bei BlowerDoor-Messungen. In: Die neue quadriga 6/2001. Verlag Kastner, Wolnzach 2001.
[6]] Passivhaus Institut: Luftdichte Projektierung von Passivhäusern. Eine Planungshilfe. Darmstadt 1999.
[7] Energie- und Umweltzentrum am Deister e. V. (Hrsg.): Messung der Luftdichtheit von Gebäuden. Theorie und Praxis. Tagungsband zur 8. EUZ-Baufachtagung. Springe-Eldagsen 1997.

MONITORING ON HR-VENT
HYBRID VENTILATION PROJECT - FIRST RESULTS

Siret, F., Savin, J.L., Jardinier, M. and Berthin, S.

Aereco S.A., 9 allée du Clos des Charmes, Collégien
F - 77615 MARNE LA VALLEE Cedex 3

ABSTRACT

More than 700 million of measured data, 730 days, 55 dwellings: the HR-VENT hybrid ventilation demonstration project applied in NANGIS (France) on a set of occupied collective dwellings is closely linked to its stakes. From January 2004 up to December 2005, the values of humidity, temperature, pressure, opening surface and gas appliance operation are saved every minute in all the wet rooms by specifically developed sensors. The first results of these new hybrid ventilation system monitoring are presented in this document.

In particular, directly linked to the local meteorological data, these measurements aim to evaluate the ability of the new hybrid ventilation system to erase the back draught effects. Moreover, it is again possible to show the correlation between indoor relative humidity and IAQ. Pressure differences and airflows comparisons between storeys, influences of wind velocities and outdoor temperatures during a really significant period is well in agreement with the previous 1993 "Passive humidity controlled ventilation for existing dwellings" - Demonstration project EE/166/87".

KEYWORDS

Measurements, results, passive stack ventilation, hybrid ventilation, monitoring, HR-VENT

MEASURED DATA

The data acquisition system involved in this measurement campaign makes it possible to measure and record every minute the following parameters

WC and bathroom equipped with a humidity sensitive extract unit.	Kitchen with domestic boiler	Outdoor conditions
Measured parameters		
Temperature (°C) Relative humidity (%) Aperture of the grille (cm^2) Pressure difference (Pa)	Temperature (°C) Relative humidity (%) Temperature of the combustion gas (°C) Pressure difference (Pa)	Temperature (°C) Relative humidity (%) Wind velocity (m/s) Wind direction (°)
Calculated parameter		
Airflow (m^3/h)	Airflow (m^3/h)	

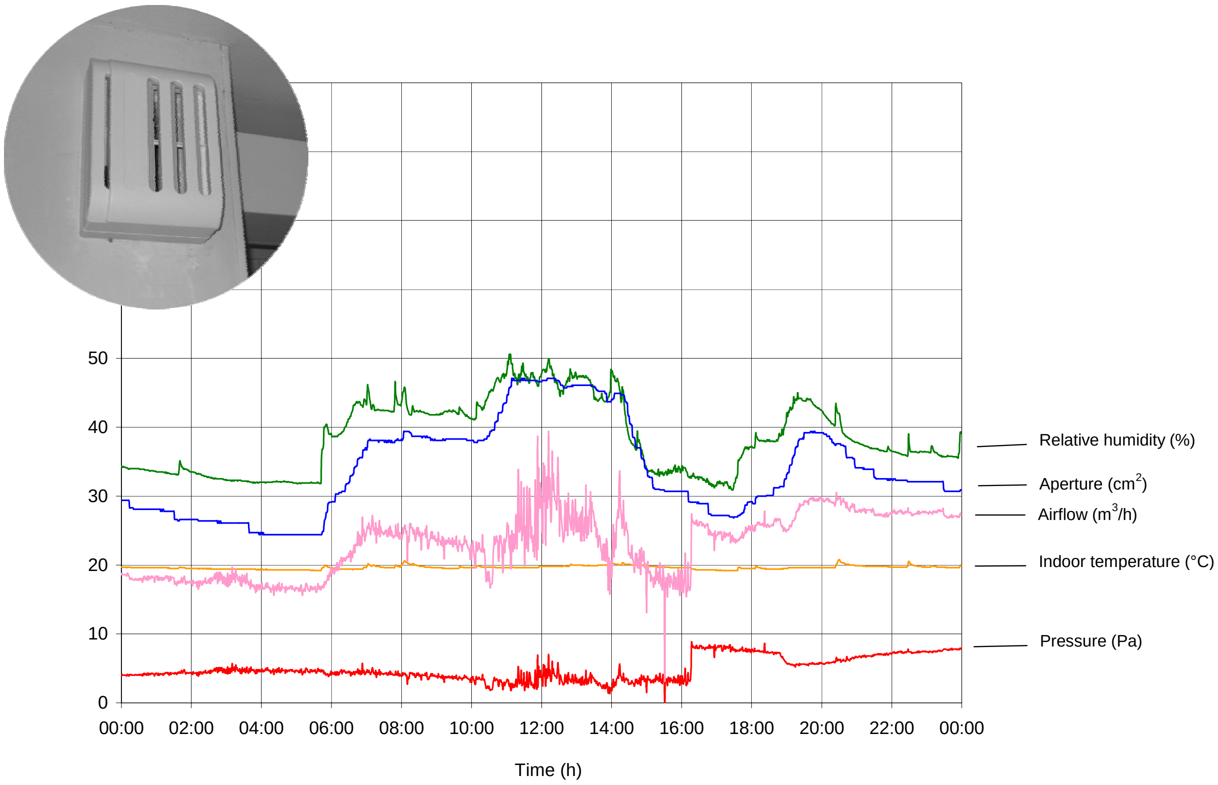


Figure 1 : Measured parameters in WC and bathroom (example)

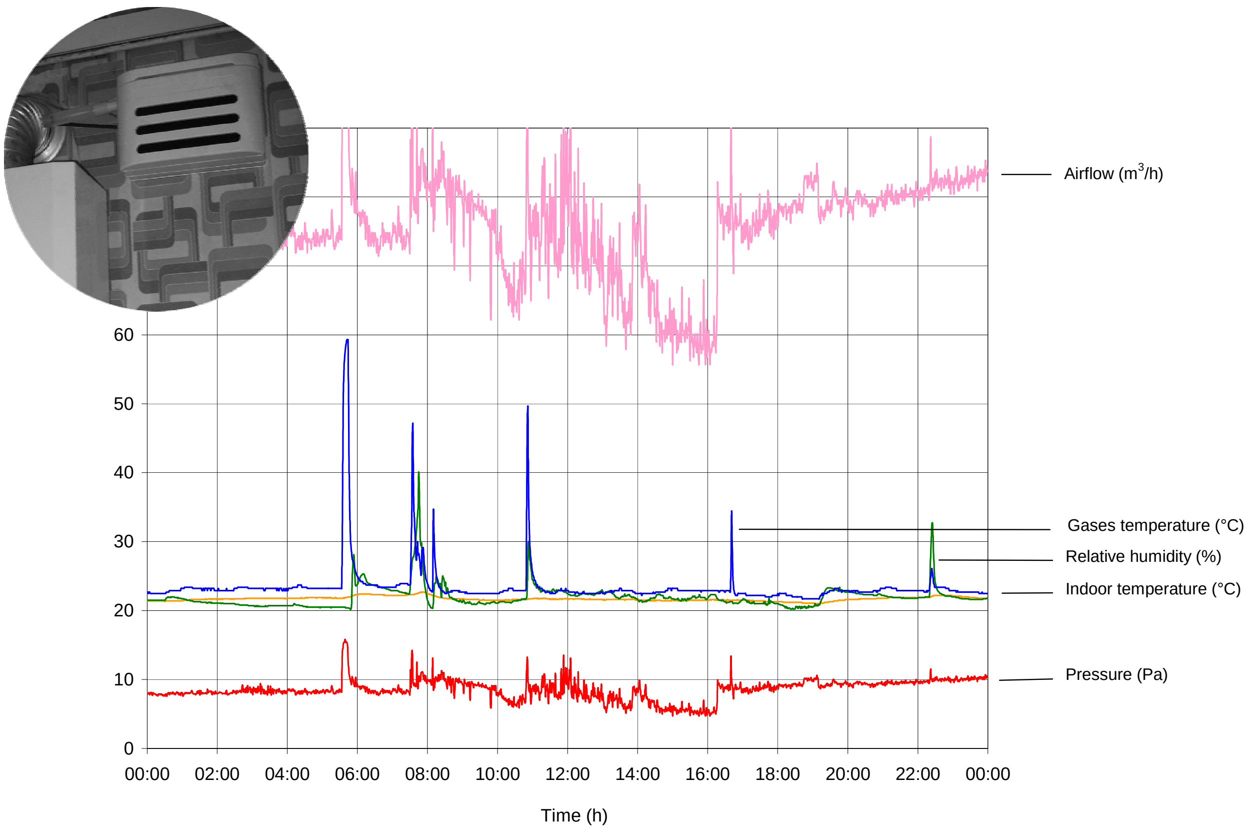


Figure 2 : Measured parameters in Kitchen (example)

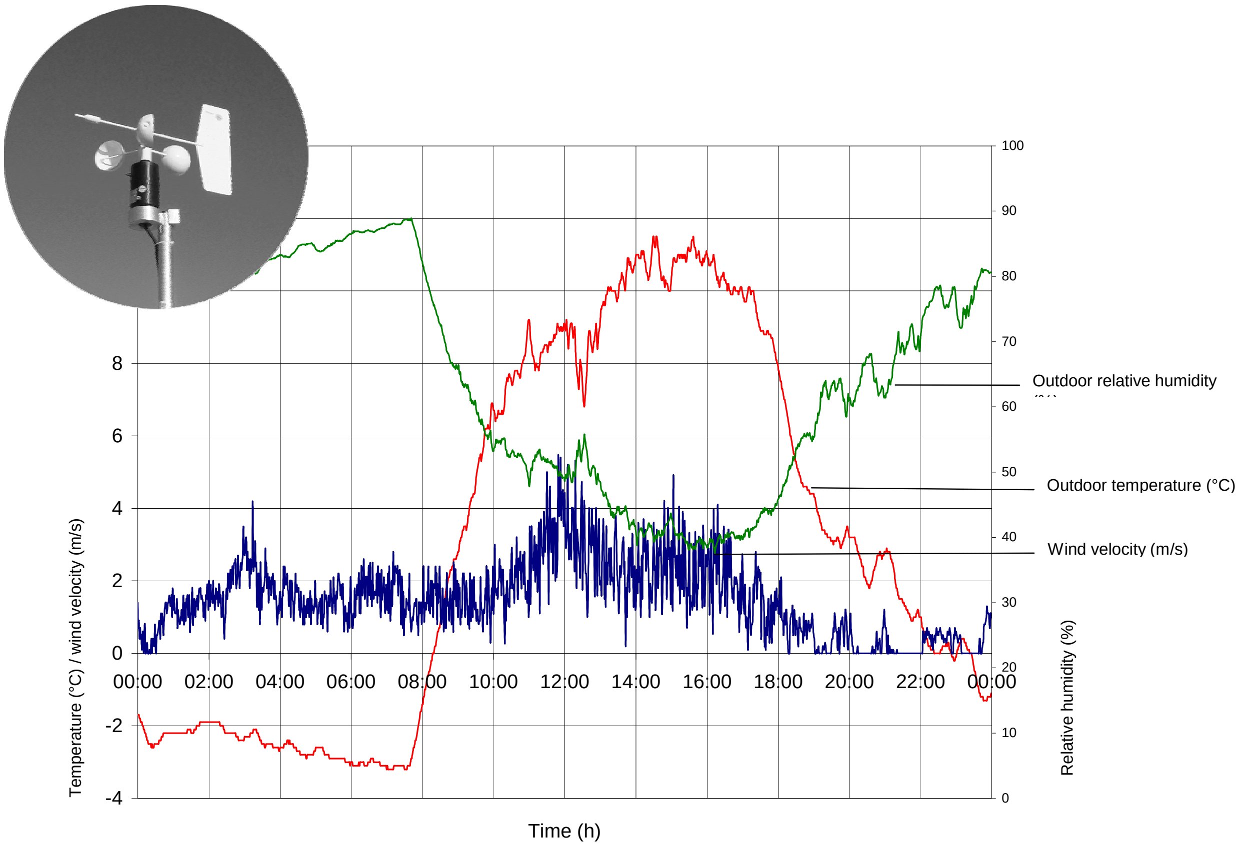


Figure 3 : Measured meteorological data (example)

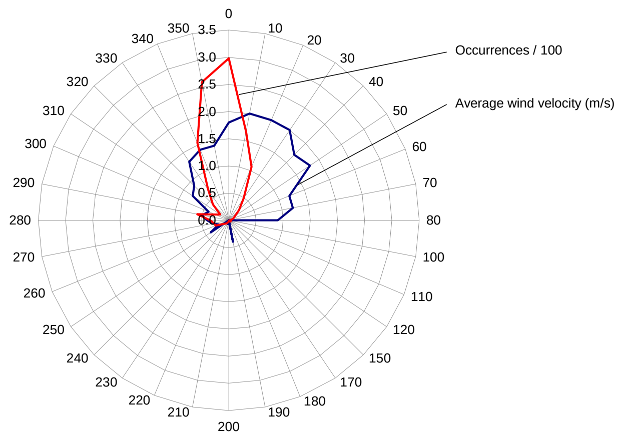


Figure 4 : local wind data (average wind velocities and occurrences vs. wind direction)

FIRST RESULTS

Humidity sensitive grilles

By putting humidity sensitive grilles in place of grilles with constant aperture, it was necessary to show again that these products ensure a good air quality throughout the year.

So, next charts (Figure 5) show the evolution of the repartition of points (relative humidity; aperture) per month. The linear curves stand for the manufacturing admitted tolerances of the grille. Outdoor absolute humidity is lower in winter than in summer. This explains the localization of the points throughout the year; in winter time, the points are mostly located in a range of low relative humidity. In summer time, they mainly fill high relative humidity range. However, whatever the season is, aperture of grilles remains proportional to relative humidity.

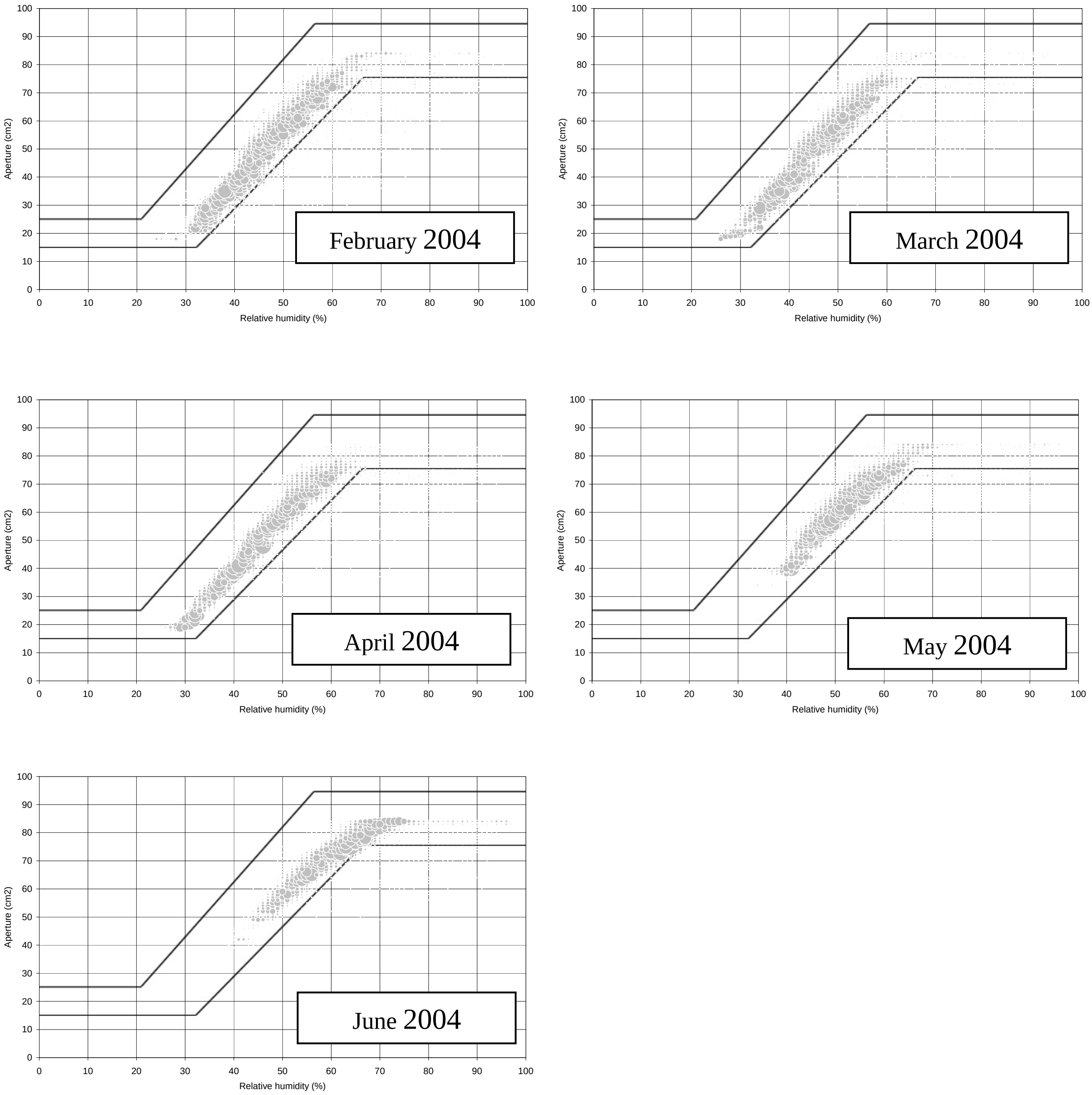


Figure 5 : Distribution of points (relative humidity; aperture) per month

In spite of these positioning differences during the year, we notice that locally grilles undergo wide variations of relative humidity. In the same time, apertures vary almost simultaneously on the complete range of relative humidity (cf. Figure 6). The theoretical aperture curve stands for the response of a “perfect” humidity sensitive grille (with no hysteresis and a reaction time equal to zero)

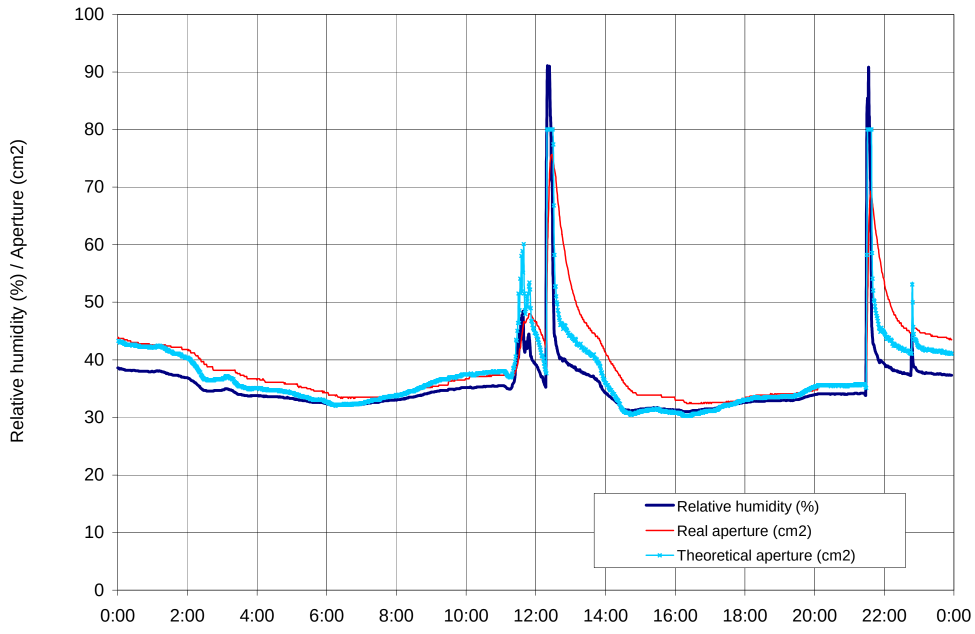


Figure 6 : Aperture vs. relative humidity

By focusing on the abrupt increasing (less than 5 minutes) and decreasing, it shows that reactivity of humidity sensitive grilles is smaller than a few minutes (Figure 7). The average error between the real and the theoretical apertures during the whole day is less than 1.5 cm^2 (i.e. 3.8%)

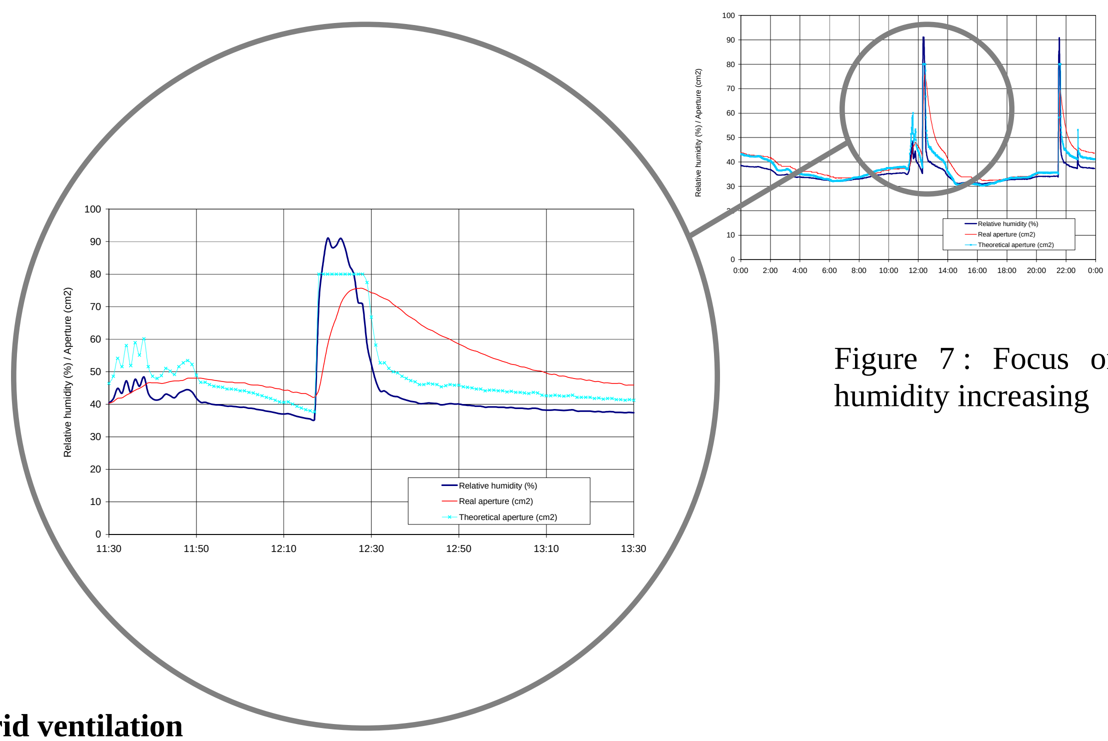
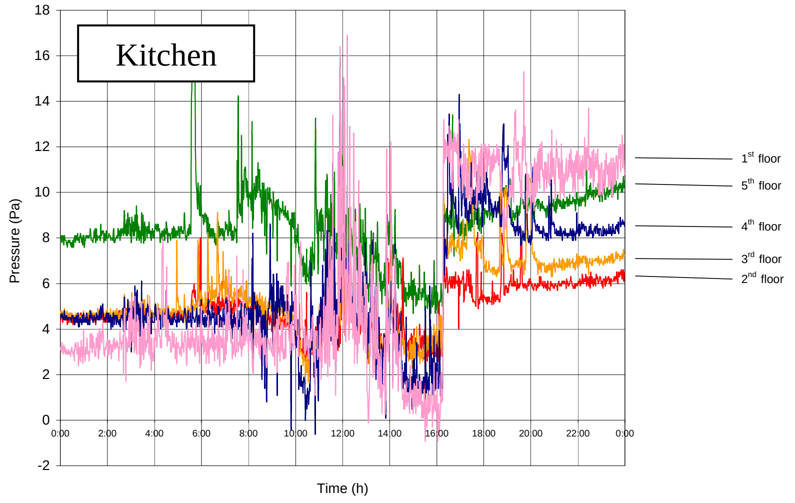
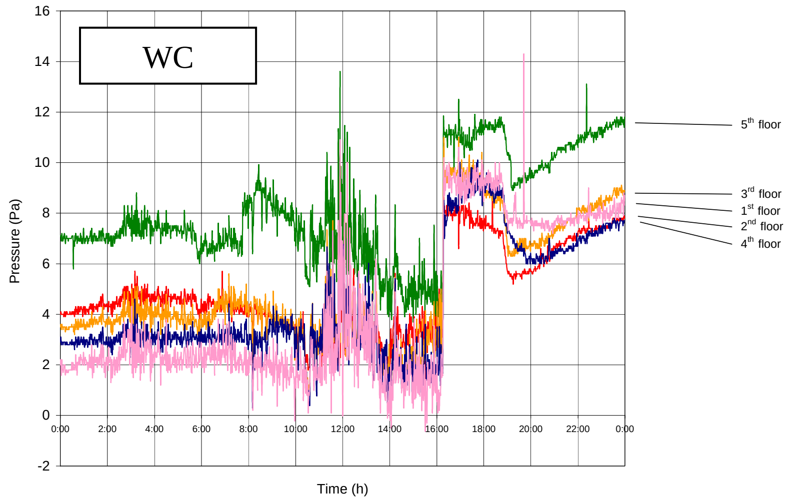


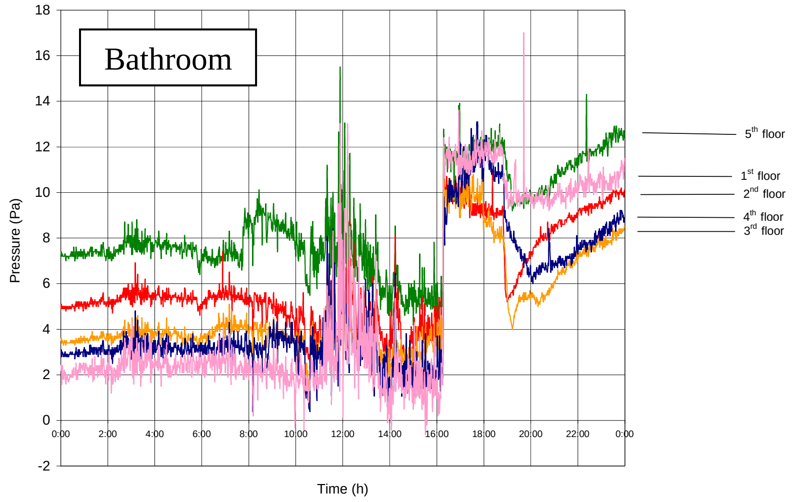
Figure 7 : Focus on humidity increasing

Hybrid ventilation

HR-VENT monitoring includes the installation of low pressure assistance fans in place of the usual static roof units. Next charts show variations of the pressure differences every minute at each level for the kitchen column, WC column and bathroom column of a same building. At about 16:00 pm, fans have been installed and plugged in.







This exchange leads to a real improvement of pressures differences. When there were a few reverse airflows just before the exchange (in particular in kitchen), there were absolutely no more with the mechanical assistance.

CONCLUSION

The scope of such a project required the setup of a specific database. After 6 months, more than 140 million of values have been recorded. The teachings wealth is as large as the quantity of data. However explicit these few examples are, a statistical study will help us to define more accurately advantages and limits of this new hybrid ventilation system. Indeed, it will be interesting to show a trend of the previous passive stack ventilation performances in comparison with the new ones. Influences of indoor and outdoor conditions are being analyzed to show that the system has been fit to the existing one without decreasing the efficiency of the usual network. The interest of this retrofitting is going to be shown by characterizing that:

- All reverse airflows have been eliminated
- Pressure differences in kitchen are compatible with the use of domestic boilers
- Airflow differences are limited between different floors (combined system of fan assistance and humidity sensitive grilles)
- Airflows are stabilized
- Acceptable air renewable rate is reached

REFERENCES

Savin, J.L., Jardinier, M. and Siret, F. (2004). "In-situ performances measurement of an innovative hybrid ventilation system in collective social housing retrofitting". *25th AIVC conference.*

Siret, F. and Jardinier, M. (2004). "High accuracy manometer for very low pressure." *25th AIVC conference.*

NUMERICAL AND EXPERIMENTAL DEVICE FOR LOCAL CONTROL OF VENTILATION

N. Cordier[1] and P. Michel[1]

[1] *Ecole Nationale des Travaux Publics de l'Etat, Département Génie Civil et Bâtiment, Laboratoire des Sciences de l'Habitat. ENTPE DGCB LASH, Rue Maurice Audin 69120 Vaulx-en-Velin, France.*

ABSTRACT

Local control of ventilation in large buildings is considered to be a main issue in energy savings regarding the huge energy losses that are usually induced by such large volumes. An efficient ventilation system and the development of local control ventilation strategies could prevent large buildings from having an unsuited or overvalued ventilation and reduce significantly the energy consumption. Considering the issue of developing such strategies, both pollutant dispersal and heat transfer models, based on Computational Fluid Dynamics codes, have been developed in Science Buildings Laboratory (LASH) in Lyon. The models are used for numerical tests of established control ventilation strategies, while an added experimental device allows to perform experimental validation.

KEYWORDS

Indoor Air Quality, Large Buildings, Local Control of Ventilation, Experimental Set-up, CFD, Modeling.

INTRODUCTION

The ventilation systems should be thought today so as to adapt the airflows to the real occupation of premises, in order to have better control on the energy consumption due to the renewal of indoor air, while maintaining an acceptable level of indoor air quality to ensure both comfort and hygiene of occupants. Large buildings are considered then, because of their highly intermittent and localized activies, to be the ones on which the reductions of the energy consumptions could be the highest, if they were equipped with ventilation systems adapted to the real needs (Barbat, 2000). A local control of ventilation within the large volumes allows to reduce significantly the energy spending related to unsuitable and overvalued airflows in the areas of very low occupation.

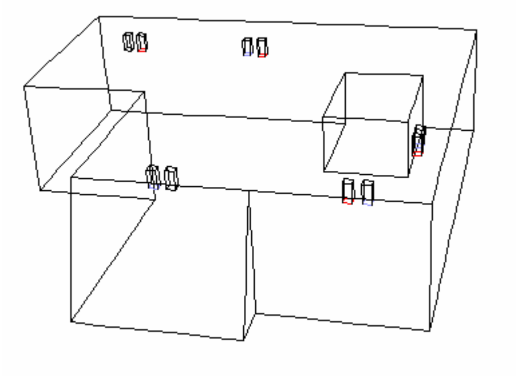
Regarding the development of future strategies of local control of ventilation, pollutant dispersal and heat transfer numerical models and an experimental device were realized to be afterward able to test and validate such strategies.

The ventilation's control should ensure a satisfactory indoor air quality and an acceptable internal comfort for the occupants. The setting of the algorithms of control will base themselves then on the precise knowledge of several characteristic parameters of air quality and comfort. The thermal comfort will be estimated by the indicator PMV, presented as an effective indicator allowing to integrate all the main parameters of comfort (Bruant, 1997), while the indoor air quality will be characterized by the concentration in pollutant CO_2. The choice of the CO_2 as a characteristic parameter is justified by the fact that, being given the office activity that is practised within the experimental premise, the occupants appear then as the main source of pollution, because of their metabolic activity. Carbon dioxide becomes then the main pollutant of indoor air and the control of its content, directly linked to the occupation of the premise, allows to ensure good indoor air quality (Woods et al, 1982, Liddament, 1996).

The aim thus was at first to elaborate a numerical model of the experimental premise that was able to calculate for the entire volume all the parameters defining the indicator PMV, to characterize thermal comfort, as well as the dispersal of the CO_2, for evaluating indoor air quality. At the same time as the development of the model, the setting of an experimental device was made to allow to test and validate the model, and to perform field testing on the strategies of local control ventilation developed.

EXPERIMENTAL PREMISE PRESENTATION

A premise of the Building Sciences Laboratory (LASH) was used for the setting of the experimental device. This premise presents all the geometrical characteristics allowing to consider it as a large building, as well as a complete ventilation and warming/cooling system with an air distribution network perfectly adapted to the field testing of strategies of local of control ventilation developed.



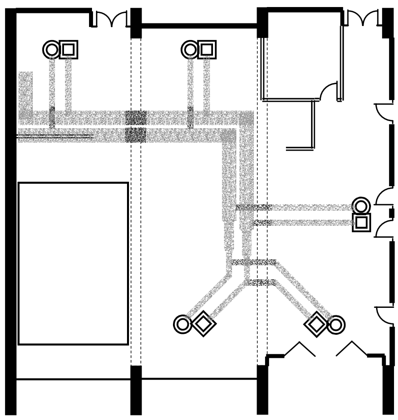


Figure 1 : Visualization of experimental premise

The premise appears as a large volume with horizontal dimensions of 16 m on 15 m, and a height under ceiling of 4,35 m, for an approximate volume of 950 m^3. It is equipped with two fans, one blowing fan and one extracting fan, for a maximum airflow of 6000 m^3/hour each, and with reversible hot air pumps, allowing to change the temperature of blowing, and so that the indoor thermal conditions. The air distribution network consists in 5 pairs of extracting and blowing diffusers distributed on the entire volume (cf. Figure 1).

NUMERICAL MODELING

A global heat transfer and pollutant dispersal model of the experimental premise described above has been developed to allow numerical testing of the local control of ventilation strategies established.

Heat transfer modeling

The heat transfer model was developed using the Computational Fluid Dynamics code given by FLUENT®.

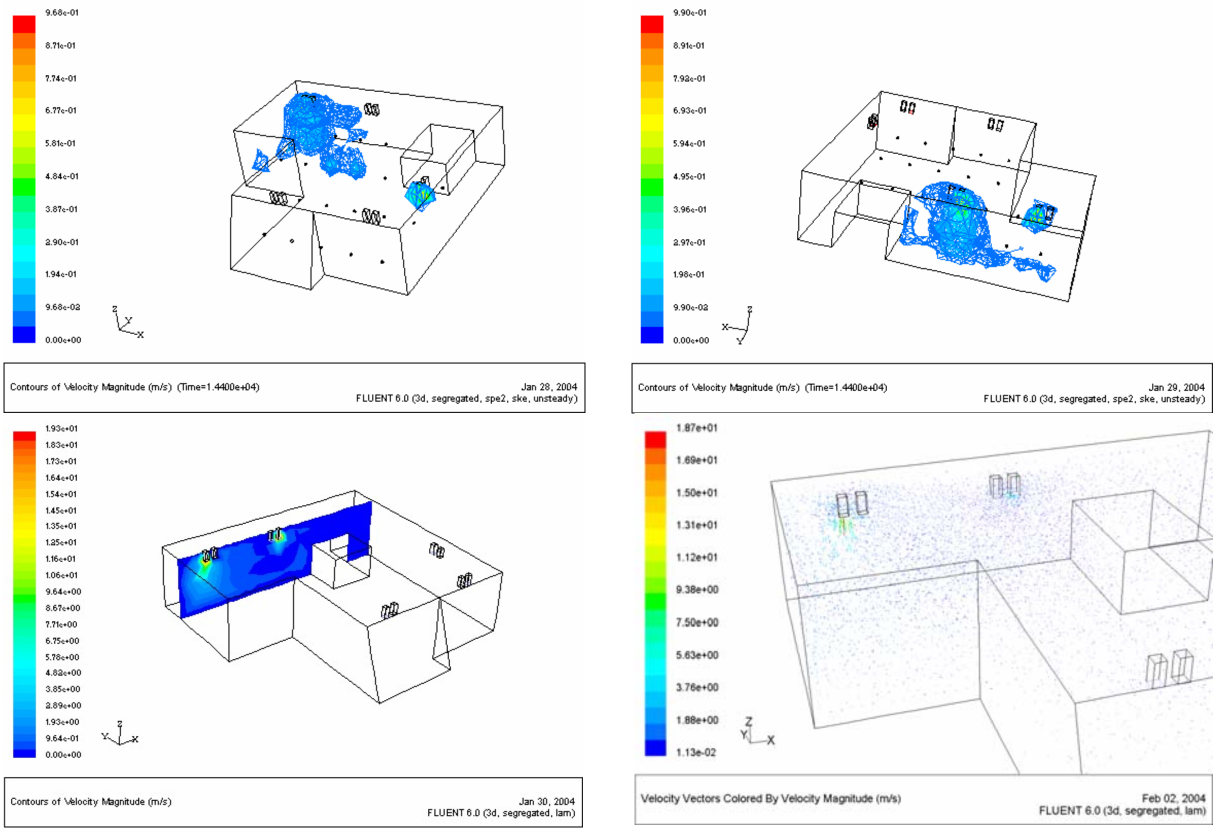


Figure 2 : Visualization of simulations realised with FLUENT

The building's geometry was simplified in a way to improve the performances, in terms of calculation's time, of the heat transfer model. Some geometrical features, having a small effect on air distribution inside the premise, were so abolished during the geometrical modeling. In the same way, the geometrical peculiarities linked to the blowing and extracting diffusers of the air distribution network were minimized so that they could have been simply modeled.

It was then necessary to proceed in a set of campaigns of experimental measures to calibrate the model, and in the second time, to validate it. The model so developed allows henceforth to determine the airflow, as well as the temperature distribution and the relative moisture content inside the entire volume of the experimental building (cf. Figure 2).

Pollutant dispersal modeling

Once the heat transfer model validated, a parallel model of dispersal of pollutant was developed, to provide, from knowledge of occupation inside the premise, the dispersal of the pollutant within entire volume. Even there, the model was established from the CFD code FLUENT.

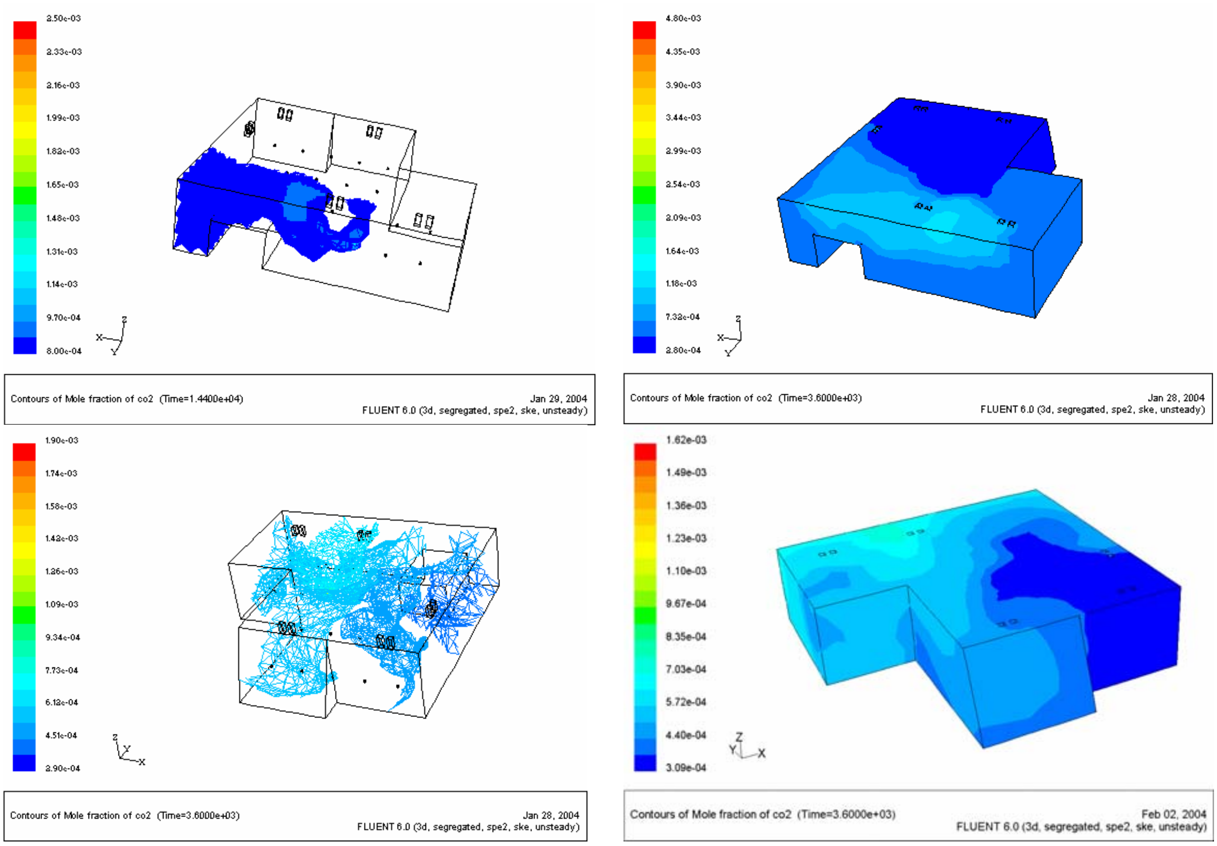


Figure 3 : Visualization of CO_2 dispersal inside the experimental premise

The pollutant that was considered to assess the indoor air quality inside the building is the CO_2. This pollutant was chosen considered the activities practised inside the premise, which are primarily office activities. The occupation (number and position of occupants) was translated into terms of carbon dioxide production, on the basis of the information provided by the guide of the AIVC (Liddament, 1996). It is henceforth possible, thanks to this model, to determine, from information of occupation and activity, the dispersal of the CO_2 inside the experimental building (cf. Figure 3).

EXPERIMENTAL SET-UP

While developing numerical models, an experimental device was conceived to perform experimental measurements to validate the models, and also to perform, afterward, tests of local control of ventilation strategies in a real situation. The premise was so equipped with a complete system of acquisition and command, automatically piloted.

Acquisition and command centre

A cockpit was installed in the experimental premise, in order to have a control over the whole device. The network of air distribution and air treatment is linked to an acquisition and command system giving information from sensors positioned within the premise, and controlling many device, such as fan’s speed or VAV’s opening. A PC computer is so installed and equipped with an acquisition card presenting analogical and digital functions, and being able to be used in several applications to automate and control equipments. The acquisition and the command is made by means of a user interface developed with Labview program.

Acquisition system

The acquisition system of the experimental device supplies all the information used in the local control of ventilation strategies. In the case of our study, the system consists in video cameras installation that can provide images of the premise used for the determination of the occupation, as well as in different sensors. A set of 5 cameras IP provides video images of entire volume. These images are analysed through a computer program that sends back information concerning the occupation. Afterward, this information is translated into terms of pollution source, and will be used for field testing. A set of sensors so allows to get back information about temperature, relative humidity, CO_2 level, and air velocity within the premise. Experimental measures of all these parameters allowed to calibrate, then to validate the numerical model developed beforehand.

Command system

The command system's user can have control on many device composing the air distribution and air treatment network. He so has the control on the speeds of both blowing and extracting fans, air blown temperature, and the openings of VAV of every diffuser of the air distribution network thanks to motors installed on VAV. The chosen motors, of type LMC24-SR-F, from brand Belimo, give the opportunity of a flexible command, from an analogical signal 0-10V. It allows to vary the opening of VAV from 0 to 90 °, and consequently the airflow in all the diffusers of the network from 0 to 100 %. The control of the airflows at the extremities of the air distribution network is an essential constituent of the local control of ventilation. All these commands allow to have a complete control on ventilation's system of the experimental premise.

The experimental device so developed allowed, by the continuous acquisition of data on various parameters of indoor air, provided by numerous sensors, to make the validation of the numerical models developed beforehand. It will afterward be used to apply and test in real situation the future strategies of local control of ventilation.

CONCLUSION

The experimental and numerical device which was conceived in the Building Sciences Laboratory (LASH) in a suitable experimental premise is now efficient for tests of strategies of local control of ventilation. The numerical models of pollutant dispersal and heat transfer developed allow numerical tests of the strategies, while the experimental device, with a complete acquisition and control centre, allow to perform field testing for future validation of the developed strategies.

REFERENCES

Barbat, M. (2000). *Contribution au développement d'un contrôle optimal de la ventilation dans les locaux de grandes dimensions*. Thèse de Doctorat. INSA, Lyon.

Bruant, M. (1997). *Développement et paramétrage de contrôleurs flous multicritères du confort d'ambiance*. Thèse de Doctorat. INSA, Lyon.

Emmerich, S. J. and A. K. Persily (1997). Literature review on CO_2-Based Demand-Controlled Ventilation. *ASHRAE Transactions* **103 : 2**, 229-243.

Ke, Y.-P. and S. A. Mumma (1997). Using Carbon Dioxide Measurements to Determine Occupancy for Ventilation Controls. *ASHRAE Transactions* **103 : 2**, 365-374.

Lepers, S. (2000). *Modélisation des écoulements de l'air dans les bâtiments à l'aide des codes CFD. Contribution à l'élaboration d'un protocole de validation*. Thèse de Doctorat. INSA, Lyon.

Persily, A. K. (1997). Evaluating Building IAQ and Ventilation with Indoor Carbon Dioxide. *ASHRAE Transactions* **103 : 2**, 193-204.

Woods, J.E., Winakor, G. et al (1982). Subjective and objective evaluation of a CO2-controlled variable ventilation system. *ASHRAE Transactions* **88 : 1**, 1385-1393.

Liddament, M.W. (1996). *A Guide to Energy Efficient Ventilation.* Air Infiltration and Ventilation Center.

EXPERIMENTAL AND NUMERICAL STUDIES ON INDOOR AIR QUALITY IN A REAL ENVIRONMENT

J.-J. A. A. Akoua[1], F. Allard[2], C. Beghein[2], B. Collignan[1], J. R. Millet[1]

[1] *C.S.T.B. - Centre Scientifique et Technique du Bâtiment, Marne la Vallée – France*

[2] *L.E.P.T.A.B. - Laboratoire d'Etude des Phénomènes de Transferts Appliqués au Bâtiment– La Rochelle, France*

ABSTRACT

This paper deals with the relevance of Computational Fluids Dynamics (CFD) results confronted to measurements carried out under uncontrolled thermal conditions. Experimental tests have been undertaken in a room and in a kitchen of an experimental house. Although the wall surface temperatures and the air intake temperature have not been imposed, the air change rates have been controlled during the measurements. Moreover, since measurements have been carried out in a real environment, air leakage has occurred at the walls. Thereafter, measurements have been used to define boundary conditions of CFD simulations.
As a result, it can be stated that as long as air leakage is slight during the experimental tests, satisfactory agreement is observed between CFD results and measurements.
However, in the case where experimental tests are carried out in a room with significant air leakage, the quality of the numerical results has been decreased since this phenomenon is not considered in the CFD model. For this case, a simplified hypothesis of modelling has been proposed and validated to deal with air leakage effects and thus to improve the accuracy of CFD results.

KEYWORDS

Indoor Air Quality (IAQ), measurements, CFD, air leakage modelling.

NOMENCLATURE

- C_e, C_P air pollutants concentration respectively at the exhaust opening and at a point P (kg/m^3)
- Dc, D_e laminar molecular diffusivity of respectively air contaminant and the mixture component e in air (m^2/s)
- g gravity acceleration (m/s^2)
- H height of the test room (m)
- m_e mass fraction of the element e of the mixture: air + air pollutant (-)
- M_{air} molar mass of air (= 28.97 g/mol at T=293 K and P =101325 Pa)
- M_C, M_e molar mass respectively of an air contaminant and of the element e of the mixture studied (kg/mole)
- P pressure of the fluid (Pa)
- q mass flow rate of air pollutant (kg/s)
- Q air flow rate (m^3/s)
- $Q_{leakage}$, Q_{red} air leakage rate and reduced air flow rate (m^3/s)
- R universal constant of gas
- S_I area of the natural air inlet (m^2)
- T temperature (K)
- T_{inlet}, T_{room} Air temperature at inlet and averaged temperature of the room (K)
- $-\overline{u_i' m_e'}$ turbulent mass fluxes (m^2/s^2)
- V_a Air molar volume (=20.1 cm^3/mol at T=293 K and P =101325 Pa)
- V_C contaminant molar volume (cm^3/mol)
- x_i coordinates: x, y, z (m)

Greek symbols

- β_T coefficient of volumetric expansion due to temperature change (K^{-1})
- β_C coefficient of volumetric expansion due to concentration change (m^3/kg)
- μ laminar dynamic viscosity (kg/m.s)
- ρ_{air} air density (kg/m^3)

Dimensionless number

- Ar_T thermal Archimedes number (-)
- Ar_c solutal Archimedes number (-)
- N_B ratio of thermal convection force on solutal convection force

1. INTRODUCTION

Since we spend 90 % of our time in enclosed spaces, indoor air quality becomes an important parameter, especially for our health. It is thus important to handle effective ventilation systems in order to obtain and/or to maintain a good quality of indoor air. Ventilation efficiency can be experimentally and numerically analysed. The numerical analysis is useful to deals with details of the internal flow and contaminant distribution. In so doing, Computational Fluids Dynamics (CFD) constitutes one of the best numerical tools. It has been validated by confronting its results to measurements [Nielsen (1974), Allard (1990)]. However, excepted the researches of Zeng et al (2000) which compared CFD results with measurements realized in a portable classroom, few studies have confronted CFD results to in situ measurements.

This paper deals with the relevance of CFD results confronted to in situ measurements.
Indeed, measurements have been carried out in a room and in a kitchen of an experimental house. The wall surface temperatures and the air intake temperature have not been imposed during the experimental test. Nevertheless, the air change rates have been controlled during the measurements.
Measurements have been used to define boundary conditions of CFD simulations. Thereafter, the quality of the CFD results is analysed.

2. EXPERIMENTAL SET-UP AND PHENOMENOLOGY OF THE FLOWS

2.1 Case of the room

Experimental tests are carried out in a room the experimental house MARIA of CSTB, Riberon et al (2002). The wall surfaces temperatures and the air intake temperature are not imposed. Nevertheless, the air flow rate is controlled at 18 m^3/h via a mechanical exhaust. This experimental test constitutes thus a transition between measurements in cell tests where all boundaries conditions are controlled and in situ measurements.

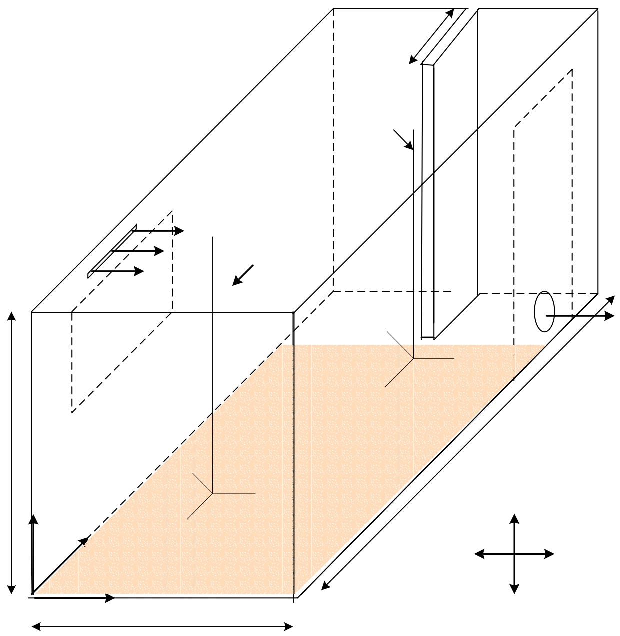


Fig. 1: Layout of the ventilated room

The air exhaust opening is located near the floor and the natural air inlet is located above the top of the room window (see figure 1).

The room has also been equipped with a pine wood floor which emits several VOCs considered as air pollutants here. The major identified VOC is α-pinene. Since its concentration in the inlet air is very slight, it has been selected as the VOC tracer of the VOCs emitted by the pin wood floor. More details of this experimental set-up is available in Akoua et al (2003).

The mass flow rate of VOC tracer emitted by the floor is evaluated as follows:

$$q = Q.C_e \tag{1}$$

$q = 0.2 \times 10^{-9}\, kg/s$.

The flow physical characteristics can be revealed with the following dimensionless numbers:

- Reynolds number, Re:

$$\mathrm{Re} = \frac{\rho (Q/S_i) H}{\mu} \tag{2}$$

- Ratio N_B:

$$N_B = \frac{\beta_T \left(T_{room} - T_{inlet}\right)}{\beta_C \left(\left(q/Q\right) - C_{inlet}\right)} \tag{3}$$

- Thermal Archimedes number, Ar_T:

$$Ar_T = \frac{g\beta_T \left(T_{room} - T_{inlet}\right) H}{\left(Q/S_i\right)^2} \tag{4}$$

- Solutal Archimedes number Ar_C:

$$Ar_C = \frac{g.\beta_C \left(\left(q/Q\right) - C_{inlet}\right).H}{\left(Q/S_i\right)^2} \tag{5}$$

The solutal Archimedes number for mass transfer is analogous to the thermal Archimedes number for heat transfer. It characterises the motion of fluid due to density differences generated by variations of the air pollutant concentration. Expression of the solutal Archimedes number comprises the coefficient of volumetric expansion due to concentration change:

$$\beta_C = -\left(\frac{1}{\rho}\right).\left(\frac{\partial \rho}{\partial C}\right)_{P,T} \tag{6}$$

Based on ideal-gas theory, β_C can be calculated as follows, Tiffonet (2000):

$$\beta_C = -\frac{V_M \left(M_C - M_{air}\right)}{V_M C_C \left(M_C - M_{air}\right) + M_C M_{air}} \tag{7}$$

For α-pinene:

β_C = - 0.65 m^3/kg and $\rho_{air}.\beta_C = -0.78$

Physical characteristics of the experimental test are summarized in table 1.

TABLE 1

Physical characteristics of the internal flow of the room.

Q	Re	Ar_T	Ar_C	$\lvert N_B \rvert$
18 m^3/h	2×10^5	0.3	5×10^{-9}	6×10^7

Implications:

- Value of thermal Archimedes number is small ($Ar_T < 1$). This thus suggests that effects of thermal convection are slight compared to convective effects of the forced flow due to the mechanical ventilation. Furthermore, the flow is almost isothermal. Nevertheless, this value of the thermal Archimedes number does not allow us to consider that the internal flow is completely isothermal. For this, it would have been necessary to have $Ar_T << 1$.
- Value of solutal Archimedes number is very small ($Ar_c << 1$). Therefore, effects of solutal convection can be neglected compared to the convective effects of the forced flow. Moreover, N_B value indicates that effects of solutal convection are slight compared to effects of thermal convection. As a result, the VOC tracer can be considered as a passive gas whose distribution is mainly governed by the thermoaeraulic field.

2.2 Case of the kitchen

Measurements are also carried out in the kitchen of the experimental house MARIA of CSTB. Air flow rate of the kitchen is controlled at 120 m^3/h via a hood. This ventilation rate corresponds to recommendations of French standards for high speed of mechanical exhaust in dwelling kitchens, journal official (1982).

Schematic diagram of the kitchen investigated is shown in figure 2.

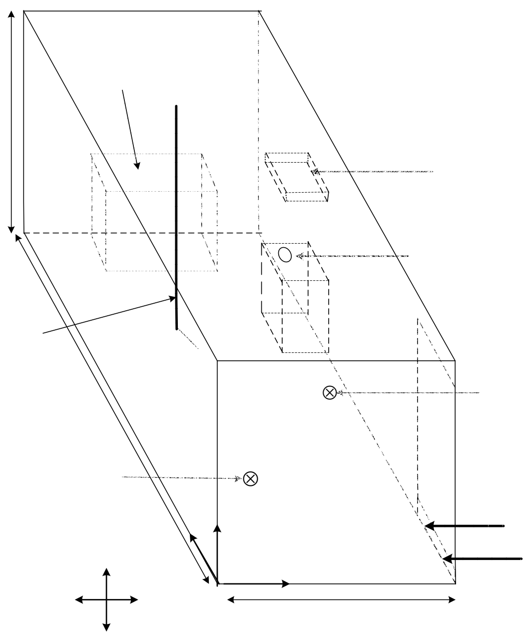


Figure 2. Schematic diagram of the kitchen investigated

The experimental set-up realized here is based on a French normative test used to assess efficiency of kitchen hoods, NF E 51-704.
However, this experimental test does not exactly correspond to the normative test. Indeed, unlike the normative test relevant to the study of the dynamics of pollutant extraction, the stationary field of pollutant concentration is studied here. In addition, the experiments were carried out in a real kitchen, not in an experimental cell as in the normative test. Therefore, walls surface temperatures and the air intake temperature could are not imposed.
The kitchen studied is also equipped with an electric cook-top. Its temperature is controlled at 110°c as in the normative test NF E 51-704. A pan is put on it.

The vapours of cooking are studied using a tracer gas (SF_6) which passes through a pan.

More details on this experimental set-up are available in Akoua et al (2004).

Moreover, physical characteristics of the internal flow of the kitchen are dealt with dimensionless number. Table 2 indicates values of these dimensionless number values.

TABLE 2

Physical characteristics of internal flow of the kitchen.

Q	Re	Ar_T	Ar_C	N_B
120 m^3/h	$3.4 \times 10^{+5}$	2.6	1.5×10^{-3}	$3.9 \times 10^{+3}$

Implications :

- Value of Reynolds number suggests turbulent flow in the kitchen.
- Value of thermal Archimedes number indicates that the flow is non-isothermal. Effects of natural thermal convection and the convective effects due to the mechanical ventilation are of the same order of magnitude.
- Solutal Archimedes number value is very less than 1. As a result, natural solutal convection due to non-uniformity of SF_6 distributions has globally slight effects on the forced convection due to the mechanical ventilation. Moreover, $N_B >> 1$.Effects of the natural solutal convection are also slight compared to effects of the natural thermal convection.

3. CFD SIMULATIONS

3.1 The numerical model

A CFD code based on "Finite Volume Method" (Fluent®) is used to numerically explore the internal flows pattern.

In the case of the room studied, the pine wood floor is considered as a solid body source of VOCs. It is assumed that it is not submitted to any adsorption phenomena of VOCs. Moreover, α-pinene is selected as tracer of VOCs emission. It is considered as a pollutant gas which has any chemical interactions with indoor air.

It is previously shown that the VOC can also be considered as a passive gas (cf.: section 2.1).
However, there may be significant concentration differences close to the pollutant source. Therefore, in the numerical model, the internal fluid is considered as a species mixture: air plus α-pinene.

In the case of the kitchen, the internal fluid is also considered as species mixture: air plus SF_6.

Whatever the case studied, the species mixture are supposed to be completely mixed. The flow is also supposed to be weakly turbulent and non-isothermal.

The mathematical equations to be solved are Navier-Stokes equations: conservation equations of continuity, of momentum and of energy.
In addition to these previously equations, an equation of species conservation is solved to deal with the distribution of the air pollutants (α-pinene or SF_6). It takes the following form:

$$\rho \overline{u_j} \frac{\partial m_e}{\partial x_j} = \frac{\partial}{\partial x_i}\left(\rho D_e \frac{\partial m_e}{\partial x_i} - \rho \overline{u_i^{'} m_e^{'}} \right) \tag{8}$$

The mixture density is defined as follows:

$$\rho(T, m_e) = \frac{P}{RT \sum_e (m_e / M_e)} \tag{9}$$

In order to solve the conservation equation of pollutant concentration, the mass diffusivity of the pollutant (α-pinene or SF_6) in air is needed. Tucker et *al* (1990) recommend using FSG method to evaluate the molecular coefficient of diffusion of a contaminant in air:

$$D_C = \frac{10^{-3} T^{1.75} \sqrt{(M_a + M_C)/(M_a M_C)}}{P\left(V_a^{1/3} + V_C^{1/3}\right)^2} \tag{10}$$

Where P is the pressure (in *atm.*)

At T = 25 °C (298 K), the coefficients of diffusion of α-pinene, $(C_5H_8)_2$, and of SF_6 in air are respectively:

$D_{\alpha-pinene}$ = 6 ×10^{-6} m^2/s.

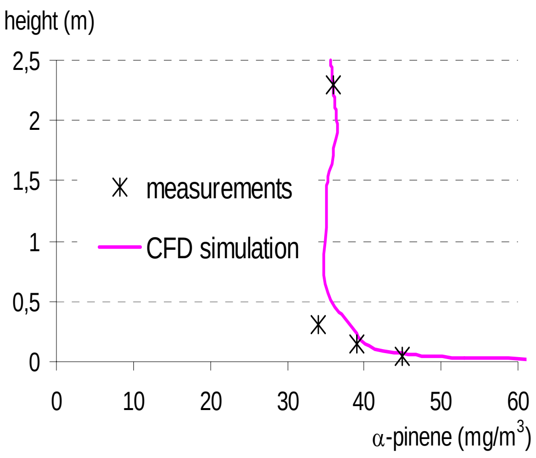
D_{SF_6} = 8.96 ×10^{-6} m^2/s.

Moreover, effects of turbulence on the flow are dealt with "realizable" k-ε model, Shih et al (1995). This is an improvement of the standard k–ε model, Lauder et al (1972).

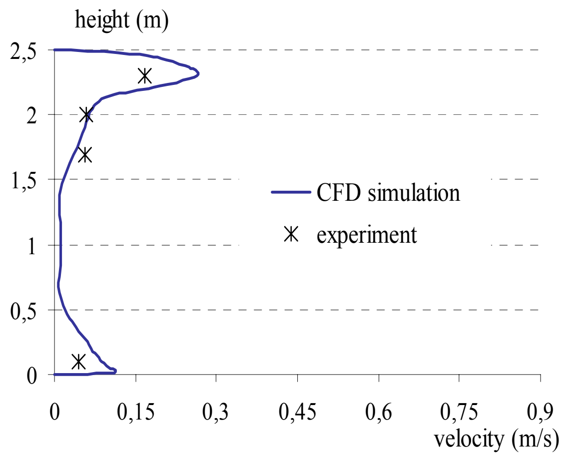
It proposes a new formulation of the eddy viscosity and a new model of the equation of dissipation rate (ε). This model is supposed to allow a better representation of the spectral energy transfer. It has been extensively used for a wide range of flows where its superiority has been established for flows including boundary layers under strong adverse pressure gradients, separation and recirculation, Shih et al (1995).

3.2 CFD results compared to measurement carried out in the room

Numerical profiles of α-pinene concentration and of air velocity are compared to measurements on figure 3. Measurements probes of α-pinene concentrations are set on the vertical stick 2 located in the volume of the room. Thermo anemometrical probes are set on the vertical stick 1 located front of the air inlet (see figure 1).



(a) α-pinene concentration



(b) air velocity

Figure 3: CFD profiles compared to measurements

Satisfactory agreements are noted between CFD results and in situ measurements carried out in the room.

3.3 CFD results compared to measurement carried out in the kitchen

Figure 4 compared numerical profile of air velocity to measurements carried out front of the kitchen air inlet (see figure 2).

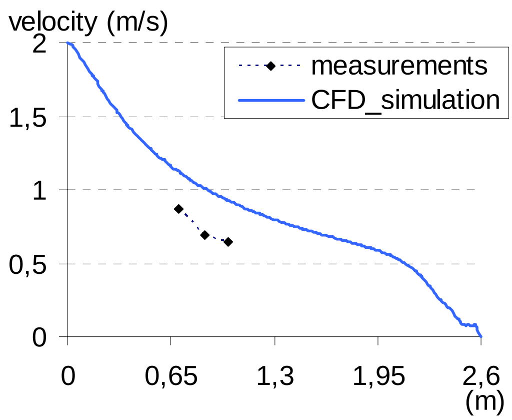
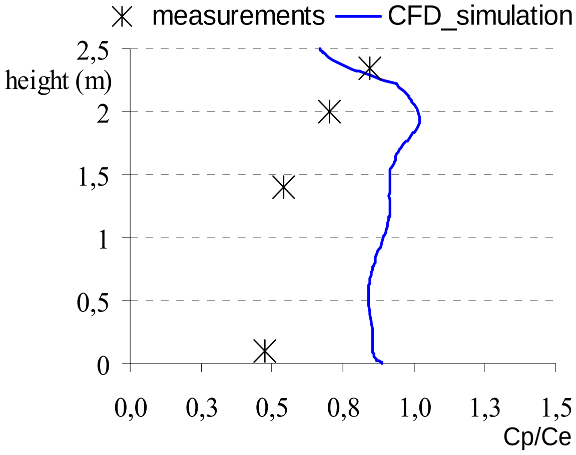
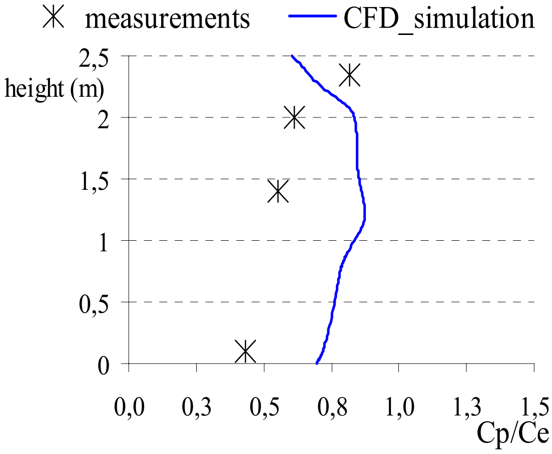


Figure 4: CFD profile of air velocity compared to measurements realized front of the air inlet

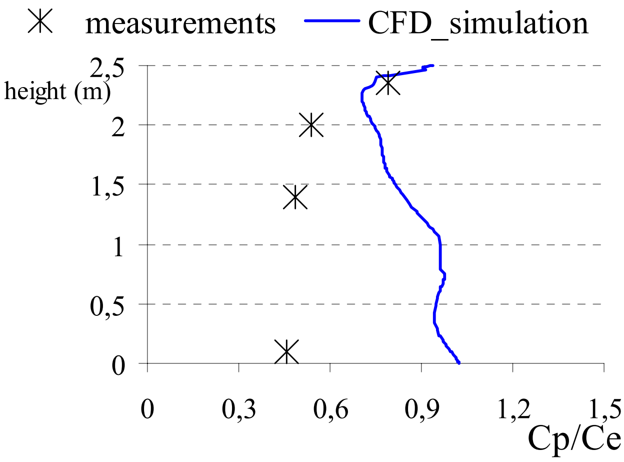
Figure 5 compared numerical profiles of SF_6 concentration to measurements realized in the kitchen.



(a): stick located on the position 1



(b): stick located on the position 2



(c): stick located on the position 3

Figure 5: CFD profiles of SF_6 concentration compared to measurements

Where Cp and Ce represent SF_6 concentrations respectively at a measurement point P and at the exhaust. Moreover, within the kitchen, the measurements probes are situated on a vertical stick. Its different locations during the measurements series are indicated on figure 2.

Figure 4 and figure 5 show that the CFD results do not correspond to measurements. This can be explained by the air leakage influence. Indeed, the measurements series have been realized in real environment. Therefore, air leakage has occurred at the walls. However, the numerical model handled in this paper does not take into account the air leakage. The next section analyses air leakage influence on the quality of the CFD results.

4. TOWARD AN IMPROVEMENT OF THE CFD RESULTS QUALITY

4.1 Influence of the air leakage

This section deals with analysis of the air leakage influence on the quality of CFD simulations. In so doing, the air leakage rates at the walls of the room and the kitchen are evaluated as followings, Moyé (1985):

$$Q_{leakage} = K.(\Delta P)^n \tag{11}$$

Where n is a constant which is generally equal to 2/3. K is also a constant. ΔP indicates the pressure difference between indoor environment and the exterior of the local studied.

Air leakage rates at the walls of the room and the kitchen are indicated on table 3

TABLE 3

Air leakage rates of the walls of the local studied (the room and the kitchen)

	$\Delta P(Pa)$	$Q_{leakage}$	Q	$Q_{leakage}/Q$
room	0.1	1.2 m^3/h	18,2 m^3/h	6 %
kitchen	5	17 m^3/h	120 m^3/h	14 %

Based on the data of the table 3, the followings points can be noted:

- Air leakage rate at the room walls is estimated to 1.2 m^3/h. This corresponds to 6 % of the fresh air which does not pass by the inlet air. Fortunately, when performing CFD simulations with boundaries conditions given by the measurements realised in the room, satisfactory quality of the CFD results is obtained although the air leakage is not taken into account in the numerical model (cf.: figure 3). The air leakage rate which represents 6 % of the room air flow rate has thus slight influence on the internal flow.

- Air leakage rate at the kitchen walls is estimated to 17 m^3/h. This indicates that, during the measurements, 14 % of the fresh air does not pass by the inlet located under the door (see figure 2). This air leakage is significant enough to decrease the quality of the numerical results since this phenomenon is not considered in the CFD model (cf.: section 3.3).

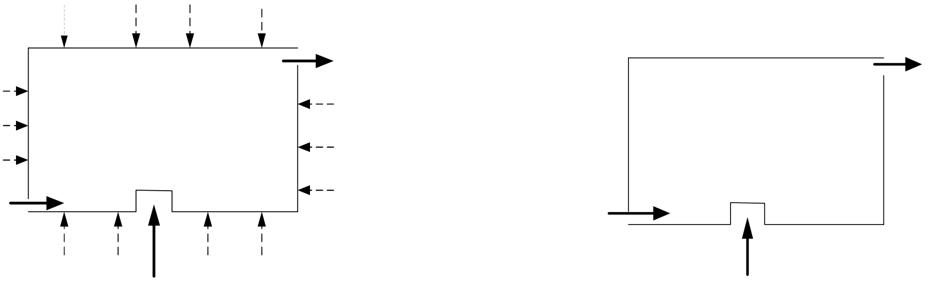
4.2 Simplified hypothesis of air leakage modelling

As shown in the section above, in the case of the kitchen, the air leakage is significant during the experimental test. It has to be taken into account in the numerical model when performing CFD simulations with boundaries conditions given by this experimental test.

In this purpose, it would have been necessary to solve $Q_{leakage} = K.(\Delta P)^n$ at the walls of the calculation field. This needs the knowledge of the pressure difference between indoor environment and the exterior of the local studied. That is currently very difficult to realize here.

As an alternative, a first level of air leakage modelling is proposed in this section. It consists in handling a reduced ventilation rate at the mechanical exhaust:

$$Q_{red} = Q - Q_{leakage} \tag{12}$$



(a): basic model (b): simplified hypothesis of modelling

Figure 6: simplified hypothesis of modelling to deal with the kitchen air leakage

Numerical profiles obtained with this hypothesis of air leakage modelling are compared to measurements in figure 7 and figure 8.

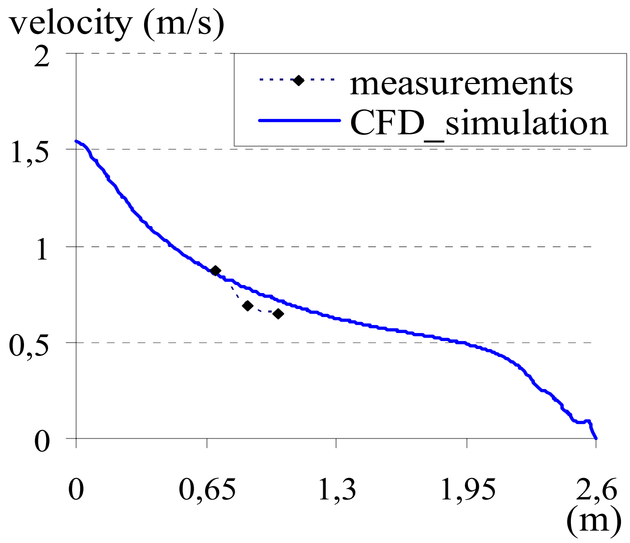
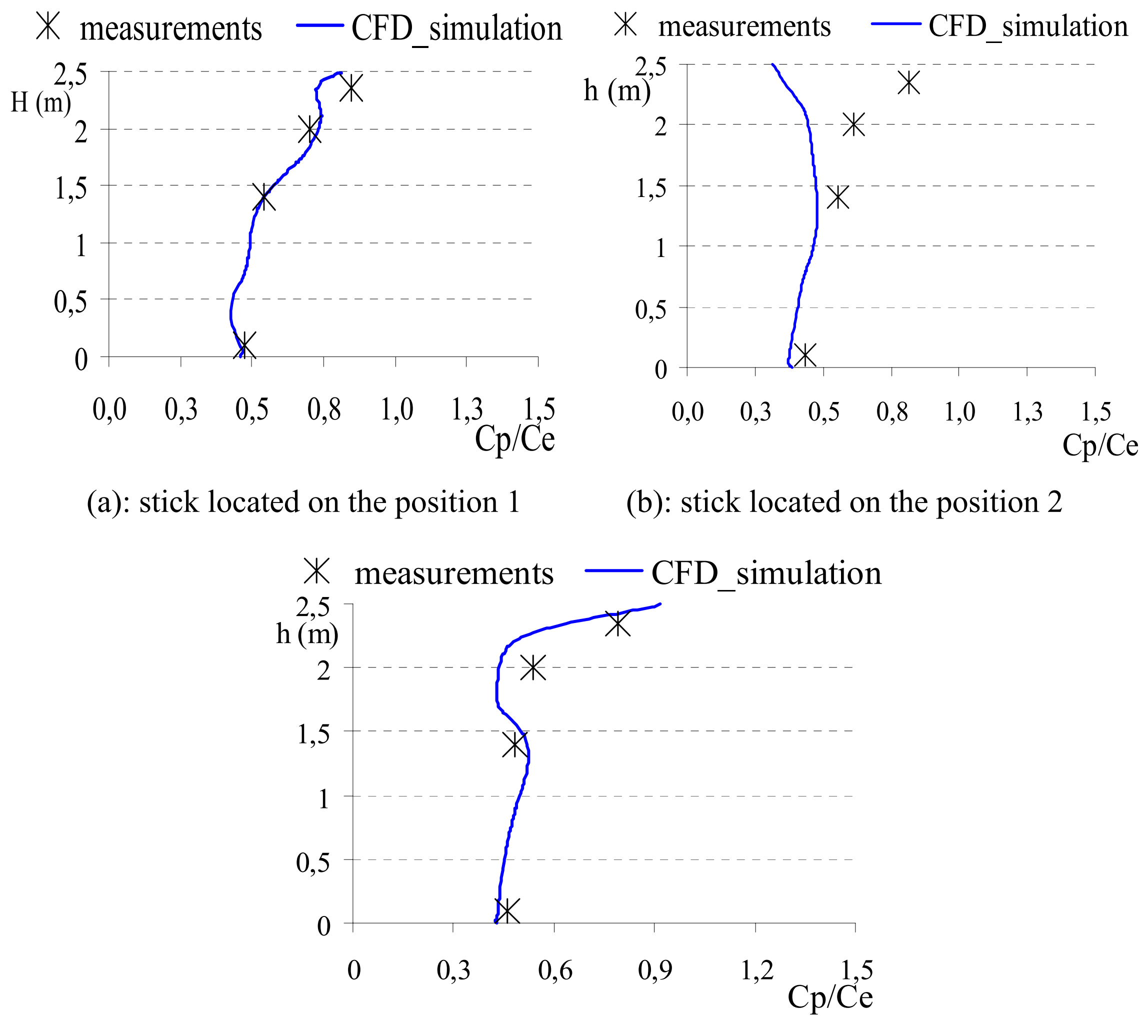


Figure 7: CFD profile of air velocity compared to measurements realized front of the air inlet



(c): stick located on the position 3

Figure 8: CFD profiles of SF_6 concentration compared to measurements

As shown on the figure 7 and the figure 8, the quality of the CFD results is globally improved by the air leakage modelling which handles a reduced ventilation rate: $Q_{red} = Q - Q_{leakage}$. However, numerical profiles of SF_6 concentrations do not correspond to measurements realized front of the air inlet (cf: figure 8_(b)). Indeed, the CFD calculations underestimate the SF_6 concentration in the air located front of the kitchen door.

This can be explained by the conservation equations of mass, momentum, energy, etc., used to model the internal flow (cf.: section 3.1). Indeed, since the mass flow rate is modified when using a reduced ventilation rate ($Q_{red} = Q - Q_{leakage}$), the solution of these equations is also modified. Therefore, the internal flow pattern obtained with the simplified hypothesis of air leakage modelling can not correspond to the reality.

To numerically deal with the real internal flow of the kitchen, it would have been necessary to solve equation $Q_{leakage} = K.(\Delta P)^n$ at the walls of the calculation field. This is currently very difficult to realize in CFD calculations.

5. CONCLUSION

This paper dealt with the quality of CFD results confronted to in situ measurements. In so doing, measurements have been carried out in a room and a kitchen of the experimental house MARIA. These in situ measurements have been used as boundaries conditions of CFD simulations. Thereafter, qualities of the numerical results have been analysed.

As a result, it is stated as long as the CFD simulations performed with boundaries conditions given by measurements carried out in a local with slight air leakage, satisfactory quality of numerical results is noted although air leakage is not considered in the CFD model. This situation is verified in the case of the room studied.

However, in the case of CFD simulations performed with boundaries conditions given by measurements carried out in a local with significant air leakage, the quality of the numerical results are decreased since this phenomenon is not considered in the CFD model. This situation is verified in the case of the kitchen studied in this paper.

To consider the air leakage in the numerical model, it would have been necessary to solve the equation $Q_{leakage} = K.(\Delta P)^n$ at the walls of the calculation field. Unfortunately, this is currently very difficult with CFD code.

As an alternative, a simplified hypothesis of air leakage modelling has been proposed. It allowed an improvement of CFD results quality.

However, the internal flow modelled with this last hypothesis can not exactly correspond to the reality.

Indeed, the mass flow rate changes when using a reduced ventilation rate ($Q_{red} = Q - Q_{leakage}$). As a result, due to the Navier-Stokes equations handled in the CFD calculations, the internal flow pattern is also modified.

Nevertheless, in the case of CFD simulations with boundaries conditions given by in situ measurements, the simplified hypothesis proposed in this paper can constitute a first level of air leakage modelling to improve the numerical results quality.

References

Akoua, A., Allard, F., Beghein, C. and Collignan C. (2004). *Analysis of indoor air quality in a kitchen*. Proceedings of RoomVent 2004, Coimbra, Portugal, 5th-8th September 2004.

Akoua, A., Collignan, C., Maupetit, F. and Ramalho, O. (2003). *Experimental and numerical VOC concentration field analysis from flooring material in a Ventilated room.* Proceedings of

7th International conference Healthy Buildings 2003, Singapore, 7th-11th December 2003. p.370-375

Allard, F., Inard, C. and Simoneau, J.P. (1990). *Experimental study and numerical simulation of natural convection in a room with heated ceiling or floor.* Engineering aero- and thermodynamics of ventilated room, Proceedings of Room Vent 1990, Oslo, Norway, June 13-15, 1990. p.16

Journal officiel: Arrêté du 24 mars 1982 modifié: dispositions relatives à l'aération des logements.

Launder B. E. and Spalding. D. B. (1972). *Lecture in Mathematical Models of Turbulence* Academic Press, London, England.

Moyé C.(1985), *la perméabilité à l'air des bâtiments d'habitation*. Cahier du Centre Scientifique et Technique du Bâtiment, septembre 1985, cahier 2019. Multiple pagination. (ISBN 2-86891-035-1)

Nielsen P. V. (1974). *Flow in air-conditioned rooms*. Ph.D. Thesis, Technical University of Denmark, Copenhagen. Multiple pagination.

Normalisation française NF E 51-704: Code d'essais aérauliques et acoustiques des hottes de cuisine raccordées à un circuit VMC.

Riberon, J. and O'Kelly, P. (2002). Maria: an experimental tool at the service of indoor air quality in housing sector. Proc. Indoor Air, Monterey, California, 30 June to 05 July 2002. p 191-195.

Shih T.-H., Liou W. W., Shabir A. and Zhu J (1995). A New k-e Eddy-Viscosity Model for High Reynolds Numner Turbulent Flows – Model Development and Validation. *Computers Fluids,* **24**, 227-238.

Tiffonet A (2000*). Contribution à l'analyse de la qualité de l'air intérieur : influence des transports de Composés Organiques Volatils (COV) entre les parois et l'ambiance*. Thèse de doctorat de génie civil et sciences de l'habitat soutenue devant l'université de La-Rochelle le 21/01/2000 p 60.

Tucker, W., A. and Nelken, L., H. (1990). Diffusion coefficients in air and water, chapter 17 of the Handbook of chemical property estimation methods: environmental behaviour of organic compounds. *American Chemical Society, Washington DC* (QD271 .L95 1990 Business/SPEA).

Zeng J., Shaw C.Y., Magee R.J., and Sander D (2000). *Study on ventilation performance and indoor air quality of a portable classroom : field measurement and numerical simulation.* Proceedings of the 7th International Conference on Air Distribution in Rooms, Roomvent 2000. 9 – 12 July 2000, Reading, UK. Vol. 2, p. 1001-1006

RELATIVE HUMIDITY ANALYSIS, RETROFITTING THE SINT-PIETERSCHURCH IN GHENT

M. De Paepe[1], W. Uyttenhove[1], A. Janssens[2]

[1] Department of Flow, Heat and Combustion Mechanics, Ghent University
St-Pietersnieuwstraat 41
9000 Gent
[2] Department of Architecture and Urbanism
J. Plateaustraat 22
9000 Gent

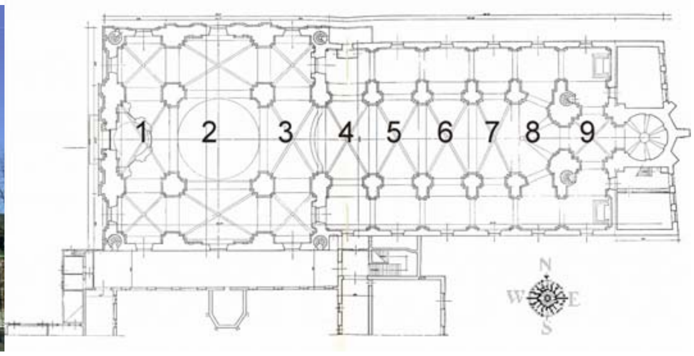
ABSTRACT

The Sint-Pieterschurch in the city of Ghent is ne of the larger churches of the city. It was build in the 17th century. The city council wants to use the church not only for it's religious functions, but also for cultural activities as concerts and exhibitions. To be able to do this the thermal comfort of the visitors has to be guaranteed. At this moment the church has no central heating system. Gas heaters are used during services. Installing a central heating system will influence the humidity and moisture behaviour of the church. As the church contains several important works of art as well as a monumental organ, it is of great importance to analyse the air humidity behaviour of the church. Rapid changes in moisture content of the valuable objects can cause great damage to them.
In this paper CFD (Computational Fluid Dynamics) using FLUENT is used to evaluate the effect of heating on air flow, temperature distribution and relative humidity variation inside the church. Measurements were done inside the church, with special attention being paid to the area around the organ. This way a suitable heating system is selected and an optimum distribution of air inlet can be determined.

KEYWORDS

CFD, heating, relative humidity

THE ST. PIETER'S CHURCH, GHENT, BELGIUM



(a) (b)

Figure 1: Front view (a) and floor plan of the St. Pieter's Church

About 630 AD Saint Amand founded the Sint-Pieters abbey at the highest point of Ghent. The abbey became very famous during the Middle Ages, but in 1566 AD the church and the abbey were badly damaged during the iconoclastic fury. Only in 1629 AD the first stone of the current baroque church was laid (Figure 1 (a)). Today, the church is used for services and

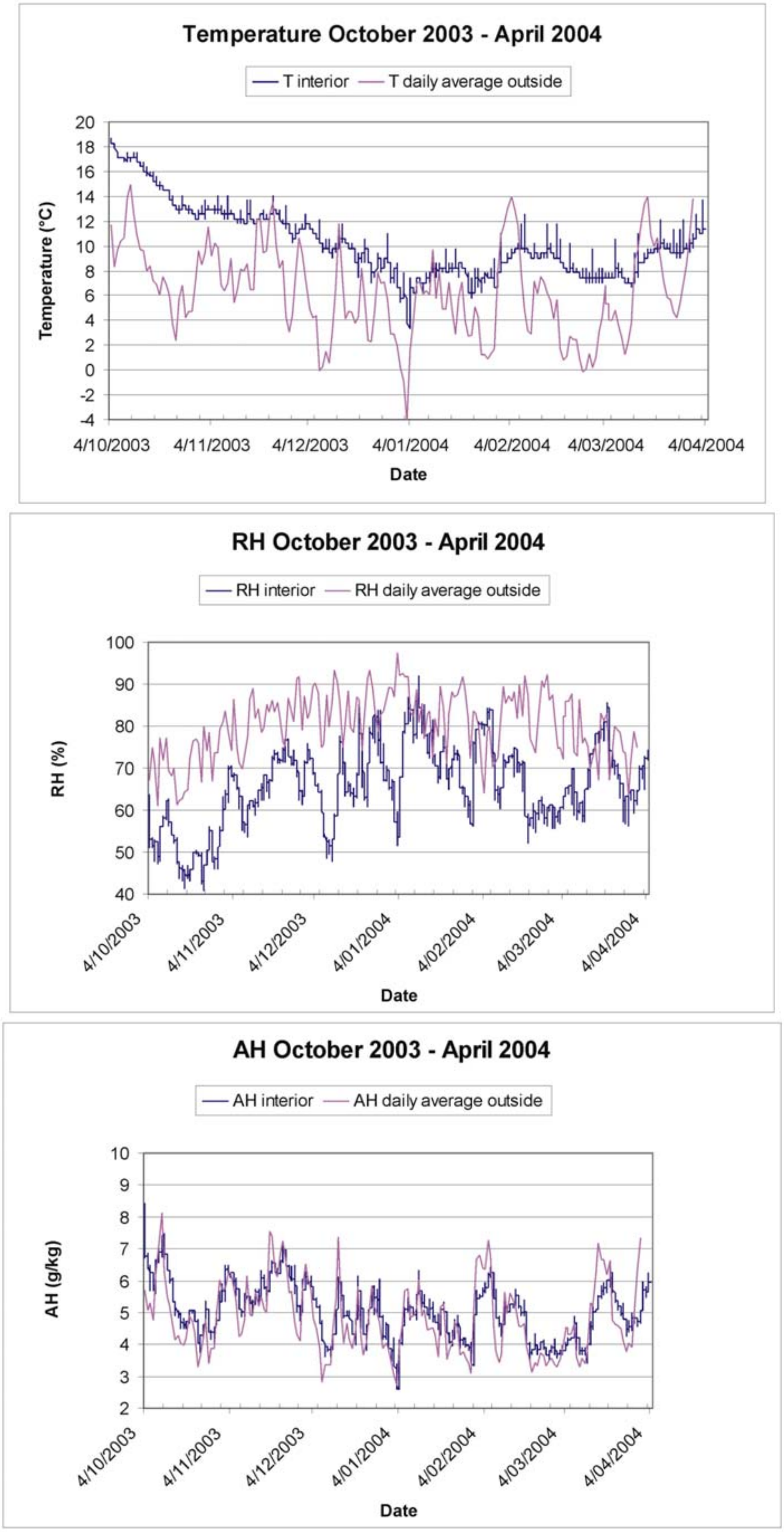


Figure 2: Global results of the measurements

cultural events and the abbey has become a tourist attraction. The St. Pieter's Church is decorated with many paintings and sculptures of famous artists. The monumental organ, built by Van Peteghem, 1849 AD, is an unique work of art (Van Driessche, 1980).

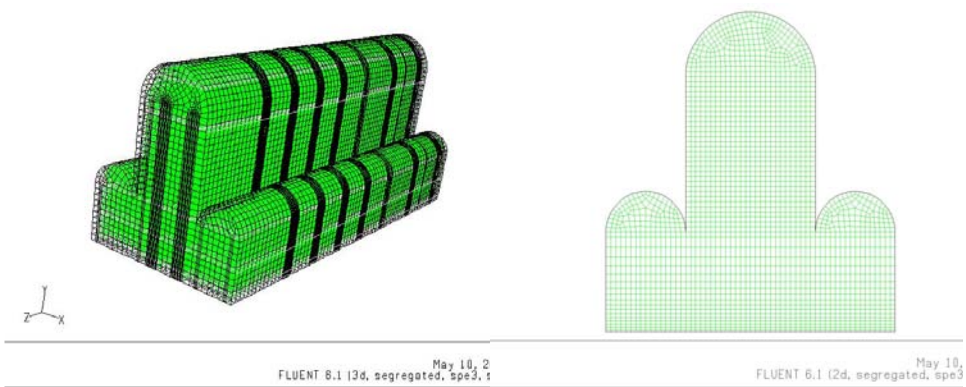
The floor plan is given in Figure 1 (b). The church has a total length of 88 m and a maximal width of 30 m. The internal height is about 17 m in the side aisles, about 32 m in the nave and about 52 m in the dome. With its 74 m, the steeple is the highest point of Ghent. The church walls are made of limestone and masonry and have an average thickness of about 1 m.
At the moment, there is no central heating system in the church. Gas burners fuelled by propane are used to heat the church during wintertime services and cultural events. The installation of a heating system is planned.

Heating causes the inside air relative humidity to drop. This can bring on problems concerning the conservation of historical works of art (Schellen, 2002). Dryer air will reduce the moisture content of for example wood. This may cause the works of art and the monumental organ to suffer from cracks due to shrinking. On the other hand, too humid conditions may cause problems of mould (RH > 80%). In this paper an analysis is made of the current behaviour of the church concerning air humidity, ventilation and moisture storage. This was done by an intensive measurement campaign. Using the obtained data, a CFD-model was built in order to analyse the impact of two heating system in the church : floor heating and convector heating.

MEASUREMENT CAMPAIGN

In October 2003 measurements were started in the church. Temperature and relative humidity (RH) loggers were installed at several points in the building. The global results are given in Figure 2. The temperature decreases from 18 °C in the beginning of October 2003 to 5 °C in January 2004. From March 2004 on the temperature increases. The relative humidity varies between 40 and 90 % and the absolute humidity (AH) varies between 3 and 7 gr/ kgair. There is a time delay between the changes in the indoor and outside climate.

Measurements confirm that the church has a stable climate. The temperature and humidity differences over the church volume are small. The current heating method only influences the indoor church climate locally and for a short time period. A few hours after turning down heaters, their influence disappears. The church can be represented as a large, homogeneous volume, with a low moisture content. Still, the existing situation with high relative humidity in winter is not without risk for mould initiation. With a thermographic camera the wall temperature was measured. Homogeneous surface temperatures were observed.



(a) (b)

Figure 3: 3D calculation model (a) and 2D calculation model (b)

MODELLING TEMPERATURE AND HUMIDITY DISTRIBUTION IN FLUENT

Calculation grid

To see the temperature and humidity distribution over the church a three dimensional calculation model was created. Some effects can be studied in two dimensions, which significantly reduces calculation time. Figure 3 shows the 3D and 2D grid.

Heat losses

Measurements in the church indicated the restricted heat losses by leakage. The main part is caused by heat transport through the walls. It is not easy to determine little losses through cracks and windows and their influence in this model is neglected. Therefore the walls are set as fixed temperature surfaces as boundary condition in FLUENT. The wall temperature is depending on the outside temperature. The estimated U-coefficient of the wall is 0.98 W/m².K.

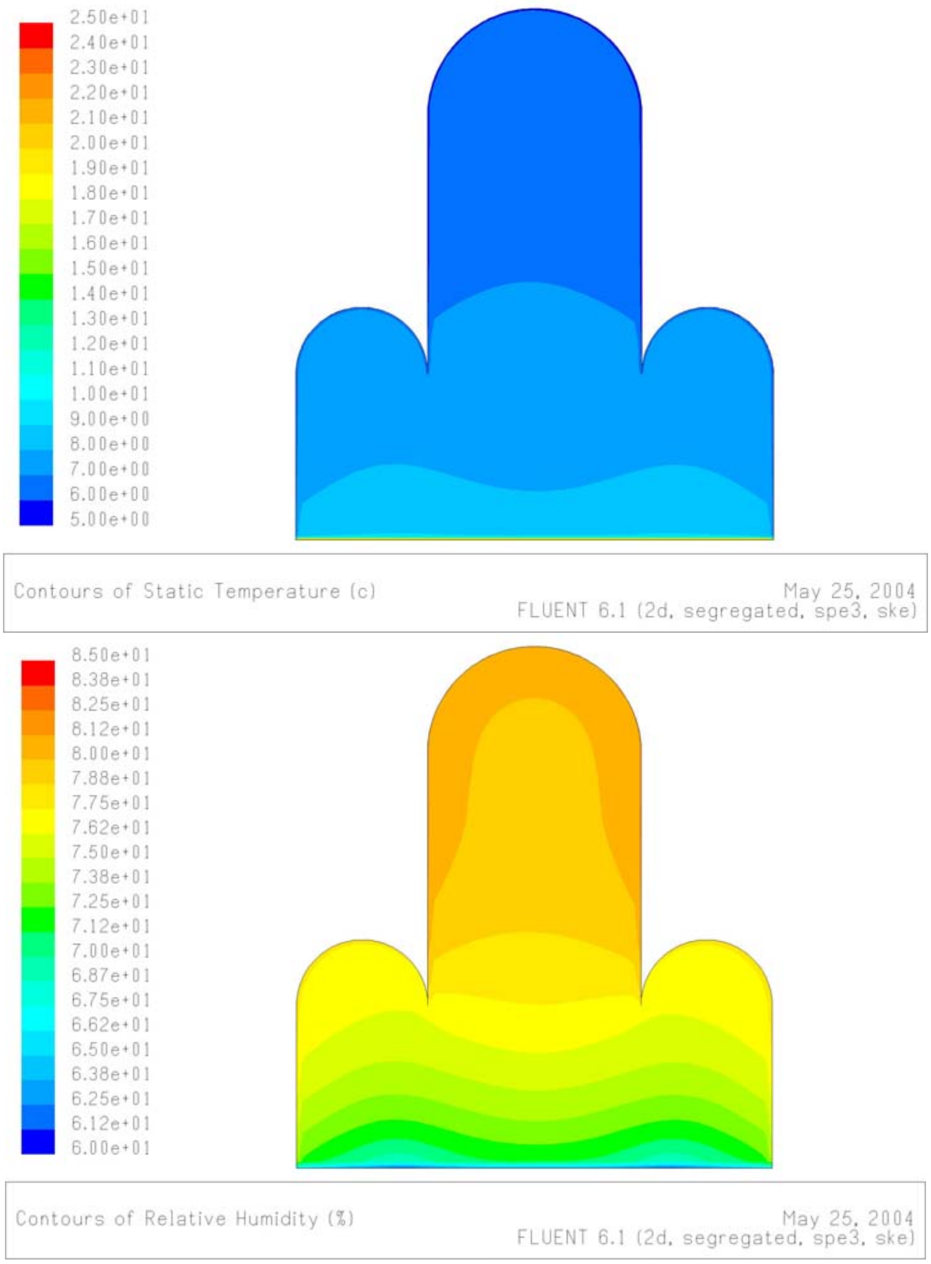


Figure 4: Floor heating simulation

Floor Heating

Modelling floor heating in FLUENT can preliminary be done in a 2D model. The whole floor is implemented as a fixed temperature wall boundary condition. FLUENT solves the energy equation by balancing the incoming and outgoing heat flows, taking buoyancy into account. Calculations were made for a typical winter day assuming an outdoor temperature of 1 °C. Floor temperature was set to 25 °C. The temperature inside the church obtained out of the simulation is on average 7 °C (Figure 4). This is not sufficient. It is thus not possible to heat the St. Pieter's Church to a sufficient level without reaching an excessively high floor temperature. The height of the church is too big in comparison to the (floor)surface available for heating. With a moisture content of 4,87 gr /kg air the relative humidity varies from 60 to 85 %.

It is clear that for detailed simulations, a more precise determination of the wall characteristics is necessary. Although this model gives a general view on the heat loss, suitable for this church.

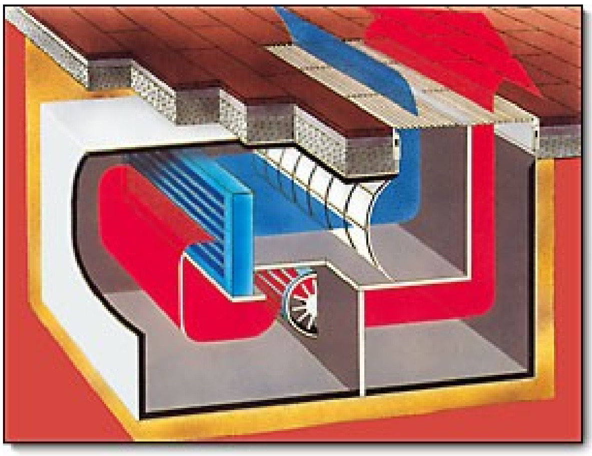


Figure 5: Mahr convector well

Convector well Heating

A convector well heating system is planned for the retrofit. Hot water will be distributed to convector wells spread around the church, where a heat exchanger will create hot air. Through the grille on floor level, cold air will be heated and the hot air will be expelled (Figure 5), as described in (Mahr 2004). This decentralised heating system can produce a maximal power of 35 kW per convector well. To simulate the effect of this heating system in FLUENT, the inlet of a convector well is defined as a velocity inlet, with a velocity magnitude of 0,4 m/s and an incoming temperature of 25 °C. The outlet is defined as a pressure outlet. The heat losses through the walls are defined as described above.

In Figure 6 the balanced situation is shown in the 3D model for a simulation with 18 convector wells with a heat input of about 5 kW each. The convector wells create a very homogenous temperature distribution and the church is heated till 11 °C. The relative humidity varies between 25 and 63 %. Despite the approximations, it is clear that sufficient heating causes low local relative humidity.

CONCLUSION

At the moment the Sint-Pieters church in Ghent has a fairly stable indoor climate, without any dry out or condensation problem. Installing a good heating system in the St. Pieter's Church is not obvious. Two possibilities are evaluated in FLUENT. In view of the building characteristics of the church, floor heating is inadequate. Convection wells can deliver enough heat, but the evolution in the relative humidity has to be taken into account.

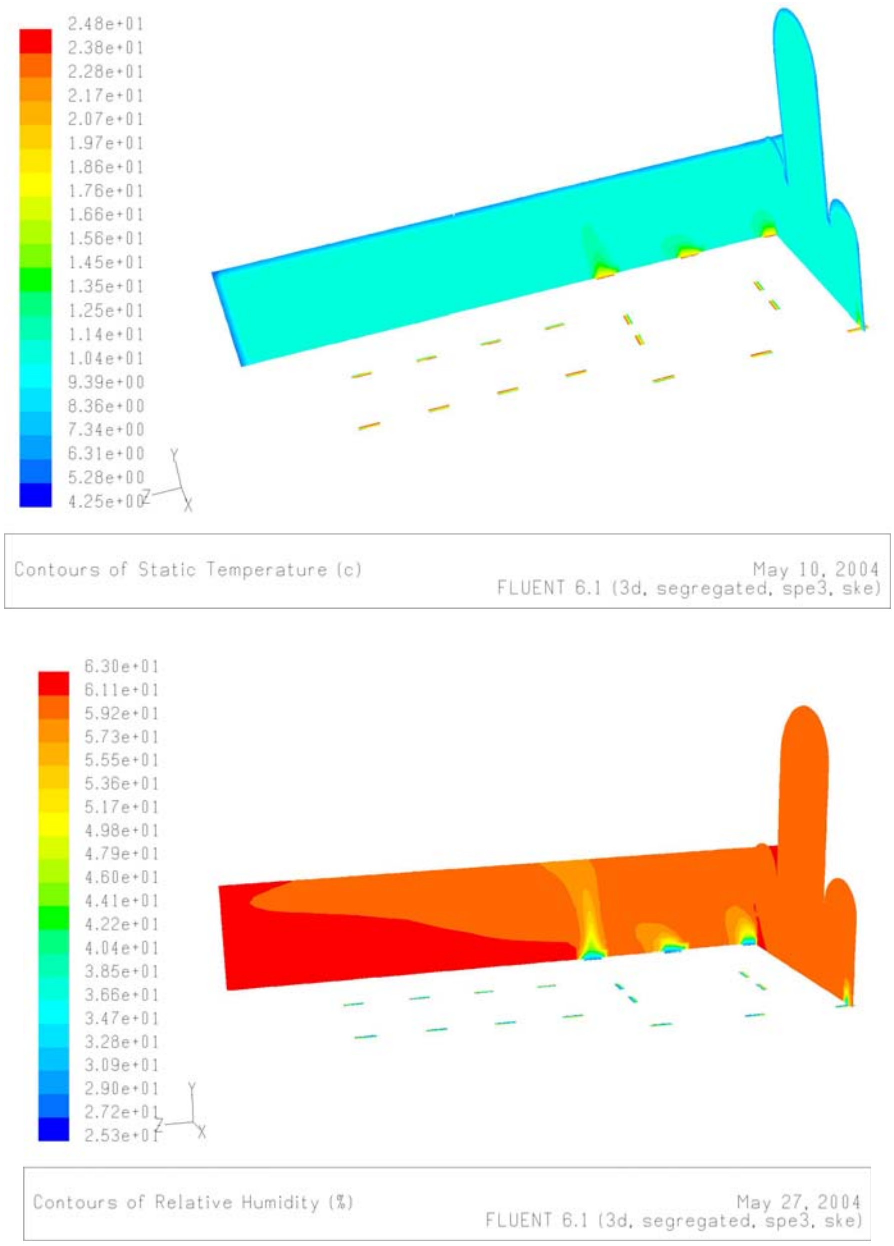


Figure 6: Convector well heating simulation

REFERENCES

Mahr (2004), *Mahr church heating systems.* http://www.mahr-heizung.de.

Schellen, H. (2002). *Heating of Monumental Churches.* Technical University Eindhoven, ISBN 90-386-1556-6.

Van Driessche, R. (1980). *De Sint-Pietersabdij te Gent, Archeologische en Kunsthistorische Studie.* Maatschappij voor Geschiedenis en Oudheidkunde Gent (In Dutch).

INDOOR CONDITIONS IN ULTRA-LIGHTWEIGHT STUCTURES: A CASE STUDY

Luigi Marletta[1], Gianpiero Evola[1], Fabio Sicurella[1]

[1]*Department of Industrial Engineering,*
University of Catania, Catania, 95125, Italy

ABSTRACT

Steel truss structures, covered with a PVC thin sheet of matt light colour, were used in recent time for the construction of three new classrooms in the University of Catania (southern Italy). Although the construction was fast and cheap, the classrooms proved to be uncomfortable in relation to thermal and luminous environment.
A first analysis revealed that the drawbacks were caused by the ultra-lightweight of the structure as a whole, resulting in thermal discomfort. Furthermore, the matt light colour gave raise to an excessively uniform luminous environment, with occurrences in discomfort glare.
To correct the architectural errors, a simple technical solution was adopted in one of these classrooms.
Before and after the intervention, the thermal and luminous parameters were recorded. In addition the thermal sensations experienced by the students were collected by a questionnaire. The comparison of the two set of data shows that the new design resulted in beneficial effects.
Final remarks are made about the relationship between ultra-lightweight structures and local climate.

KEYWORDS

Thermal comfort, visual comfort, lightweight structures, questionnaires.

INTRODUCTION

In 1997 three new classrooms were built in the University Campus of Catania (Southern Italy) to meet the increasing number of students. These classrooms were realised by means of a steel truss structure, covered by a PVC spread fabric of matt light colour. Low conductive panels were used for the vertical walls, and single-pane windows and doors were set up. The floor extension is 15 x 15 m^2 for each classroom, with 222 seats.
The fruition of these classrooms resulted in many complaints because of the discomfort conditions related to the acoustic, thermal and visual environment. As a consequence, the managers decided to bring corrective intervention in order to improve the indoor quality.
An extensive measurement campaign was carried out to detect the main causes of this discomfort and to propose effective technical solutions. The results of this campaign are reported in a previous paper (Compagno and Marletta, 2000).
A PVC spread fabric double ceiling appeared to be a cheap and easy solution to limit the high radiant heat transfer and the excessive illuminance levels (Figure 1). In order to investigate the real effectiveness of this solution, the following procedure was carried out:

1. Application of the PVC double ceiling in one of the classrooms (classroom B);
2. Measurement of the physical parameters to evaluate the real environmental conditions;
3. Comparison between classroom B and classroom A (where there is no PVC double ceiling), based on the results of the measurements.

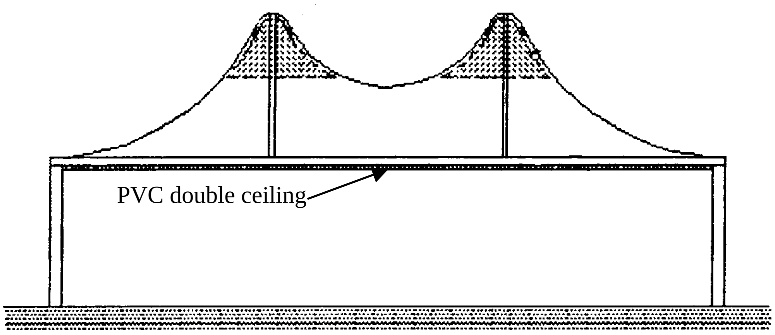


Figure 1: Vertical section of the classroom B, after the adoption of a PVC double ceiling.

METHODS

The data were collected from March to May 2001 by means of a multi-channel apparatus. The measurements were carried out according to the ISO Standards (ISO, 1994) (ISO, 1996); antemeridian and postmeridian measurement sessions were organized, and an apparatus sampling rate of 10 minutes was used. Tables 1 to 3 report the climatic local conditions, the main features of the classrooms and the examined physical parameters.

Then, the PMV and PPD indexes were determined assuming I_{CL} = 0.5 clo and M = 1 met as to the clothing's thermal resistance and the occupants' metabolic rate, respectively. The illuminance levels were measured at 0.8 m from the floor.

To complete the measurement campaign a questionnaire, prepared by the Authors in accordance with ISO requirements (ISO, 1995), was distributed and filled in by more than 300 students, in order to compare the measured data to the real perceived sensations.

TABLE 1
Climatic conditions

Location	University Campus (Catania, Italy)
Latitude	37°30' N
Altitude	150 a.s.l.
Distance from the sea shore line	3 km
Climate type	Temperate subtropical
Max/min outdoor temperature (July)	31/22°C
Max/min outdoor temperature (Jan.)	14/8°C
Max solar irradiance	900 W/m^2 (on horizontal surface)

TABLE 2
Main features of the classrooms

	CLASSROOM A	CLASSROOM B
Year of construction	1997	1997
Persons per room	222	222
Floor surface	15x15m	15x15m
Frame	Steel truss	Steel truss
Wall material	Insulated boards	Insulated boards
Roof material	PVC spread fabric	PVC spread fabric
Adopted technical solutions	None	A PVC double ceiling

TABLE 3
List of measured parameters.

TYPE		DESCRIPTION	UNIT	SYMBOL	
				Indoor	Outdoor
Thermal	Measured	Dry bulb temperature	°C	T_{dbi}	T_o
		Wet bulb temperature	°C	T_{wbi}	T_{wbo}
		Globe temperature	°C	T_g	-
		Air velocity	m/s	V_i	V_o
	Calculated	Relative humidity	%	RH_i	RH_o
		Mean radiant temperature	°C	T_{mr}	-
		Predicted Mean Vote	-	PMV	-
		Predicted Perc.of Dissatisf.	%	PPD	-
	Inquired	Mean Vote	-	MV	-
		Percentage of Dissatisfied	%	PD	-
Optical	Measured	Illuminance	lux	E	-

RESULTS

Because of the lightweight of the structure, the indoor air temperature is strongly influenced by the outdoor conditions. Figure 2 shows that the difference between indoor and outdoor air temperature is very low in both the examined classrooms (A, B). This effect is most relevant in the classroom A, where the temperature gap lays around 2 °C, and the profiles of the indoor and the outdoor temperature are nearly homotetic, due to the extremely low thermal mass of the building. In the classroom B, thanks to the adoption of the PVC double ceiling, the indoor air temperature keeps lower than classroom A. The space between the roof and the PVC sheet is not ventilated, so significantly reducing convective heat transfer.

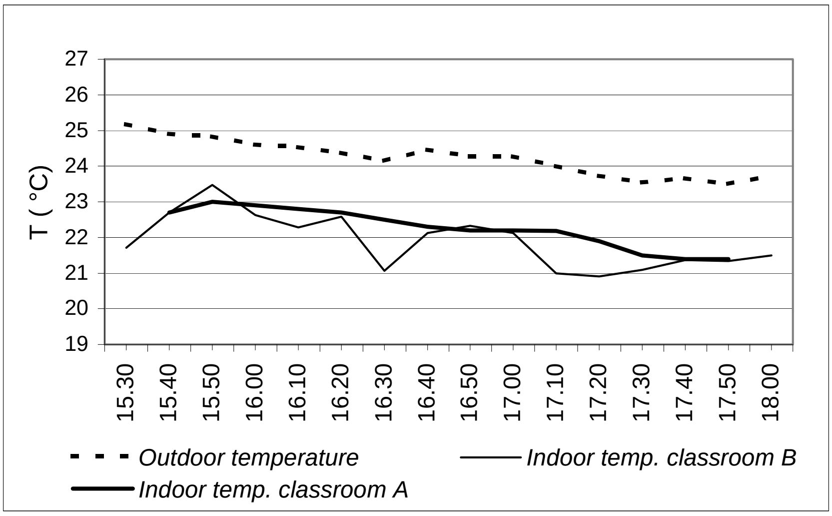


Figure 2: Comparison between the outdoor temperature and the indoor temperature of classroom A and classroom B.

But the main effect of the PVC double ceiling is related to the reduction of the solar radiation transmitted through the ceiling. Figure 3 shows that the difference between the mean radiant temperature (T_{mr}) and the dry bulb indoor air temperature (T_{dbi}) in the classroom A is generally higher than 4°C, while in classroom B this value falls to about 2 °C, so that this environment can be classified as "thermally moderate". The mean radiant temperature has been calculated by means of Eqn. 1 (ASHRAE, 1992):

$$T_{mr} = T_g + k \cdot \sqrt{V_i} \cdot (T_g - T_{dbi}) \quad (1)$$

Here k = 2.2, T_g is the globe temperature, measured through a spherical shaped sensor, and V_i is the indoor air velocity (m/s), measured by an anemometer.

According to the measured data, PMV and PPD have been then calculated following the Fanger's theory (ISO, 1994). Figure 4 shows the PMV profile determined during a measurement session in May; the predicted sensation evidently gets worse in the hottest hours of the day. As a consequence, PPD index is negatively influenced, too. A similar trend has been obtained for classroom B, but PMV values keeps lower than PMV = 1, revealing better comfort conditions than the in classroom A.

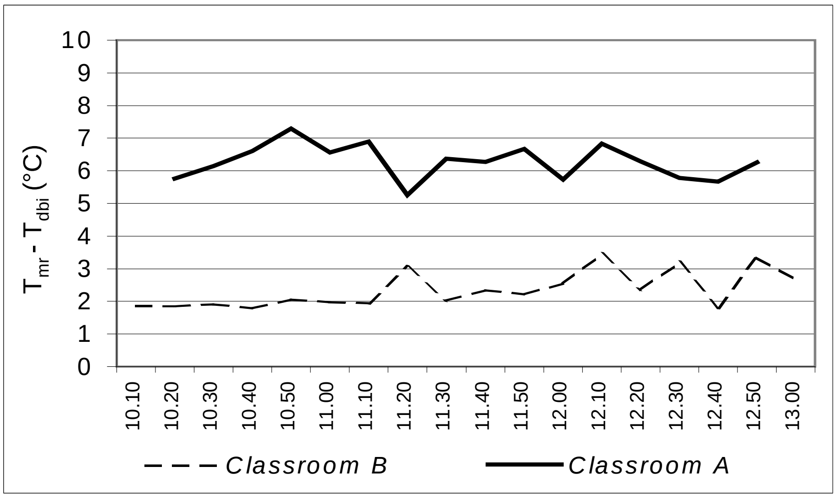
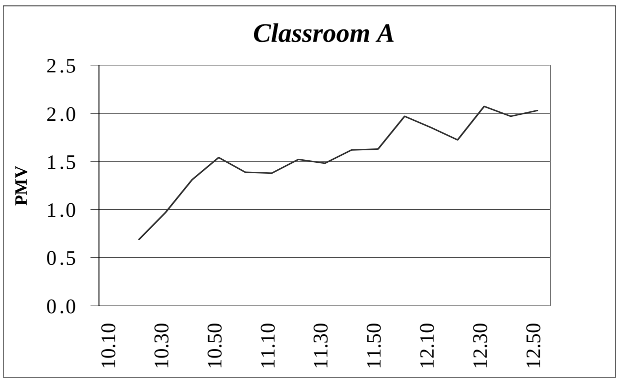


Figure 3: Difference between mean radiant temperature (T_{mr}) and dry bulb indoor air temperature (T_{dbi}) for the two classrooms in a typical day (May).



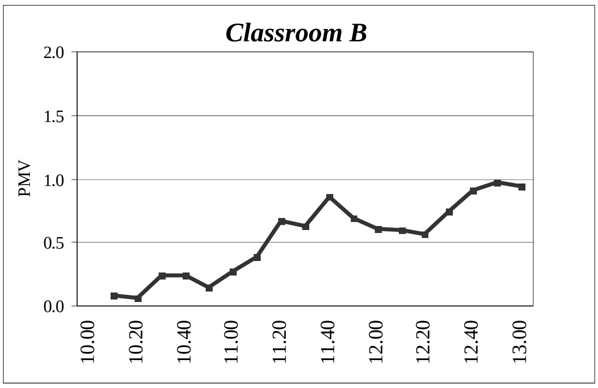


Figure 4: The PMV profile of the classroom B and the classroom A in a typical day of May.

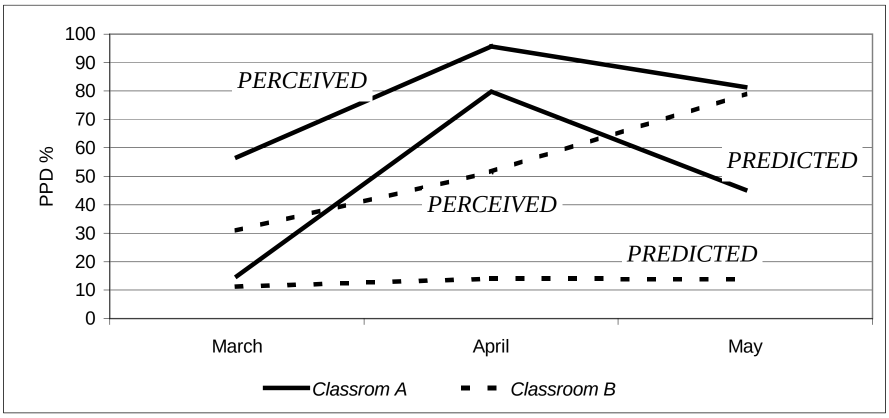


Figure 5: Comparison between the predicted and the perceived (real) percentage of dissatisfied into the two classrooms from March to May.

By means of the questionnaires filled in by more than 300 students, the perceived mean vote MV and the real percentage of dissatisfied PD have been determined. Figure 5 shows a comparison between perceived and predicted percentage of dissatisfied; it demonstrates that the predicted percentage of dissatisfied underestimates the perceived thermal sensation recorded by the questionnaires. This disagreement between predicted and perceived indexes could be due to the negative effect of a stressful mental activity on the perception of the thermal comfort: in fact the answers were given by the students at the end of the lectures.

This statement is confirmed by the results of a previous study (Compagno and Marletta, 2000), where calculated and perceived results were quite close for a similar ultra-lightweight structure used as a refectory; this means that a mentally relaxed condition and a short period of permanence by nature reduce the sensation of discomfort.

As regards the luminous environment, the high transmittance of the material used for the roof, in daylight time, produces illuminance levels too high for the visual task. In addition, the excessive uniformity of the luminance causes a difficult vision. In Figure 6 the mean illuminance levels measured during a day of May are shown for the two classrooms. In the classroom A the values are too high with respect to those recommended for classrooms (from 500 to 1000 lux) (UNI, 1994). The adoption of the PVC double ceiling in the classroom B has sensibly reduced the illuminance to more acceptable values, with beneficial effect on the visual comfort. This is evident by Figure 7, where the distribution of the illuminance on the working plane is shown.

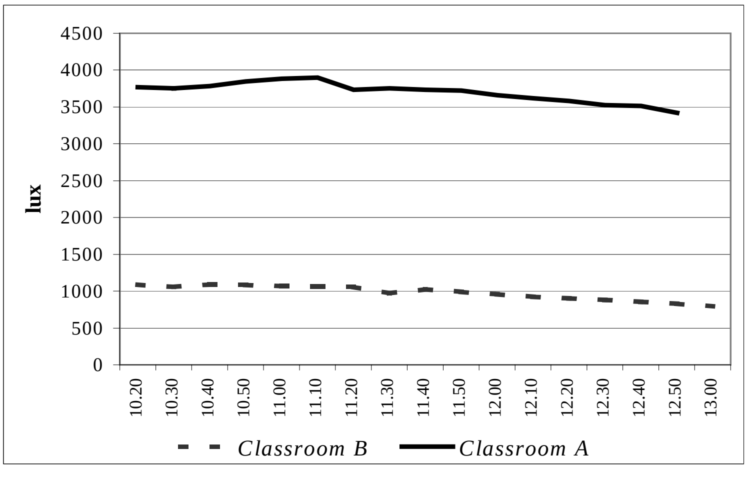


Figure 6: Mean illuminance levels during the measurement session in May.

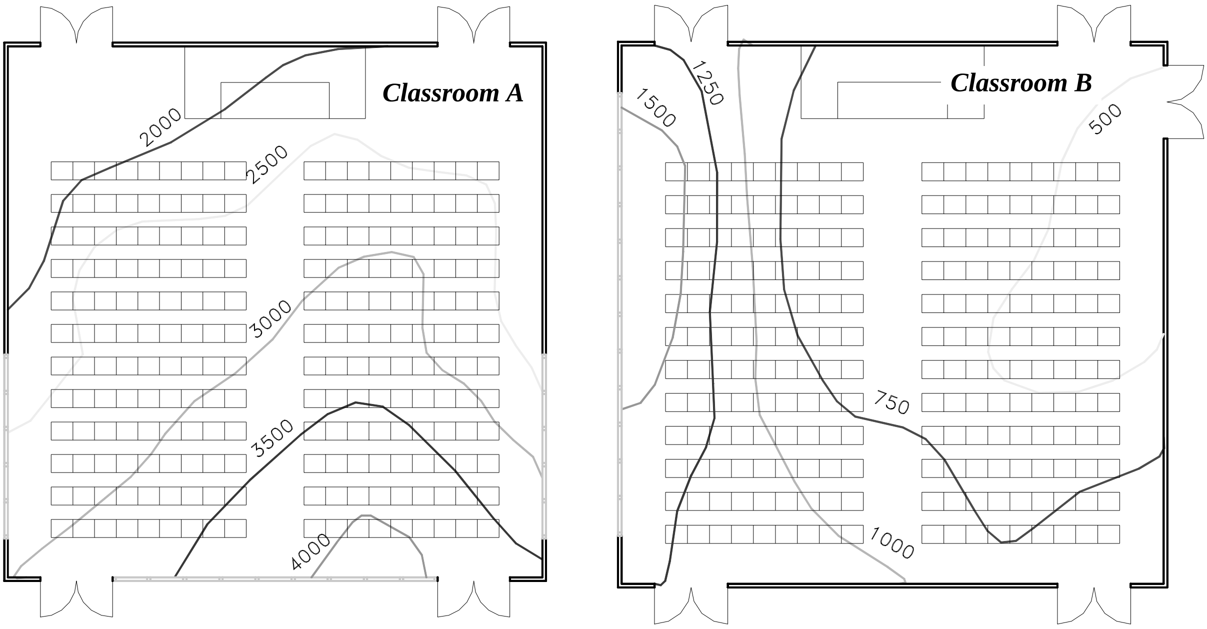


Figure 7: Distribution of the illuminance E on the working plane (lux).

CONCLUSIONS

The previous analysis has shown that the ultra lightweight structures are inadequate to produce a satisfying environmental comfort in regions with temperate subtropical climate. For these ones, the buildings should have a thermal inertia high enough to contrast the consistent temperature swing, especially in summer. Nevertheless, simple in-field interventions can increase the indoor environmental quality.

In addition, the predicted percentage of dissatisfied disagrees with the one determined through the questionnaires: under mental stressful activities, like a two-hour lecture, the perception of discomfort is higher than that predicted by Fanger’s theory. So a generalisation of a thermal comfort theory should include the mental conditions as a significant variable.

REFERENCES

ANSI-ASHRAE Standard 55-1992 (1992). *Thermal environmental conditions for human occupancy.* Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Compagno L., Marletta L. (2000). Measurement of IAQ in an university campus. The lesson learned for architects and designers. *Proceedings of Healthy Buildings 2000*, vol.2, pp. 593-598.

ISO Standard 7730 (1994). *Moderate Thermal Environments: Determination of PMV and PPD indices and specification of the conditions for thermal comfort*, Geneva: International Standard Organisation.

ISO Standard 7726 (1996). *Thermal environments: Instruments and methods for measuring physical quantities*, Geneva: International Standard Organisation.

ISO Standard 10551 (1995). *Assessment of subjective thermal comfort using standardized judgement scale*, Geneva: International Standard Organisation.

UNI Standard 10380 (1994). *Indoor lighting with artificial light*, Italian Standardization Board.

SURVEY ON MINIMUM VENTILATION RATE OF RESIDENTIAL BUILDINGS IN FIFTEEN COUNTRIES

Hiroshi Yoshino[1], Shuzo Murakami[2], Shin-ichi Akabayashi[3], Takashi Kurabuchi[4], Shinsuke Kato[5], Shin-ichi Tanabe[6], Koichi Ikeda[7], Haruki Osawa[8], Takao Sawachi[9], Akira Hukushima[10], Mayumi Adachi[1]

[1] *Department of Architecture & Building Science, Graduate School of Engineering, Tohoku University, Miyagi Prefecture, Japan, Phone: +81-22-217-7883, Fax: +81-22-217-7886, yoshino@sabine.pln.archi.tohoku.ac.jp*
[2] *Faculty of Science and Technology, Keio University*
[3] *Dept. of Graduate School of Science and Technology, Niigata University*
[4] *Dept. of Architecture, Faculty of Science and Technology, Science University of Tokyo*
[5] *Institute of Industrial Science, University of Tokyo*
[6] *Dept. of Architecture, Waseda University*
[7] *National Institute of Public Health*
[8] *Building Research Institute*
[9] *National Institute for Land and Infrastructure Management, Ministry of Land, Infrastructure & Transport*
[10] *Hokkaido Government*

ABSTRACT

The Minimum Ventilation Rate standard for dwellings is essential not only to provide occupant health and comfort, but also to remove and dilute the dominant pollutants. The purpose of this survey is to clarify and compare the regulations, standards or guidelines of ventilation requirements for residential buildings of various countries. The studies are based on the many literatures and interviews with the specialists in building regulation. The main viewpoints in this study are, how much the minimum ventilation rate is required, whether the regulations are mandatory or not, and what the ventilation requirements are based on. All regulations were applied to a model house proposed by the Architectural Institute of Japan in order to compare the minimum air change rates.
The conclusions of this study are shown as follows, (1) In Sweden, Denmark, France and Japan, the regulations were confirmed to be mandatory, but in other countries, there were some obscurities. (2) In each of the regulation, the ventilation requirement was based on the total volume of houses, the conditioned volume, the floor area, people and ventilation systems etc. (3) It was found that the air change rates applied to the model house were nearly 0.5 ACH, which is equal to the Japanese requirements.

KEYWORDS

Minimum Ventilation Rate, Air Change Rate, House, Building Standard

INTRODUCTION

The objectives of this study are to compare information of the regulations, standards and guidelines of ventilation for dwellings, in 15 developed countries - Norway, Sweden, Finland, Denmark, Belgium, France, Netherlands, Germany, Switzerland, United Kingdom, Italy, Greece, the Commission of the European Communities, Canada, U.S.A and Japan, and to discuss the characteristics of each of these regulations, standards and guidelines. After that each country's minimum air change rate is applied to a model house proposed by the Architectural Institute of Japan in order to compare each other.

VENTILATION REQUIREMENT IN EACH COUNTRY

Norway [2]

According to the Norwegian building Regulations of 1997, the total exhaust ventilation from kitchen, bathroom, the toilet and washing room must ensure a supply of outdoor air of at least 0.5 ACH for a dwelling. Minimum required extract airflows are from toilet (10 L/s (36 m^3/h)), bathroom (10 L/s (36 m^3/h) (openable window) or 30 L/s (108 m^3/h)), washing room (10 L/s (36 m^3/h) (openable window) or 20 L/s (72 m^3/h)) and kitchen (10 L/s (36 m^3/h) + 20 L/s (72 m^3/h) (from exhaust hood in use)).

Sweden [4]

According to the Swedish building regulations (BBR94) that contains mandatory provisions and general advisory notes, the ventilation systems of buildings shall be designed in such a way that the required quantity of outside air is supplied to the building to remove contaminants from activities, respiration, products from persons and airborne emissions from building materials, as well as moisture, bad smell and substances hazardous to health. Rooms shall have air changes continuously when they are in use. The outside airflow rate shall not be less than 0.35 L/s (1.26 m^3/h) per m^2 of floor area, which corresponds to a ventilation coefficient of 0.5 ACH in a room with a free height of 2.5m. In the situation of the rooms are not in use, the airflow rate may be reduced but not to such an extent that health risks arise or there is a risk of damage to the building or in the form of intermittent operation. In general recommendation, the outdoor air to rooms or parts of rooms for sleeping and resting should not be less than 4 L/s, person (14.4 m^3/h, person). Mechanical ventilation should be designed so that the capacity to provide rates of flow of extract air is not less than those set out in Table 1.

After the building completion, airflow testing must be exercised in order to check whether the ventilation systems fulfill the mandatory provisions stated on the regulations of Obligatorisk Ventilation Kontrol (Obligatory Ventilation Check). When the ventilation systems are found not to conform to the provisions, the systems must be repaired.

Table 1
Rate of flow extract air (Sweden)

Space		Minimum rate of flow of extract air
Dwellings, institutional premises, hotel and similar.	Kitchen	10 L/s (36m^3/h)
	Kitchenette, kitchen cubicle	15 L/s (54m^3/h)
	Bathroom or shower room with open window	10 L/s (36m^3/h)
	Bathroom or shower room extraction without open window	10 L/s (36 m^3/h) rate up to 30 L/s (108 m^3/h), or 15L/s (54m^3/h)
	Lavatory	10 L/s (36 m^3/h)
Service spaces	Laundry room, drying room	10 L/s (36 m^3/h)
	Refuse storage room	5 L/s m^2 (18 m^3/h m^2)
	Refuse storage room for dry refuse only	0.35 L/s m^2 (1.26 m^3/h m^2)

Finland [5)]

Regulations and guidelines of indoor air quality and ventilation for dwellings are shown in D2 Indoor Atmosphere and Ventilation of Building Regulation and Guidelines 2003. During the periods of occupancy, an outdoor air flow that guarantees a healthy, safe and comfortable quality of indoor air must be routed to the occupied premises. Ventilation in dwellings is normally designed on the basis shown in Table 2. As a general rule, the outdoor airflow rate should be at least 0.35 L/s m^2 (1.26 m^3/h m^2).

Table 2
Airflow rate in each room (Finland)

Area / application	Outdoor air flow per person	Outdoor air flow	Extract air flow
Dwelling areas:	6 L/s (21.6 m^3/h)	-	-
Dwelling rooms	-	0.5 L/s m^2 (1.8 m^3/h m^2)	-
Kitchen -boost during occupancy	-	*1	8 L/s (28.8 m^3/h) 25 L/s (90 m^3/h)
Cloakroom, storage room	-	*1	3 L/s (11.4 m^3/h)
Bathroom - boost during occupancy	-	*1	10 L/s (36 m^3/h) 15 L/s (54 m^3/h)
WC - boost during occupancy	-	*1	7 L/s (25.2 m^3/h) 10 L/s (36 m^3/h)
Utility room - boost during occupancy	-	*1	8 L/s (28.8 m^3/h) 15 L/s (54 m^3/h)
Sauna in the apartment	-	*2	2 L/s m^2 (7.2m^3/h m^2) *2

*1: Outdoor air flow is normally substituted with transfer air flow routed from the dwelling rooms.
*2:But not less than 6 L/s (21.6m^3/h). Air flows in the sauna are not taken into account in the calculation of the sauna's ventilation coefficient if the sauna's outdoor air flow rate is equal to the used air flow rate.

Denmark [6, 7)]

The requirements of indoor air quality in Danish dwellings are provided in the Danish Building Regulations for Small Dwellings 1998 and in the Danish Building Regulations 1995. The requirements are given as minimum ventilation rates. In single-family houses it is allowed to have natural ventilation, mechanical exhaust or mechanical ventilation. In multi-story houses only mechanical exhaust or mechanical ventilation are allowed.
The regulations require that each habitable room and the entire dwelling shall have at least a total air exchange rate of 0.5 ACH. In dwellings with natural ventilation, minimum opening areas are required. In dwellings with mechanical exhaust or mechanical ventilation, minimum exhaust flow is required from kitchen or bathroom. The exhaust shall be continuously operated. In small flats with mechanical exhaust, the air exchange rate can be up to 1.0 ACH.
Kitchens, bathrooms, sanitary, lavatories etc. must be furnished with exhaust systems and should satisfy the required outdoor air flow rates.
The Danish Building Regulations are mandatory and one would get fined for the act of disobedience.
Table 3 shows the opening area and ventilation airflow rate for areas prescribed by building regulation.

Table 3
Open area and airflow rate in each room (Denmark)

Area	Small Dwellings	Multi-story houses

	Supply air flow	Exhaust air flow	Supply air flow	Exhaust air flow
Openings area in living room	At least 2.4 cm^2/m^2 floor area (natural ventilation) At least 1.2 cm^2/m^2 floor area (mechanical ventilation)	-	At least 1.2 cm^2/m^2 floor area	-
Kitchen	At least 30cm^2 or an opening of at least 100 cm^2 to the access room	72 m^3/h or a cooker hood or natural exhaust draught with a duct cross section of at least 200 cm^2	Hinged window, hatch or door or fresh air valve	72 m^3/h through an extractor hood
Sanitary accommodation	At least 100cm^2 or an opening of at least 100 cm^2 to the access room	54m^3/h or natural exhaust draught with a duct cross section of at least 200cm^2	Hinged window, hatch or fresh air valve, and/or opening to the access room	54m^3/h
Utility rooms, storerooms	At least 50cm^2 or an opening of at least 100 cm^2 to the access room	36m^3/h or natural exhaust draught with a duct cross section of at least 200cm^2	Hinged window, hatch or fresh air valve, and/or opening to the access room	36m^3/h
Basement rooms	A ventilation opening fresh air valve with at least 30cm^2	36m^3/h or natural exhaust draught with a duct cross section of at least 200cm^2	-	-

Belgium [3)]

In Belgium, the National Standard describes the requirement in terms of ventilation of residential buildings (NBN D50-001). The basis assumption of the standard is that the quality of the outdoor air must be good enough to be used as ventilation air, and the described airflows are adapted to remove occupancy pollutants only and that mechanical ventilation must be permanent. The basic rule is to deliver 1 L/s m^2 (3.6 $m^3/h\ m^2$) with minimum and maximum airflows according to the destination of the room, as shown in Table 4.

Table 4

Airflow rate in each room (Belgium)

Type of room	Supply/Exhaust	Airflow	Minimum airflow	Maximum airflow
Living rooms	Supply	1 L/s m^2	75 m^3/h	May be limited to 150 m^3/h
Bedrooms, Studies, Play rooms	Supply	1 L /s m^2	25 m^3/h	May be limited to 36 m^3/h per person
Kitchens, Bathrooms, Laundries	Exhaust	1 L /s m^2	50 m^3/h	May be limited to 75 m^3/h
WC	Exhaust	25 m^3/h	-	-

France [3)]

In France, the regulations of indoor air quality and ventilation for dwellings have to be obligatory applied. The ventilation was required to provide air change continuously in each habitable room. It has to supply fresh air in order to the habitable rooms to exhaust stale air from the service rooms. The extract flow rates are given corresponding with the number of habitable rooms as indicated in Table 5. However, these flow rates can be reduced with respect to the values shown in Table 6. In the case of using controlled systems, which adjust automatically the extract flows, the values illustrated in Table 6 can be reduced in the absence of occupancy given in Table 7.

Table 5

Airflow rate in each room (France)

Number of habitable rooms	Extract flow (m^3/h)				
	Kitchen	Bathroom or shower-room	Other water-room	Toilets	
				Single	Multiple
1	75	15	15	15	15
2	90	15	15	15	15
3	105	30	15	15	15
4	120	30	15	30	15
5 +	135	30	15	30	15

Table 6

Minimum airflow rate in each room (France)

	Number of habitable rooms						
	1	2	3	4	5	6	7
Minimum flow in kitchen (m^3/h)	35	60	75	90	105	120	135
Minimum flow for all the dwelling (m^3/h)	105	120	150	165	210	210	210

Table 7

Minimum airflow rate during non-occupancy (France)

	Number of habitable rooms						
	1	2	3	4	5	6	7
Minimum flow for all the dwelling (m^3/h)	10	10	15	20	25	30	35

Netherlands [1,8)]

In the Netherlands, the building decree prescribed about ventilation is for staying area, staying room, toilet room, bathroom, and other rooms. The provision for the supply of fresh air to a staying area and for the discharge of inside air from that area shall have a capacity, and it is determined in accordance with NEN 1087 of at least 0.9 L/s m^2 of floor area of that area (3.24 $m^3/h\ m^2$), with a minimum of 7 L/s (25.2m^3/h). Minimum ventilation for a toilet room shall be 7 L/s (25.2 m^3/h) and for a bathroom shall be 14L/s (50.4m^3/h), whether or not combined with a toilet room. The above discharge of inside air shall take place directly to the open air.

Germany [3)]

The German industrial norm DIN 1946 is a series concerning ventilation and air–conditioning, in which Part 2 gives the general requirements and Part 6 deals with residential buildings. In term of CO_2 concentration, it is recommended to keep the level below 1500 ppm. Furthermore for variably used rooms, different air change rates are specified. However, there is no instruction indicated how the demands of air change can be met. Airflows in dwellings according to DIN 1946 part 6 are shown in Table 8.

Table 8

Airflow rate (DIN)

Area of the flat (m^2)	Planned occupancy (persons)	Planned outdoor air change rate	
		Natural ventilation (m^3/h)	Mech. Ventilation (m^3/h)
< 50	Up to 2	60	60
50 ...80	Up to 4	90	120
> 80	Up to 6	120	180

Switzerland

According to SIA 180 – Heat and moisture protection in buildings (1998), the minimum airflow rate is determined by the maximum steady state pollutant or humidity concentration and the source strength. In rooms where smoking is not allowed and with a maximum CO_2 concentration of 1500ppm, the air flow rate of 12~15 m^3/h per person is required. In rooms where smoking is allowed the airflow rate has to be 30~70 m^3/h per person.
According to SIA 382 - Technical requirements to ventilation equipment (1992), in rooms where smoking is not allowed with a maximum CO_2 concentration of 1000ppm, the air flow rate of 25~30 m^3/h per person is required. On the other hand, with a maximum CO_2 concentration of 1500ppm, the air flow rate is equal to SIA 180 and the air flow rates above 0.3 ACH is recommended in unoccupied rooms.

United Kingdom [9)]

The British Building Regulations 2002 prescribe that rapid ventilation, background ventilation, extraction fan rates and passive stack ventilation, as shown in Table 9, should be designed. There is no regulation of outdoor airflow rate for habitable room.

Table 9

Airflow rate (United Kingdom)

Room	Rapid ventilation (e.g. opening windows)	Ventilation openings	Extract ventilation fan rates or passive stack -PSV
Habitable room	1/20th of floor area	8000mm^2	-
Kitchen	Opening window (no minimum size)	4000mm^2	30L/s adjacent to a hob or 60 L/s elsewhere or PSV
Utility room	Opening window (no minimum size)	4000mm^2	30L/s or PSV
Bathroom (with or without WC)	Opening window (no minimum size)	4000mm^2	15L/s or PSV
Sanitary accommodation (separate from bathroom)	1/20th of floor area or mechanical extract 6L/s	4000mm^2	-

Italy [1)]

According to the Italian Ministerial Decree 05.07.75 Ventilation requirements for residential buildings, airflow rates should meet the values indicated in Table 10.

Table 10
Airflow rate (Italy)

Room	Ventilation requirement
Naturally ventilated dwellings	0.35ach to 0.5ach
Kitchen	1.0 ach
Bathroom	2.0 ach
Ante - bathroom	1.0 ach
Normal living space	$15m^3$/h per person

Greece [1)]

The Greek Legislative Framework Document gives the demand ventilation for each room shown in Table11. The minimum ventilation airflow rate is 8.5 m^3/h per person.

Table 11
Airflow rate (Greece)

Space	Estimated persons per $100m^2$ of floor area	Demanded Ventilation (m^3/h per person)	
		Minimum	Recommended
Detached houses			
Sitting rooms, bedrooms	5	8.5	12-17
Bathrooms, Kitchens	-	34	50-85
Block of Flats			
Sitting rooms, bedrooms	7	8.5	12-17
Bathrooms, Kitchens	-	34	50-85

Commission of the European Communities [10)]

In the Report No.11 - Guidelines for Ventilation Requirements in Buildings by the Commission of the European Communities, the ventilation rate required for health and comfort should be calculated separately and the highest value of ventilation rate should be used for design. The ventilation required for health is calculated by an equation including the pollution load of chemical and the allowable concentration of chemical. The ventilation required for comfort is calculated by an equation including sensory pollution load (olf) and perceived air quality (decipol). In the EC report, an example of determination of required ventilation rate is shown. In this paper, the ventilation rate - 0.4 L/s, m^2 (1.44 m3/h, m^2) is adopted as the value used for design.

Canada [11, 12)]

National Building Code of Canada

National Building Code of Canada 1995 prescribes natural ventilation and mechanical ventilation system during non-heating-season and mechanical ventilation system during heating season. In natural ventilation, the unobstructed openable ventilation area to the outdoors for rooms and spaces in residential buildings ventilated by natural means shall conform to Table12.

Mechanical ventilation during non-heating-season shall be provided to exhaust inside air from the room or space, or to introduce outside air to there at the rate of

a) 0.5 ACH if the room or space is mechanically cooled during the season, or

b) 1.0 ACH if it is not mechanically cooled during the season.

In the meantime, mechanical ventilation during heating-season shall be designed so that it can operate on a continuous basis and has a minimum ventilation air capacity that is the greater of the sum of the individual room requirements as defined in Column 1 of Table 12; or 0.3 ACH based on the conditioned volume of the dwelling unit.

Table 12

Minimum Ventilation Air Requirements

Space classification	Column 1	Column2*1	Column 3*1
	Minimum Ventilation capacity, L/s （m^3/h）*2	Intermittent exhaust, L/s （m^3/h）*2	Exhaust, L/s （m^3/h）*2
Category Ａ			
Master bedroom*3	10 (36)	-	-
Basement*4	10 (36)	-	-
Single bedrooms	5 (18)	-	-
Living room*5	5 (18)	-	-
Dining room*5	5 (18)	-	-
Family room	5 (18)	-	-
Recreation room	5 (18)	-	-
Other habitable rooms*6	5 (18)	-	-
Category Ｂ			
Kitchen*5	5 (18)	50 (180)*7	30 (108)
Bathroom	5 (18)	25 (90)	10 (36)
Laundry	5 (18)	-	-
Utility room	5 (18)	-	-

*1: Either intermittent or continuous exhaust is required.

*2: Based on an air temperature of 20 ^{o}C.

*3: Master bedroom is the bedroom most likely to be occupied by two adults.

*4: Where a basement incorporates rooms of the types designated in this Table, the ventilation requirements for each room shall be as specified above. Basement areas used for other purposes that exceed 2/3 of the total basement area shall have a minimum ventilation requirement of 10L/s; those that are less than 2/3 of the total area shall have a minimum requirement of 5 L/s. This Standard does not require ventilation of mechanical service and storage rooms.

*5: Ventilation requirements for any combined living room, dining room, and kitchen shall be determined as if they were individual rooms.

*6: Other habitable rooms not listed shall have a minimum ventilation requirement of 5 L/s. This dose not include spaces intended solely for access, egress, or storage, such as vestibules, halls, landings, storage rooms, service closets and furnace rooms.

Canada R-2000, Builders' Manual

Canada R-2000 provides that the sizing of the ventilation system shall meet the Program specifications which include:

a) The demonstrated capability of the system to provide a ventilation rate of at least 0.5 ACH or 50 L/s (180 m^3/h), whichever is greater,

b) The ability of the system to provide a minimum and constant distribution of fresh air to each room of the houses at a rate of at least 5 L/s (18 m^3/h).

ASHRAE Standard 62.2-2003 [13)]

ASHRAE Standard 62.2, Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings, provides the minimum requirements necessary to achieve acceptable indoor air quality for dwellings. It can be applied to new or existing houses. Whole-house ventilation is intended to dilute the unavoidable contaminant emissions from people, from materials and from background processes. But the Standard does not address specific pollutant concentration levels.
A mechanical exhaust system, supply system, or combination should be installed for each dwelling unit to provide whole-building ventilation with outdoor air each hour at no less than the rate specified in Table 13 or equivalent to Equation (1) which is based on the floor area of the conditioned space and number of bedrooms. And this includes a default credit for ventilation provided by infiltration of 0.36 $m^3/h,m^2$ of occupiable floor space.

$$Q_{fan} = 0.18\, A_{floor} + 12.6\, (N_{br} + 1)\ (m^3/h) \qquad (1)$$

Where:
A_{floor} = floor area (m^2)
N_{br} = Number of bedrooms; not to be less than 1.

Table 13
Ventilation Air Requirements, L/s (m^3/h)

Floor Area (m^2)	Bedrooms				
	0-1	2-3	4-5	6-7	>7
<139	14 (50.4)	21 (75.6)	28 (100.8)	35 (126)	42 (151.2)
139.1-279	21 (75.6)	28 (100.8)	35 (126)	42 (151.2)	50 (180)
279.1-418	28 (100.8)	35 (126)	42 (151.2)	50 (180)	57 (205.2)
418.1-557	35 (126)	42 (151.2)	50 (180)	57 (205.2)	64 (230.4)
557.1-697	42 (151.2)	50 (180)	57 (205.2)	64 (230.4)	71 (255.6)
>697	50 (180)	57 (205.2)	64 (230.4)	71 (255.6)	78 (280.8)

Japan [14)]

The Japanese Building Code of ventilation for residential buildings has been revised since July 2003 in order to deal with IAQ problems in sick buildings. According to this new code, habitable rooms adopt ventilation systems must not less than 0.5 ACH based on the conditioned volume as a rule. This value is based on HCHO emission rates and the concentration provided by Ministry of health, Labour and Welfare. When the building materials used are below a certain HCHO emission rates, minimum airflow rates required are 0.3 ACH. When the materials are beyond a certain HCHO emission rates, minimum airflow rates are 0.7 ACH.

MINIMUM VENTILATION RATES FOR A MODEL DWELLING BY ARCHITECTUAL INSITUTE OF JAPAN

Explanation for Calculation

The calculation of the minimum airflow rates for a model house is based on the regulations and standards of the 15 investigated countries in this study. The model house is shown in Figure 1 and the description of the model house is found in Table 14. This model house is assumed to be occupied by a couple with two children.

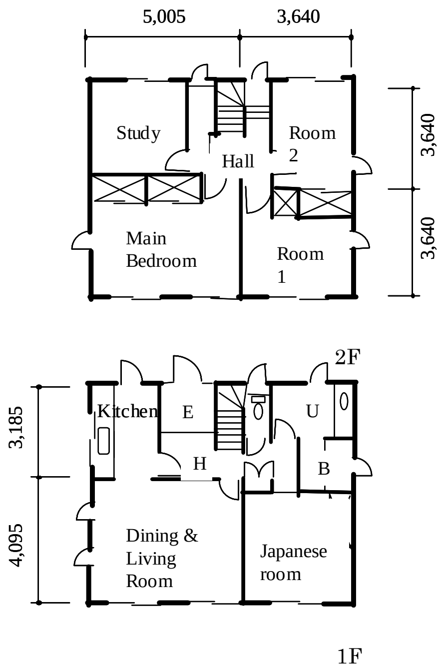


Figure 1: Floor plan of the model house

Table 14
The model house's floor area & volume

Type of room		Floor area m^2	Volume m^3
1 F	Living & Dining room	20.5	49.2
	Kitchen	7.2	17.4
	Japanese room	13.3	31.8
	Bathroom	3.3	7.9
	Lavatory	5.0	11.9
	WC	1.7	4.0
	Other	12.0	28.9
	Sum of 1F	62.9	151.0
2F	Main Bedroom	20.5	49.2
	Room 1	11.6	27.8
	Room2	11.6	27.8
	Study	10.1	24.3
	WC	1.7	4.0
	Other	7.5	17.9
	Sum of 2F	62.9	151.0
Total		125.9	302.1

Calculation results

The minimum airflow rates of each regulation were calculated by the procedures indicated in Table 15. The calculated result obtained in this study is shown in Figure 2.

Table 15
Procedures for calculation

Norway	Though the minimum airflow rates are 0.5 ACH - 151 m^3/h, total exhaust ventilation rates (216 m^3/h -0.71ACH) from a kitchen (36m^3/h), a bathroom (108 m^3/h) and 2 toilets (72 m^3/h) are considered as the minimum in a dwelling.
Sweden / Finland	The minimum airflow rates are 159m^3/h -0.53ACH, as minimum airflow rates are 1.26m^3/h per floor area and all the floor areas are 126m^2.
Denmark / Italy /Japan	The minimum airflow rates are 0.5 ACH- 151 m^3/h.
Belgium	The minimum airflow rates for each room were calculated according to the basic rule, which is to deliver 3.6m^3/h, m^2 with minimum and maximum air flows shown in Table 1, and add together in this paper, as the standard of Belgium does not describe the total minimum airflow rates.
France	The minimum airflow rates are 210m^3/h -0.70ACH- according to Table 1 and 6 rooms in this house.
Germany	The minimum airflow rates are 180m^3/h -0.60ACH- according to Table1.
Switzerland	The minimum airflow rates are 60 m^3/h -0.40ACH- according to 15 m^3/h per person and 4 people living in this house.

Greece	The minimum airflow rates are 153m^3/h -0.50 ACH- according to the requirements for the rooms as defined in Table 11, as the standard of Greece does not describe the total minimum airflow rates.
Canada	The minimum airflow rates are 198m^3/h -0.66 ACH- according to the sum of the individual room requirements greater than 0.3 ACH.
Canada R-2000	The minimum airflow rates are 180m^3/h -0.59 ACH greater than 0.5 ACH.
U.S.A	The minimum airflow rates are 118m^3/h -0.36 ACH- according to Equation (1), 3 bedrooms and 126m^2 floor areas
Commission of the EC	The minimum airflow rates are 181.3m^3/h –0.60 ACH- according to the ventilation for comfort 1.44m3/h, m^2 and 126m^2 floor areas.

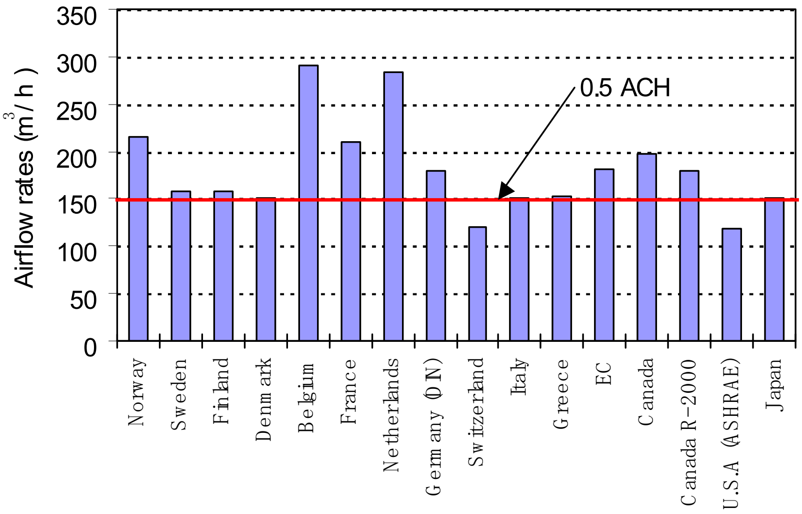


Figure 2 : Calculation results

CONCLUSIONS

A survey of the regulations, standards or guidelines of ventilation for dwellings of 15 developed countries was carried out in this study. The airflow rates of each of the regulation were based on the total volume of houses, the conditioned volume, the floor area, people, and ventilation systems etc.

In Sweden, Finland, Denmark, France and Japan, the regulations have mandatory provisions. Especially, in Sweden, airflow testing must be exercised in order to check whether the ventilation systems fulfill the mandatory provisions after the building completion. When the ventilation systems are found not to conform to the provisions, the systems must be repaired.
In Denmark, there are penalties for disobeying the regulations.

Concerning the grounds for these regulation requirements, Switzerland, the Commission of the European Communities and Japan use the pollutant/humidity concentration and strength to calculate the minimum airflow rates. In contrast with the other countries' regulation in this study, what those values are based on is not obvious.

In this paper, most of the air change rates applied to a model house were found nearly 0.5 ACH.

References

1) Mark J. Limb. (2001). A Review of International ventilation, Airtightness, Thermal Insulation and Indoor Air Quality Criteria, AIVC Technical Reports55

2) Performance assessment of advanced ventilation systems in the framework of energy and IAQ regulations: Critical issues, challenges and recommendations, Version 15-05-2002

3) HYVENT project, WP4 Standards and Regulations support unit (STAR-SUN), Opportunities, barriers and challenges in relation to the application of standards and regulations on hybrid ventilation systems, Version 2.4-31-05-2002

4) Building Regulations BBR 94, Mandatory provisions and general recommendations, BFS 1993:57, with amendments BFS 1995:17, BFS 1995:65

5) D2 Finnish Code of Building Regulations Ministry of the Environment Department of Housing and Construction, Indoor Atmosphere and Ventilation of Buildings Regulations and Guidelines 2003

6) Danish Ministry of Housing, Danish Building and Housing Agency (1995). Building Regulations,

7) Danish Ministry of Housing, Danish Building and Housing Agency (1998). Building Regulations for small dwellings

8) DECREE of 16TH DECEMBER (1991). HOLDING TECHNICAL REGUALATIONS REGARFING THE CONSTRUCTION OF CONSTRUCTION WORKS AND THE STATE OF EXISTING CONSTRUCTION WORKS (BUILDING DECREE)

9) New Building Regulations 2002, Section1, Domestic Buildings

10) Commission of the European Communities, Report No.11 Guidelines for Ventilation Requirements in Buildings

11) National Building Code of Canada 1995

12) CANADA R-2000 BUILDERS' MANUAL

13) ANSI/ASHRAE Standard 62.2-2003, ASHRAE STANDARD Ventilation for Acceptable Indoor Air Quality in Low-Rise Residential Buildings

14) Ministry of Land, Infrastructure & Transport, http://www.mlit.go.jp/english/index.html

FIELD INVESTIGATION OF INDOOR AIR QUALITY IN VARIOUS CHINESE RESIDENTIAL BUILDINGS

Liyan Guo [1], Bin Chen [2], Feifei Peng [2], J. Owen Lewis [1]

[1] *Urban Institute Ireland, University College Dublin, Richview, Dublin14, Ireland*

[2] *Dept. of Civil Engineering, Dalian University of Technology, Dalian116023, China*

ABSTRACT

In recent years, the housing market in China has expanded tremendously due to economic development. Building envelopes have become more and more airtight because of improvements in building technology and concerns on energy conservation. But a lack of knowledge on domestic ventilation performance and difficulties in achieving suitable standards have led to more and more complaints from occupants, and reported cases of building related illness (BRI). For these reasons, we carried out an investigation on indoor air quality and building performance of various residential buildings in a northeast coastal city in China. Field measurement of indoor/outdoor parameters was conducted in combination with questionnaire survey during 2001~2002. Statistical analysis was performed to reveal the factors that influence indoor air quality in typical buildings. The relationships between pollutant levels, building characteristics and inhabitant's living patterns were also discussed. The conclusions can be summarized as follows: 1. Carbon Dioxide concentration measurements indicated that 1/3 of test rooms were suffering from inadequate ventilation in winter. 2. A total of 29.7% households reported that air in their homes is bad, especially when smoking, excessive occupancy or cooking occurs. 3. The formaldehyde concentration in older houses is lower than in new-built or newly decorated houses. 4. Occurrence of building related symptoms in new dwellings is higher than that in old buildings.

KEYWORDS

Indoor air quality, Domestic ventilation, Field investigation, Residential building

INTRODUCTION

In recent years, Chinese housing market has expanded tremendously because of rapid economic development. Newly-built residential units are increasing in number rapidly. Due to concerns on energy efficiency and improvements in building techniques, the energy performance of residential building built after the 1996 regulation (B.C.D. 1996) should be generally better than those built before. Requirements of envelope U-value and air-tightness are indicated in the standard. Improvement of post-occupancy operation also contributes to energy conservation. But meanwhile, we have to pay attention to the emergence of more and more complaints, even cases of disease related to indoor air quality in recent years. The incidence of allergies such as asthma (especially in children) is increasing rapidly. A.P. Jones gave an extensive review on the risk of asthma in domestic environments (Jones 1998). Considering the large number of households which have moved into new-built or newly-decorated homes, which are more airtight than before, it is necessary to carry out a study on the evaluation of sick buildings and their influence on IAQ and people's health. From another point of view, we don't have building regulations which considering requirements for residential ventilation in China. But in Europe and USA, study on ventilation for acceptable IAQ has been a very important topic since the 1970s. ASHRAE standard 62 series, standards for EU and individual countries all provide statement of minimum ventilation requirements for different kinds of buildings. They are in constant development and revision following research progress in this area, but we even lack basic knowledge on local domestic ventilation performance and IAQ. So we carried out this field study to better understand the situation of residential indoor environments, and to explore the association between building features and IAQ.

Figure 1: Location of Dalian

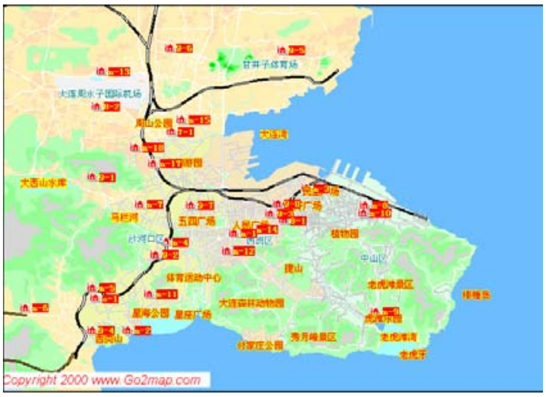


Figure 2: Location of the 30 dwellings

We selected Dalian, a coastal city in northeastern China, for the field investigation. Dalian is located between $38^{\circ}43'$ to $40^{\circ}10'$ north latitude and $120^{\circ}58'$ to 123° east longitude, in the southernmost point of Liaodong Peninsula; with the Yellow Sea to its east and the Bohai Sea to its west (see fig.1). The climate is temperate continental monsoon with four distinct seasons. Average temperature is $8.4^{\circ}C$ to $10.5^{\circ}C$ with a high of $35^{\circ}C$ and low of - $24^{\circ}C$. Annual precipitation is 600~790mm. As in other Chinese cities, the housing market of Dalian has seen vast development during past ten years. Up to 2000, the total built-up area in Dalian was

53.97 million ㎡, among which 29.98 million ㎡ is residence. It is increasing at the rate of 1.5 million ㎡ each year (2001).

METHOD

Questionnaire Survey

A questionnaire survey was conducted in two stages in summer and winter. Self-report questionnaires were submitted to families of senior school students, which were distributed in different areas around the city. All questions were explained to the students in advance and the householder of each family (normally parents) was responsible for the answers. Questions covered aspects of building features, facilities and operation, lifestyle of occupants, occupant's perception of indoor environment and their heath experience etc.

The summer survey was from 20th July 2001 to 10th August 2001, during which 650 questionnaires were handed out and 117 were fully answered (response rate 18%). The winter survey was carried out from 1st Jan to 3rd Jan 2002 using a modified questionnaire based on the summer one. Eventually 550 were collected from the 630 issued (response rate 87%) due to improved technique of interview. All valid data sets were processed by statistical analysis.

Field Measurement

Table 1: Measurement Summary

Measuring Parameters	Instrumentation	Ref. Criteria *
Temperature	TR-51A, TR-72S and RHLOG data logger	-
Relative Humidity	TR-72S and RHLOG data logger	-
Formaldehyde	TH-150 Air Sampler (0.5L/min, 30min) and 721-Spectrophotometer	0.08mg/m^3
Radon	Sun Nuclear Radon Monitor M 1027	200 Bq/m^3 for old buildings 100 Bq/m^3 for new buildings
CO_2	Testo Infrared CO_2 Probe and Monitor	1000 ppm
Radiation	Inspector (S.E. Intl, Inc)	

Note: National Standard China GB/T 16146-1995 for radon, GB/T 16127-1996 for formaldehyde and GB/T 17094-1997 for carbon dioxide.

Besides the questionnaire survey, 30 residential buildings were selected to do indoor environment monitoring and pollutant measurement. The locations of 30 dwelling are shown in Fig.2, in which each home is marked by a house symbol and a square containing a number. We divide samples into three groups according to the age of building, which is group A - 10 houses built in recent three years; group B – 10 houses age 4~10 years and group C – 10 houses more than 10 and up to 50 years old. Included are 27 (90%) multi-story apartments /flats, two detached houses and one bungalow. The fieldwork lasted about six weeks from January to February 2002. Temperature and relative humidity were recorded continuously in the living room and the main bedroom of each house for durations of 4 days to 1 week. Radon, formaldehyde, carbon dioxide and radiation were measured at the middle of one test room in each house. Parameters and instrumentation details are listed in Table 1. Questionnaires were completed by interviewer and occupants during the visit.

RESULTS AND DISCUSSIONS

Results Of Questionnaire Survey

Distribution of building characteristics

In the sampled households, 98.4% live in multi-story flat/apartments (93.7% are lower than 9 stories and 4.7% are high-rise). Just 1.6% live in detached town house. From the distribution of building age shown in Fig 3, about 2/3 dwellings were built in the recent 10 years, which is a large proportion compared with developed countries. Fig 4 shows features of window, which play important roles in insulation, infiltration and ventilation, including double or multiple glazing and new window frame materials.

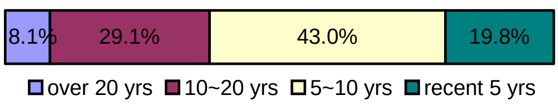


Figure 3: distribution of building ages

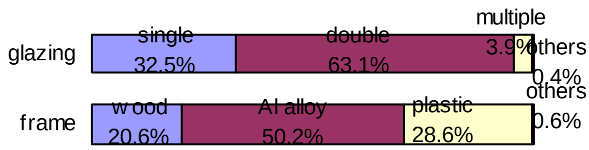


Figure 4: characteristics of windows

Residential Ventilation Styles And Occupant Ventilating Habits

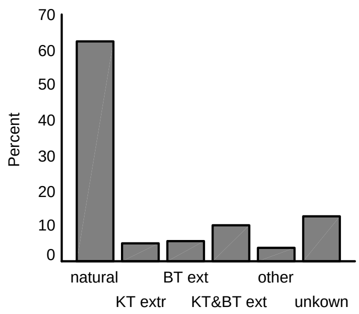


Fig 5: ventilating styles

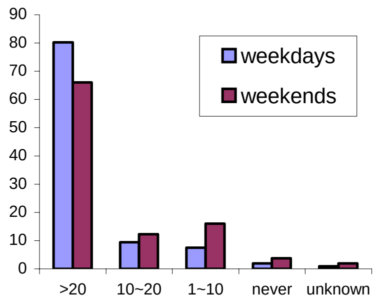


Fig 6: summer window open hrs

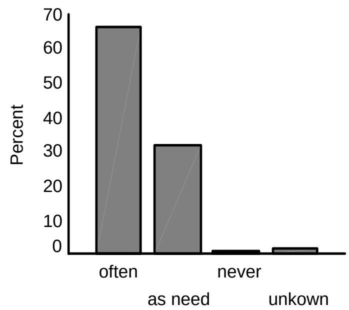


Fig 7: winter window open freq

Fig 5~7 show information about how occupants ventilate their home in summer and winter. Most residential buildings are naturally ventilated by opening windows, with about 1/5 having extract fan in kitchen (KT) or bathroom(BT) or both. In summer, most households have their windows continuously open for more than 20 hours per day while in winter they are briefly open but frequently, or when need.

The Perceived Indoor Air Quality

When asked the question "Do you think indoor air quality of your home is good or bad?" 29.7% occupants' answer was "Bad". The ranked reasons causing bad IAQ are smoking, excessive occupancy, and cooking. Considering the degree of discomfort, 22.4% regarded their living environment as slightly uncomfortable, about 2% were uncomfortable and people who felt very uncomfortable and unbearable were 1% respectively.

Indoor Air Pollutant Levels

Summary Of Measurement Results

The results of pollutant measurements are summarized in table 2.

Table 2: Concentration of indoor air pollutants in 30 dwellings

Pollutant	Minimum	Maximum	Mean	Std. Deviation
CO_2_LR (ppm)	446	1650	840	330.56
CO_2_BD (ppm)	465	1552	760	278.54
CO_2_KT (ppm)	404	1795	772	368.81
HCHO (mg/ m3)	0*	0.50	0.13	0.1335
Radon (Bq/m3)	3.7	92.5	41.8	29.634
Radionuclide Level (μSv/hr)	0.02	0.19	0.11	4.228E-02

Note: "0" means undetected. The minimum detected range for formaldehyde is 0.04 mg/m^3.

Carbon Dioxide

Carbon dioxide concentration in fig 8 indicates that although most families have acceptable levels of CO_2, 1/3 of measured homes are suspected of suffering from inadequate ventilation in winter. To estimate ventilation rate from carbon dioxide concentrations (Persily 1997; Beisteiner and Coley 2003), continuous measurement is required. CO_2 level can also be used as the indicator of IAQ. Gas cooking probably causes higher concentrations in kitchens.

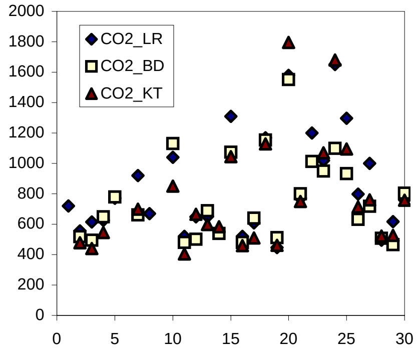


Figure 8: CO_2 concentration in 30 dwellings

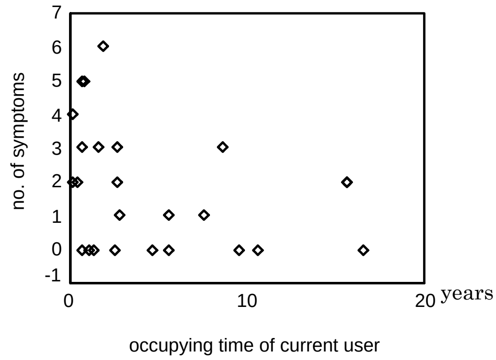


Figure 9: symptom occurrence vs. occupying time

Radiation – Radon and Radionuclide

Radon concentrations and radionuclide level indicate the risk of radiation exposure, which is normally unperceivable but can cause severe health problems e.g. cancer. Radon results in our survey are all lower than the recommended level. However, the highest concentration case was a new apartment with electrical ceiling radiant heating system. The householder reported that he almost never opened windows during winter because of the high electricity bills.

Radionuclide level is the only parameter we measured which is not influenced by ventilation. It comes from building materials made from industrial waste or natural materials, e.g. marble and granite, which are widely used in Chinese decoration. Different form Radon, which damages human body by inhalation, the exposure pathway of radionuclides is direct (external) exposure. Being aware of radiation pollution, the General Administration of Quality Supervision, Inspection and Quarantine of China (GAQSIQ) has issued National Standard to classify building materials into three grades according to the radioactive level of radionuclides (GAQSIQ 2001). The applying boundaries of different materials are also regulated.

Formaldehyde

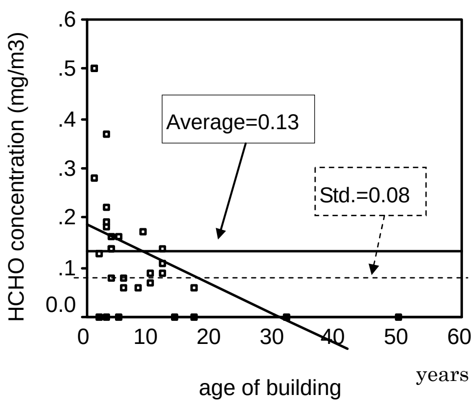


Figure 10: HCHO vs. building age

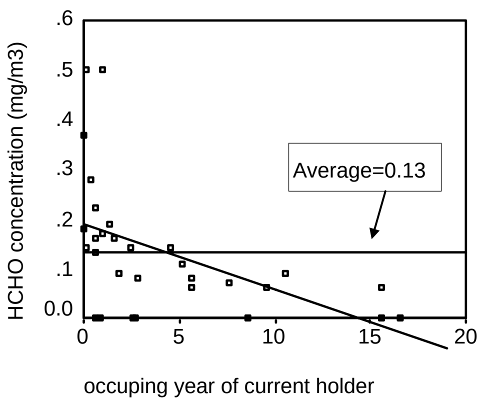


Figure 11: HCHO vs. occupying time

Fig 10 indicates serious formaldehyde pollution especially in new homes. Performing Pearson correlation analysis, the correlation of building age and HCHO concentration is significant at 0.05 level (Fig 10), and correlation of occupied time and HCHO concentration is significant at 0.01 level (Fig 11). HCHO concentration decreases when building age or occupied period increases. Sakaguchi and Akabayashi (2003) show similar results in their study. Significant correlation of HCHO and room temperature was not found in our study.

Opening windows is the most practical strategy to remove pollutants for the majority of naturally ventilated homes. To investigate its effect on HCHO removal, we conducted extra tests in two newly-completed apartments, which had the highest HCHO concentration (0.5 mg/m^3) in the 30 dwellings. After 20 minutes opening window in test rooms, HCHO concentration in one unit decreased to 0.27 mg/m^3; HCHO in the other unit was undetected (lower than 0.04 mg/m^3). So opening a window has a positive and rapid effect, but cannot ensure good level of IAQ continuously, especially in cold winter. To achieve optimum effect, further study is required on the interaction between HCHO emission rate, local conditions and the arrangement of ventilation strategies.

Occupants' Symptoms and Perceived IAQ

We asked 11 questions considering building-related symptoms (acute or chronic) such as headache, fatigue, depression, dry eyes, irritation of eyes or nose, arthritis and so on. In calculating the responses, 26.7% people had more than three symptoms. But it is somewhat difficult to conclude that indoor pollution is the only cause of the symptoms. When we examine numbers of symptoms occurring in various households versus the duration of their living in their current home which is shown in fig 9, we find that people living in new homes seem at higher risk of health problems. We also learn that the perceived IAQ level and the measurement results are not compatible. For example, among 17 people who evaluate their home as comfortable, 10 are living in homes with HCHO concentration above recommended criteria including one case of maximum concentration (0.5 mg/m^3); six are living in homes in which CO_2 levels are higher than 1000ppm.

CONCLUSIONS

From the results of the investigation, we obtained better knowledge of residential ventilation and IAQ. Changing building components, household lifestyle etc has led to more problems to be considered. 62.2% of surveyed dwellings are ventilated by natural means, which is easily influenced by occupant behaviour. A total of 29.7% of households reported that air in their house is bad, especially when smoking, over-occupied or cooking. According to the field measurements, HCHO concentrations in new-built or new-decorated houses are higher. There was no relation found between HCHO concentration and room temperature. Opening windows has a rapid effect on removal pollution but the effect is influenced by HCHO emission rate, local conditions and the arrangement of ventilation strategies. It is important to ensure adequate ventilation in new and airtight house. People living in new homes seem at higher risk of building related health problems. The perceived IAQ levels reported by households are not compatible with the measurement results. So the assessment of IAQ level should be based on both occupant perception and parameter measurement.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the participation in this work of Dalian Environmental Protection Department, China and OM Solar Association, Japan.

REFERENCES

(2001). Statistical data of Dalian construction, Dalian Urban&Rural Construction Committee.

B.C.D. (1996). *Energy conservation design standard for new residential buildings JGJ26—95,* Building and Construction Depart., China.

Beisteiner, A. and D. A. Coley (2003). "Carbon dioxide levels and summertime ventilation rates in UK schools." *International Journal of Ventilation* **1**(3): 181-187.

GAQSIQ (2001). *Radionuclide Standard In Building Materials.* **GB 6566-2001**.

Jones, A. P. (1998). "Asthma and somestic air quality." *Soc. Sci. Med.* **47**(6): 755-764.

Persily, A. K. (1997). Evaluating building IAQ and ventilation with indoor carbon dioxide. Gaithersburg, Md, Building and Fire Research Laboratory at the National Institute of Standards and Technology.

Sakaguchi, J. and S. Akabayashi (2003). "Field survey of indoor air quality in detached houses in Niigata Prefecture." *Indoor Air* **13 (Suppl. 6)**: 42-49.

INDOOR AIR QUALITY IN CLASSROOMS: FIELD CAMPAIGN BY QUESTIONNAIRES AND MEASUREMENTS

S. P. Corgnati and S. Viazzo

Department of Energy Technologies, Polytechnic of Torino, Corso Duca degli Abruzzi n. 24, 10129 Torino (ITALY) – phone: +39.011.564.4507; fax: +39.011.564.4499; e-mail:stefano.corgnati@polito.it

ABSTRACT

A research project aimed at investigating IAQ and thermal, acoustic and visual comfort was carried out in Italian high school and university classrooms. The investigations were performed through field campaigns during regular lesson periods consisting of subjective surveys and measurements.

This work focuses in analysing the results from the IAQ investigations at four high schools of *Provincia di Torino* during the heating period. Measurements were addressed to evaluate the air change rate through the tracer gas technique, the air permeability of the building envelope through the blower door technique and the indoor air quality through monitoring the CO_2 concentration. Results from measurements were compared with the requirements from Italian standards and regulations for school buildings. At the same time, questionnaires were filled by students in order to qualify the perceived air quality.

KEYWORDS

High schools, indoor air quality, field campaign, measurements, subjective surveys.

INTRODUCTION

Indoor air quality (IAQ) is one of the major issues to satisfy in school building and students are very sensible to this environmental aspect.

Within a wide research project about global environmental comfort in Italian university and high school buildings (Corgnati et al, 2003; Corgnati et al, 2004), a specific study was dedicated to indoor air quality in classrooms.

In particular, this work shows the results from a field campaign performed at four high schools of the *Provincia di Torino* (Astolfi et al, 2003).

The field campaign was performed during regular lesson periods (morning or in the first part of the afternoon) and it consisted of both subjective surveys and measurements. Students judged IAQ in terms of air pleasantness and odour perception (human odours, smoke, chemical odours). At the same time, the outdoor and indoor CO_2 concentrations were measured and the CO_2 increase (ΔCO_2) was used as an objective indicator of the air quality. The Fanger's relationship expressing the percentage of dissatisfied people (PD) as a function of the ΔCO_2 concentration (CR 1752, 1999) was calculated and compared with the subjective answers.

Moreover, both the number of air changes per hour (ACH) and the envelope air permeability were measured. ACH was evaluated using the tracer gas technique (decay method), while the envelope air permeability was estimated by the blower door pressurisation method.

Results from measurements were compared with the requirements concerning ventilation and IAQ from Italian standards and regulations.

CLASSROOMS DESCRIPTION

The analysed classrooms were selected in order to give a representative sample of typical high school Italian classrooms. All the classrooms are medium-sized and parallelepiped shaped.
The four examined high schools are located three in Turin suburban city settings (“C. Levi”, “B. Vittone” and “A. Gramsci”) and one in Turin downtown (“Regina Margherita”). They are naturally ventilated and equipped with water- heating systems (radiators): this is the most typical configuration for Italian classrooms. The main characteristics of the analysed classrooms are summarised in table 1.
The study was performed during the heating period, which in Turin ranges from October 15th to April 15th. In particular, the investigations were carried out from the end of January to April. Turin is in the North West part of Italy at the foot of the Alpes. It has a continental climate, characterised by cold-dry winter and hot-humid summer. In particlar, during the heating period the mean outdoor temperature and mean irradiace on a horizontal surface are respectively 5.6°C and 90 W/m^2. The details about the climate conditions during the measuremets are given in the following chapter.

TABLE 1 - Main characteristics of analysed classrooms

School		Classroom	NS	NST	V [m^3]	F [m^2]	H [m]	W/F	EXP	WA [m^2]
High-school	C. Levi (Le)	4B	22	21	224	68	3.3	0.08	O	5,30
		2C	18	17	181	55	3.3	0.10	E	5,44
		LAB	20	17	276	84	3.3	0.07	E	5,44
	Regina Margherita (RM)	3 BL	18	17	222	54	4.1	0.20	S	10,80
		4 DB	22	22	258	63	4.1	0.18	E	10,70
		5 AL	22	21	219	54	4.1	0.20	E	10,28
		LAB	15	12	230	56	4.1	0.31	E; N	17,47
	B. Vittone (Vit)	2 D	20	20	166	55	3.0	0.17	N	9,52
		3 C	24	23	166	55	3.0	0.17	S	9,52
		LAB	25	23	332	100	3.3	0.16	O	17,56
	A.Gramsci (Gra)	1 A	22	22	138	46	3.0	0.17	NNE	8,60
		3 B	28	27	138	46	3.0	0.17	SSO	8,60
		LAB	15	14	292	97	3.0	-	-	9,7

NS = number of seats	H = height [m]
NST = number of students	W/F = glassed area / floor area
V = volume [m^3]	EXP = windows esposure
F = floor area [m^2]	WS = windows area [m^2]

VENTILATION

A field campaign for the measuring air change rate was performed in six classrooms of the examined school buildings using the tracer gas decay technique, employing SF_6 as tracer gas (ASTM, 1995).
The results were elaborated in order to obtain the local mean age of the air and the number of air change per hour. The analysis was performed with windows both opened and closed. All the classrooms are naturally ventilated (Brager et al, 2000). As a consequence, the air change rate depends on the climatic conditions of the site: the average conditions of the indoor and outdoor air during the measurements in the investigated classrooms are summarised in table 2. In figure 1 the results with closed windows, that is the typical winter configuration during lesson periods, are shown and compared to the values suggested by the Italian standard UNI 10339 (1995) (defining the ACH per person at 24 m^3/h for school buildings) and regulation D.M. 18/12/1975 (fixing the number of ACH at 5).
In figure 2, the changing of the air change rate with the number of opened windows is shown for

classrooms Le 4B. The windows have the same dimensions, 0,94 m of width and 0,94 m of height. As shown in figure 1 and 2, in the typical winter configuration with all the windows closed, the air change values prescribed by the Italian standard and regulation are not satisfied. The measured ACH maintain always below 1, except in Le 4B having 1,2 ACH. Such values are highly lower than the requirements.

TABLE 2 – Indoor and outdoor air: average conditions during measurements

Classroom	Indoor			Outdoor		
	T [°C]	RH [%]	v [m/s]	T [°C]	RH [%]	v [m/s]
RM 4DP	25,1	35	0,07	9,1	71	0,85
RM 3BL	24,8	33	0,06	9,1	71	0,85
Vit 2D	24,5	46	0,04	20,4	62	2,16
Gra 3B	24,4	32	0,07	9,7	25	1,28
Gra 1A	26,4	21	0,05	9,7	25	1,28
Le 4B	27,0	32	0,03	7,6	81	1,41

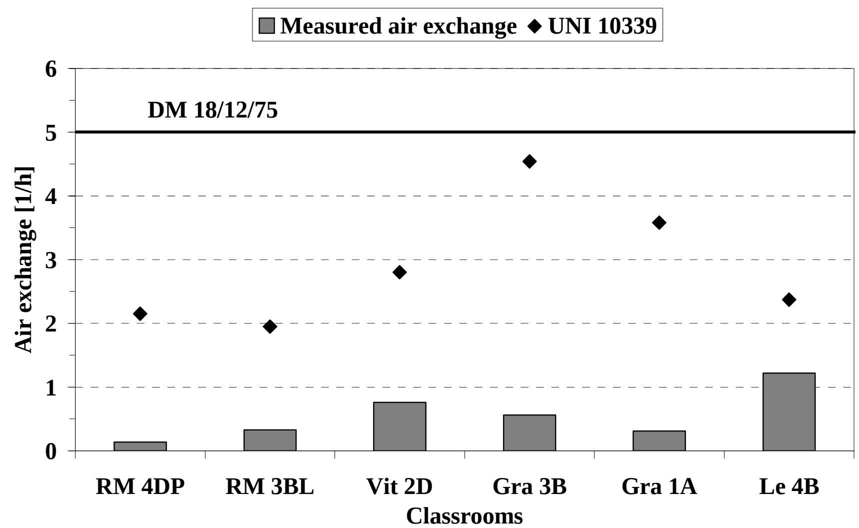


Figure 1 – Windows closed: measured air exchange and standard requirements

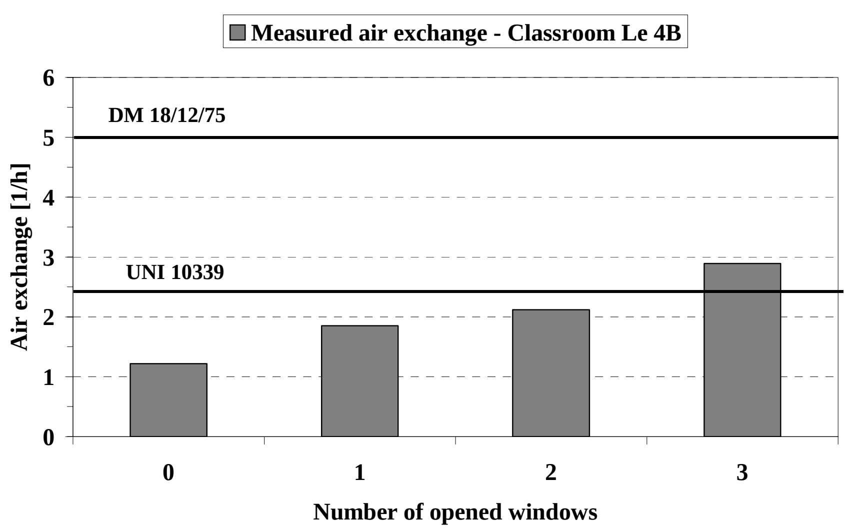


Figure 2- Le 4B with opened windows: measured air exchange and standard requirements

Results in figure 2, referring to classroom Le 4B, show that only with 3 opened windows the ACH prescribed by standard UNI is overcome. The 5 ACH required by D.M. 18/12/75 are never met.

AIR PERMEABILITY OF THE BUILDING ENVELOPE

The air permeability of the building envelope was investigated in one classroom for each school building, using the "blower door" pressurisation technique (Charlesworth, 1988). Through such a technique, the relationship between indoor-outdoor pressure difference Δp and air flow rate V' is obtained, so that the properties of the building envelope in terms of air permeability may be highlighted.
The measured experimental points (see Figure 3) were interpolated by an expression like

$$V' = C\,\Delta p^{\alpha}$$

where C is the global air permeability of the building envelope and α is the flow coefficient, set at 0,67 in the performed analyses. The presented data refers to the configuration with all the windows closed.
The obtained results confirmed the ones concerning the measurement of the air change rate in the classrooms. In fact, classrooms RM 3BL shows the lowest air permeability (and the minimum value of air change per hour) while classroom Le 4B shows the higher air permeability (and the maximum value of air change per hour).

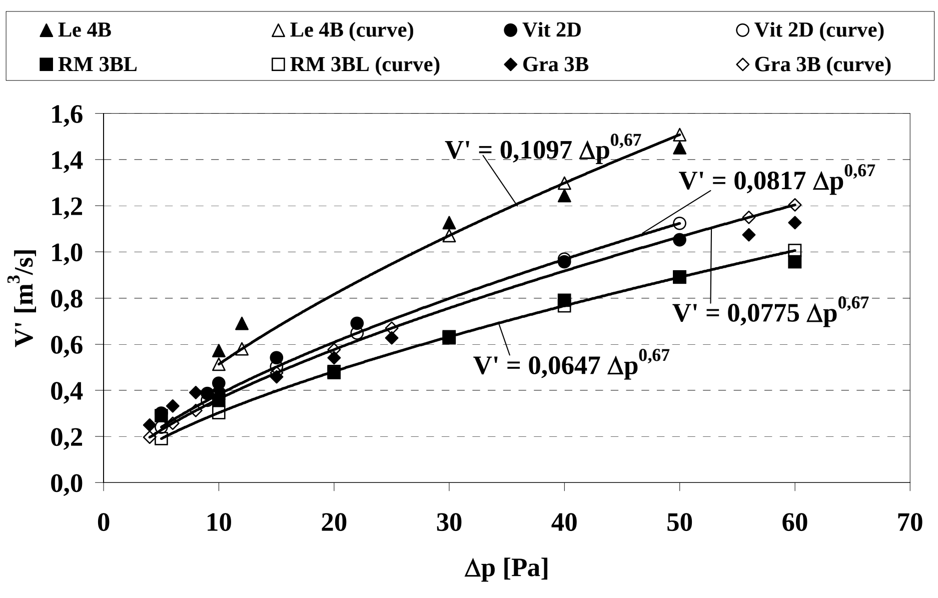


Figure 3 – Air flow rate vs. Pressure difference: results from the "blower door" pressurisation technique with closed windows

From results in figure 3, it can be calculated that a pressure difference of 1,6 Pa and 2,6 Pa are required respectively in classrooms Le 4B and RM 3BL to ensure the air change per hour according to Italian standard UNI 10339; such values increase respectively to 4,8 Pa and 10,3 Pa to ensure the air change per hour required by Italian regulation D.M. 18/12/1975. But in the analysed sites, for typical climatic conditions, the Δp values are lower than 1 Pa.

AIR QUALITY

People are the main contaminant source within a classroom. As a consequence, the CO_2 concentration level can be taken as a good indicator of the bio-effluent emission from occupants and, as a consequence, of the indoor air quality.

This is confirmed by the results of the questionnaires filled by the students about the air pleasantness (a vote ranging from 1 to 5 was assigned) and the odour perception (human odours, smoke, chemical odours). It was verified that the odour most frequently perceived in classrooms was the one from human bodies, even if other odours, like chemical and tobacco smoke odours, are considered more annoying (see figure 4).

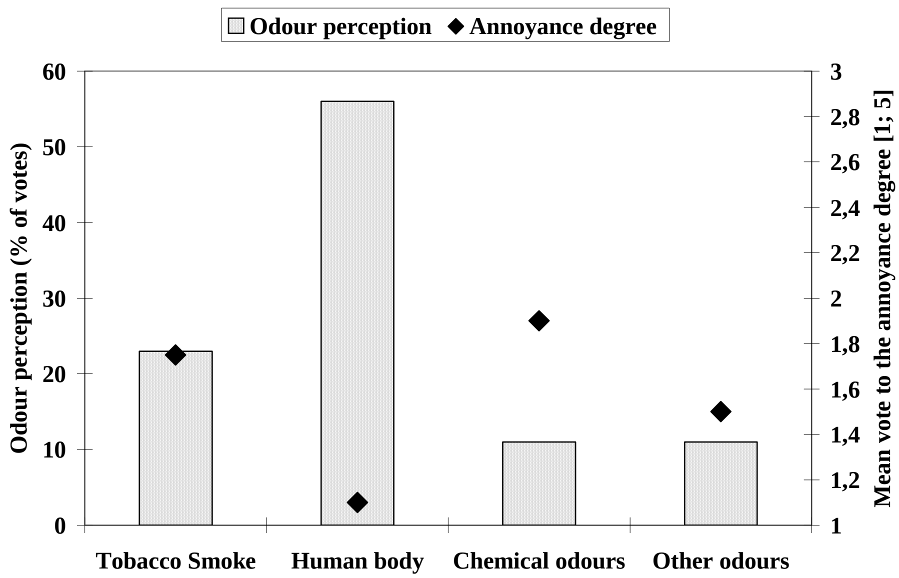


Figure 4 – Odour perception and annoyance from questionnaires (vote 1 = minimum annoyance)

As a consequence, the bio-effluent emission is traced by the CO_2 concentration level, which depends from the person activity level: for sedentary school work it is around 22 l/h per person. According to standard CEN 1998 [7], the maximum acceptable increase of the CO_2 concentration with respect to the outdoor background CO_2 concentration level is 660 ppm, corresponding to a percentage of dissatisfied people for the indoor air quality of 20%.

In table 3, the measured CO_2 concentration and the corresponding PD are presented together with the mean vote given to students to the perceived indoor air quality.

Results in table 3 show a ΔCO_2 concentration from 312 to 886 ppm. In the most of cases, the ΔCO_2 maintains below or around the prescribed limit (660 ppm), corresponding to a maximum percentage of dissatisfied people of 20%. Only in classroom RM 4BD and Vit 2D, the ΔCO_2 is appreciable higher than the limit. But, the vote given by students of such classrooms to the perceived air quality does not differ to the one given in the other classrooms: in fact, the subjective mean vote to IAQ maintains in a short range from 2.2 to 2.6 (mediocre air quality).

Table 3 – Measured CO_2 concentration, PD and mean subjective vote to IAQ

<table>
<tr><th colspan="2">School</th><th>Classroom</th><th>ΔCO_2</th><th>PD (CR1752)</th><th>Mean vote to the air quality*</th></tr>
<tr><td rowspan="9">High-school</td><td rowspan="2">C. Levi (Le)</td><td>4B</td><td>679</td><td>20.3</td><td>2.7</td></tr>
<tr><td>LAB</td><td>312</td><td>10.8</td><td>2.3</td></tr>
<tr><td rowspan="2">Regina Margherita (RM)</td><td>3 BL</td><td>651</td><td>19.7</td><td>2.2</td></tr>
<tr><td>4 DB</td><td>730</td><td>21.4</td><td>2.2</td></tr>
<tr><td>B. Vittone (Vit)</td><td>2 D</td><td>886</td><td>24.6</td><td>2.2</td></tr>
<tr><td rowspan="3">A.Gramsci (Gra)</td><td>1 A</td><td>414</td><td>13.7</td><td>2.0</td></tr>
<tr><td>3 B</td><td>423</td><td>14.0</td><td>2.1</td></tr>
<tr><td>LAB</td><td>483</td><td>15.6</td><td>2.6</td></tr>
<tr><td colspan="6">* vote 1 = worst judgement to the air quality</td></tr>
</table>

It has to notice that there is not a perfect inverse correlation between ΔCO_2 and measured ACH, as resulting by a steady state mass balance equation of CO_2 (ASHRAE, 2001). In fact, the measured ΔCO_2 are always lower than the one calculated from the application of the balance equation. This is because a steady state balance can not be applied due to the student habit of opening the window during the breaks at the end of each lesson (that is about 1 opening of a couple of minutes every one or two hours): as a consequence the contaminant concentration in classrooms is highly variable during the time. It is remarkable that students expressed in their questionnaires a very high degree of satisfaction in controlling "personally" the air change by opening/closing the windows.

CONCLUSIONS

The main results of the experimental campaign in naturally ventilated classrooms can be summarised as follow:

- with closed windows (typical winter condition), the measured ACH are significantly lower than the value required by Italian standards and regulations
- it is confirmed that bio-effluents are the first cause of unpleasant odours in classroom, so that the air quality can be effectively controlled using CO_2 as indicator
- the measured CO_2 concentrations in the most of cases maintains below the recommended values for good air quality (PD lower that 20%)
- the range of air quality evaluated according to CO_2 concentration is larger than the one indicated by the student judgements
- CO_2 concentrations increasing during lesson time (with closed windows) is controlled by the student habit of opening the widows every lesson breaks (one break every 1 or 2 hours)
- students express an high degree of satisfaction in controlling "personally" the air change by opening/closing the windows.

REFERENCES

ASHRAE 62. (2001). Ventilation for acceptable indoor air quality. Atlanta, USA.

ASTM. (1995). Standard test method for determining air change in a single zone by means of a tracer gas dilution. E 741 – 95.

Astolfi, A., Filippi, M., Mutani G. and Pellegrino, A. (2003). Objective and Subjective Assessment of Environmental Global Comfort in Italian High School Classrooms. In: Proceedings of International Congress CISBAT 2003. Lusanne, October 2003

Brager, G. S. & de Dear, R. (2000). A Standard for Natural Ventilation. ASHRAE Journal: 21-28

Charlesworth, P.S. (1988). Air excahnge rate and airtightness measurement techniques – an application guide, AIVC Guide

CR 1752. CEN 1998 UE Standard. (1999). Ventilation for Buildings: Design Criteria for the Indoor Environment. European Committee for Standardization, Bruxelles 1999

Corgnati, S.P., Filippi, M., Viazzo,S. (2003), Perception of the thermal environment in university classrooms: subjective preferences and thermal comfort. In: Proceedings of International Congress CISBAT 2003. Lusanne, October 2003

Corgnati, S.P., Viazzo, S. (2004). Thermal comfort and environmental quality in high-school and university classrooms – objective and subjective surveys**.** In: Proceedings of International Congress CLIMAMED 2004. Lisboa, April 2004

D.M. 18/12/1975. Norme tecniche aggiornate relative all’edilizia scolastica, ivi compresi gli indici minimi di funzionalità didattica, edilizia ed urbanistica, da osservarsi nella esecuzione di opere di edilizia scolastica, Min. LL.PP., G.U. n. 29, 2/2/1976. Roma

UNI 10339 Ente Nazionale Italiano di Unificazione. (1995). Impianti aeraulici al fine di benessere. Generalità, classificazione e requisiti. Regole per la richiesta d’offerta, l’offerta, l’ordine e la fornitura. Italian Standard UNI 10339. Milano

IMPACT OF VENTILATION SYSTEMS ON INDOOR AIR QUALITY AND ANNUAL ENERGY CONSUMPTION IN SCHOOL BUILDINGS

J. Ferdyn-Grygierek

Department of Heating, Ventilation and Dust Removal Technology,
Silesian University of Technology, 44-100 Gliwice, Poland

ABSTRACT

The paper presents the results of the analysis of the impact of various ventilation systems on indoor air quality and energy consumption, performed for a typical Polish elementary school that was built in 1970s. Simulations were made with the use of two computer codes: *CONTAM W* and *ESP-r*. A multizone model of the global capacity of 9464 m^3 was performed. The model contained 17 classrooms and 10 additional rooms typical of such buildings. The simulations were made for the whole heating season, the breaks in teaching and twenty-four-hour variability of internal heat gains were taken into account. The goal of the tests was to find a compromising solution which would provide good indoor environment and economical energy consumption. Carbon dioxide concentration was used as the air quality indicator, the seasonal energy consumption of the whole building was selected as the energy efficiency indicator.
The results clearly show that natural ventilation systems, traditionally applied in classrooms, cannot provide suitable conditions for learning. The CO_2 concentration is very often more than 3000 ppm. Indoor air quality is better when classrooms are regularly ventilated during breaks by opening the windows. However, during periods of low outdoor temperature it causes large decrease in the indoor temperature below 10 ^oC. Better quality of the indoor air can be achieved by using mechanical ventilation, which makes it possible to keep CO_2 concentration at the level of 1000 ppm.

KEYWORDS

school buildings, carbon dioxide, indoor air quality, simulation, energy consumption

INTRODUCTION

Indoor air quality is a factor which influences children's efficiency of learning. This is the reason why high level of the indoor air quality in classrooms is required in many countries. It may be obtained only by sufficient ventilation. Better quality of indoor air increases energy consumption which is opposite to the necessity of the energy saving.

It is commonly observed that ventilation rates are reduced from 7 l/s/p to even 0.5 l/s/p (Thompson[1998]). However, energy should not be saved without taking into account the occupant's comfort and health, especially in school buildings. Thus in design and analysis of ventilation systems the airflow rate cannot be reduced even it causes increase in the energy consumption.

The most popular indicator of indoor air quality is concentration of carbon dioxide generated by people. In most standards which, determine the necessary airflow rate, the value of 1000 ppm is applied as a limit of CO_2 concentration. This value was given in 1858 by German physiologist Pettenkofer[1858]. Up to now, the published analyses of air contaminations in school buildings have shown that indoor air quality in classrooms is not able to provide acceptable conditions for learning. In majority of the cases discussed carbon dioxide concentration in classrooms exceeds 1000 ppm, significantly reaching even 4000 ppm (Prill et al.[2002], Weinläder et al.[2000]).

In Poland most of the school buildings were built in 1960s and 1970s. These buildings are characterized by relatively high energy consumption. The increase in heating costs which was observed in 1990s showed how expensive the maintenance of such buildings was. For that reason, many of the buildings have been recently renovated. The purpose of such renovation is to reduce the energy consumption by means of thermal insulation, windows replacing and central heating modernising. However, modernization of ventilation systems is rarely performed.

The paper presents the results of analysis of the impact of different ventilation systems on indoor air quality and energy consumption. The analysis referred to a typical Polish elementary school, which was built in 1970s, after retrofitting (windows replacing + thermal insulation of external walls).

DESCRIPTION OF THE ANALYSIS

A four-storey elementary school building of total cubature 9464 m^3 and usable heating area of 2277 m^2 was chosen for the analysis. The building contained 17 classrooms and 10 additional rooms. Its technical data is presented in Table 1

TABLE 1
Technical equipment of the building

Building façade	external walls	brick 40 cm + polystyrene 8 cm; U=0.4 W/m^2K
	windows	double glass U=1.1W/m^2K air tightness factor a=0.2 $m^3/(mhPa^{2/3})$
	roof	rib-and-slab roof 22 cm, insulated by slag 20 cm + polystyrene 10 cm; U=0.3 W/m^2K
Heating	central heating system system with radiators, all radiators equipped with thermostats; gas boiler; all rooms except store-room are heated	
Ventilation ducts	all rooms except corridors equipped with gravitational ventilating ducts – one or two individual ventilating ducts (27×14 cm) connecting each room with the outlets on the roof	

The classrooms were occupied by 25 or 30 students and 1 teacher. The lessons were in progress from Monday to Friday according to the timetable from 8:00 am to 4:30 pm. One lesson lasts 45 min. and the brakes last 10 minutes except for the two long brakes which last 20 minutes.

The analysis was made with the use of two computer codes: *CONTAM W*, the latest version of which can simulate the control of ventilation rates based on contaminant concentrations (Dols and Walton[2002]) and *ESP-r*, the energy simulation system which is capable of modelling the energy and fluid flows (ESRU[1997]). The multizone model containing 21 zones was prepared (see Figure 1)

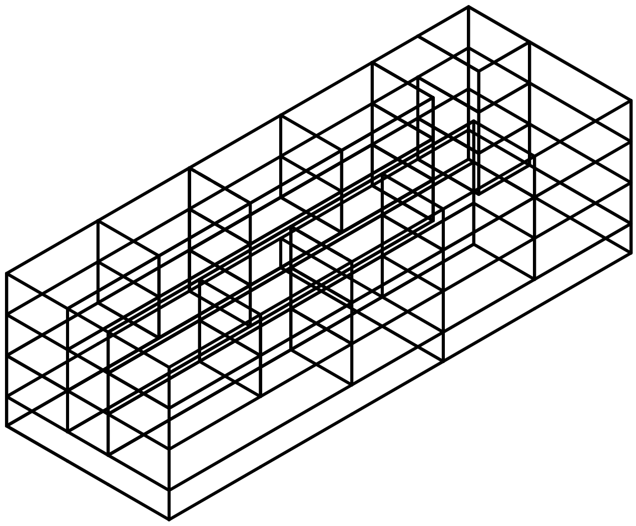


Figure 1 Multizone model

Simulations were made for the whole heating season, the breaks in teaching and twenty-four-hour variability of the internal heat gains were taken into account. It was assumed that each person in school was a source of emission of 13 l of carbon dioxide per hour as well as a source of sensible heat depending on the job: pupils during lessons 63 W, pupils during brakes 75 W, teachers 100 W and the others 95 W. The temperature in rooms was 20 ^{o}C from 6:00 am to 5:00 pm. In the evening and at weekends it was reduced to 15 ^{o}C.

Six ventilation systems were simulated. The fourth case was selected as the reference case:

A: Gravitational ventilation system, the windows in all rooms always closed.
B: Gravitational ventilation system, the classrooms additionally ventilated by opening the windows during brakes, in the other rooms the windows always closed.
C: Gravitational ventilation system, the windows in all the rooms equipped with air inlets, the classrooms additionally ventilated by opening one window during brakes, the other windows always closed; from 5:00 pm to 7:00 am and during weekends the flow through the air inlets limited to 20% of their whole capacity.
D: Mechanical, exhaust ventilation system: the windows in all the rooms equipped with air inlets operated as in case C, gravitational ventilating ducts in classrooms and in toilets equipped with roof fans of constant capacity: classrooms 470 m^3/h, toilet 360 m^3/h. The fans operating on working days from 8:00 am to 4:30 pm, afterwards gravitational ventilation system used. The other rooms as in case C, in all the rooms the windows always closed.
E: As case D but the fans in the classrooms equipped with CO_2 DCV control.
F: Mechanical, supply and exhaust demand controlled ventilation system: the classrooms equipped with individual compact air unit with rotary heat recovery unit (recovery efficiency depending on the airflow with the average from 60% to 80%), the units equipped with CO_2 DCV. The units operating on working days from 8:00 am to 4:30 pm, afterwards gravitational ventilation system used. The other rooms like as case D, in all the rooms the windows always closed.

Figure 2 presents the systems described above for one classroom (fourth storey, on the west side of the building)

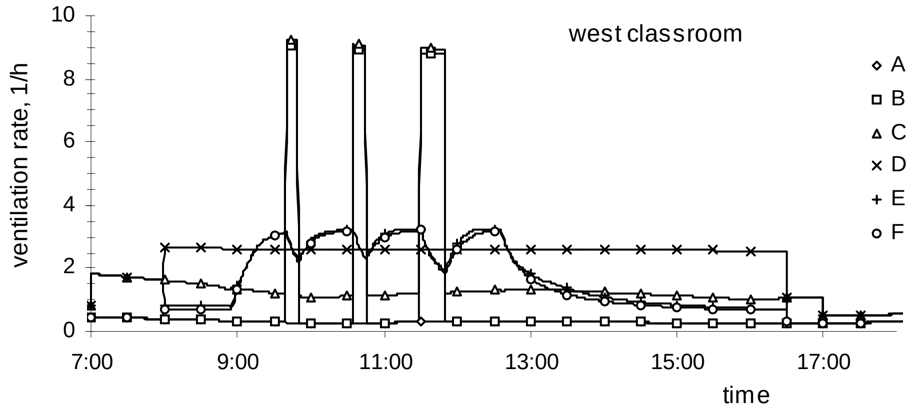


Figure 2 Airflow in six case study for one classroom during one day

Each of the cases was simulated for a period of 7 months – the whole heating season (from October to April) at 1 min time step. The energy analysis accounted for the total load of building. This load was determined for each case over an entire heating season of the weather data for Warsaw climate.

RESULTS

In result of the simulations, the text files containing the values of the ventilation airflow in each zone, distribution of carbon dioxide concentration in the classrooms, heat demand for ventilation air heating and total heat demand of the building. The calculation results are presented in Fig 3 and 4 and Table 1 and 2.

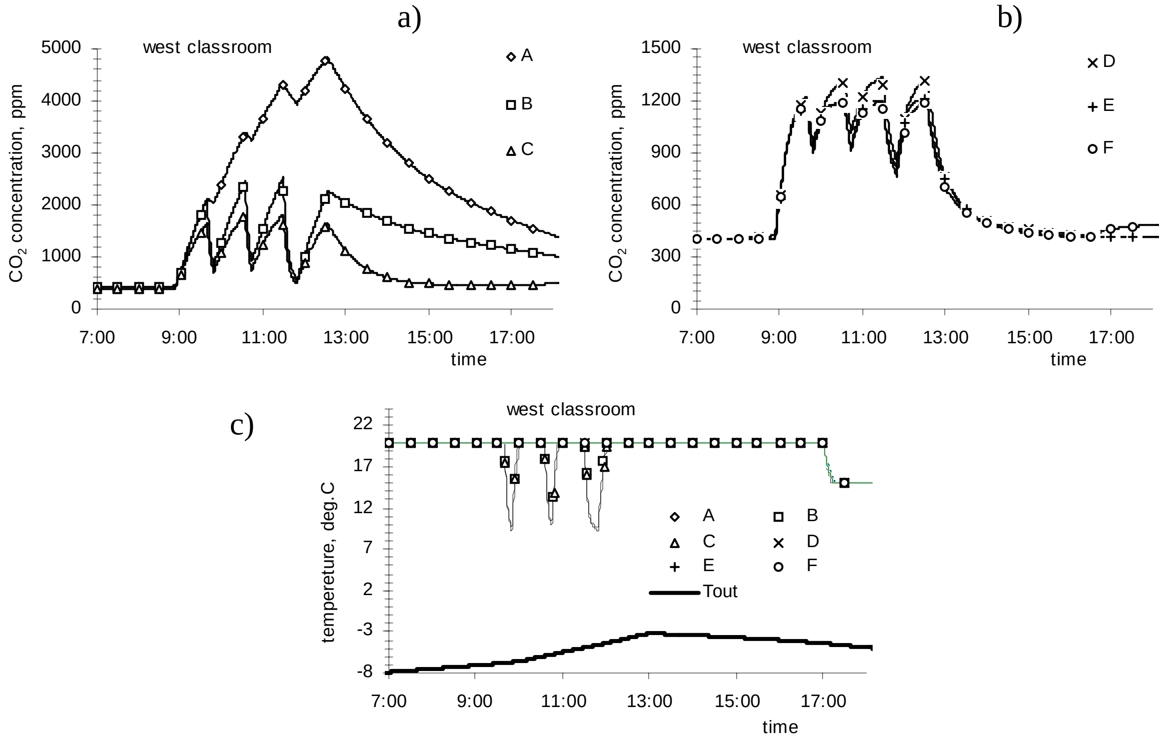


Figure 3 a), b) CO_2 concentration during one day for the classroom selected (see Fig. 2)
c) indoor temperature during one day for the classroom selected (see Fig. 2)

The variation of airflow rates for the cases considered, average in the heating season (October to April) are presented in Table 1. As an indicator of the indoor air quality CO_2 concentration in classrooms during lessons was assumed (only net time of lessons). Figure 4 presents the average distribution of CO_2 concentration in the classrooms for cumulative distribution function 50% (C50) and 90% (C90).

Case A illustrates the conditions in schools after retrofitting, where ventilation systems have not been renovated. Ventilation rates at the level of 0.3 1 per hour result in low indoor air quality, when carbon dioxide concentration reaches 5000 ppm. Additional ventilation of the classrooms by opening the windows during the brakes (case B) could improve situation, the maximum CO_2 concentration falls below 3000 ppm, but during the periods of low outdoor temperature it causes large decrease in the indoor temperature below 10^{o}C (see Fig.3c).

TABLE 1
Average ventilation airflow and carbon dioxide concentration in building

			A	**B**	**C**	**D**	**E**	**F**
Ventilation rate, 1/h	working days: 8:00 am÷4:30 pm	classrooms	0.3	0.8	1.6	2.6	1.7	1.7
		toilet	0.2	0.2	2.0	3.1	3.0	2.4
		the other rooms	0.3	0.3	0.5	0.6	0.5	0.5
		the whole building	**0.3**	**0.4**	**1.4**	**2.1**	**1.7**	**1.5**
	working days: 4:30 pm÷8:00 am weekends and holidays: all day long	classrooms	0.3	0.3	0.5	0.5	0.5	0.3
		toilet	0.2	0.2	0.6	0.6	0.6	0.4
		the other rooms	0.2	0.2	0.3	0.3	0.3	0.3
		the whole building	**0.2**	**0.2**	**0.5**	**0.5**	**0.5**	**0.3**

Satisfactory indoor air quality is acquired only with the use of mechanical ventilation systems (case D-F) by providing several times higher ventilation rate Then, the average CO_2 concentration in classrooms during lessons does not reach 1000 ppm (see Fig.4).

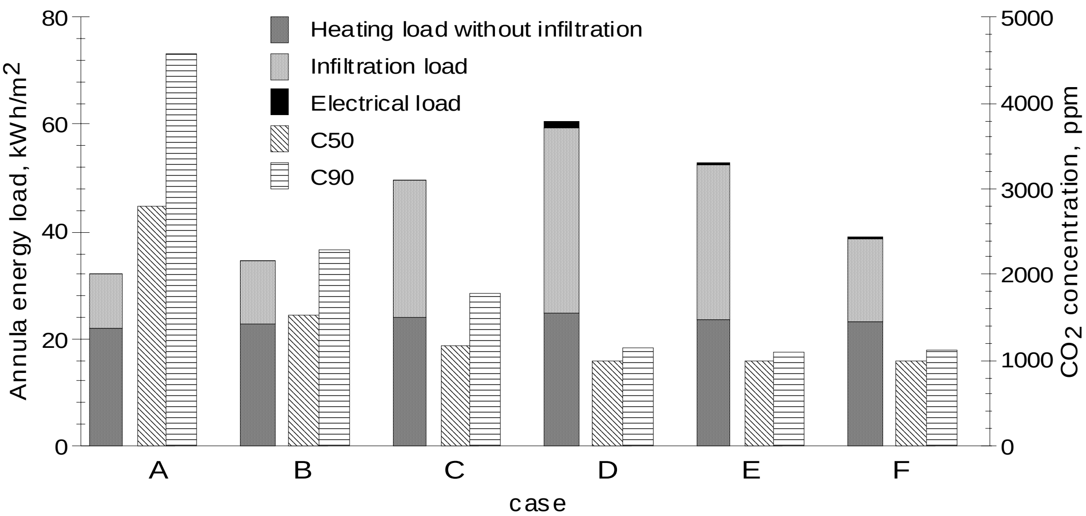


Figure 4 Annual energy consumption in the whole building and CO_2 concentration, average in all classrooms

Annual energy consumption, divided into infiltration and electrical energy for fans is presented in Figure 4 and Table 2.

TABLE 2
Annual energy consumption and average concentration of CO_2 in the building

	A	B	C	D	E	F
Infiltration, kWh/m^2	10.1	11.8	25.5	**34.6**	28.8	15.6
Electrical load, kWh/m^2	-	-	-	**1.2**	0.7	0.4
Total heating load, kWh/m^2	32.1	34.7	49.5	**59.3**	52.3	38.6
Ratio of heating loads (in comparison with case D)	54%	58%	83%	**100%**	88%	65%
Average CO_2 concentration in classrooms, ppm	2787	1539	1172	**991**	991	994
Ratio of CO_2 concentration (in comparison with case D)	281%	155%	118%	**100%**	100%	100%

Table 3 presents estimated investment costs for introduction of the analysis systems to existing school building.

TABLE 3
Investments costs for introduce discussing ventilation systems

	A	B	C	D	E	F
Investments costs, EURO	-	-	6 500	30 000	40 000	110 000

CONCLUSIONS

The results of the simulations show variability of ventilation rates and the indoor air quality related to it in the analysis of school buildings and total energy consumption for heating. It may be concluded that natural ventilation systems, commonly used in Polish schools, are not able to provide acceptable conditions for learning. Indoor air quality is improved when classrooms are regularly ventilated during breaks by opening the windows. However, during periods of low outdoor temperature it causes dramatic decrease in the indoor temperature (below 10^{o}C). The best quality of the indoor air can be achieved by using mechanical ventilation, which makes it possible to keep CO_2 concentration at the level of 1000 ppm. Maintaining such good indoor air quality in the existing school buildings is connected with the increase in the heating costs. Investments for such renovations should not be considered only from the economical point of view but as necessity in respect of the pupil's health and comfort.

REFERENCES

Dols, W. S. Walton, G. N. (2002) *CONTAM 2.0 User Manual Multizone Airflow and Contaminant Transport Analysis Software*. National Institute of Standards and Technology NISTIR 6921 Gaithersburg, USA.

ESRU (1997) *The ESP-r System for Building Energy Simulation User Guide Version 9 Series.* ESRU Publication, University of Strathclyde, Glasgow

Pettenkofer, M. (1858) Uber den Luftwechsel in Wohngebäuden, München.

Prill, R., Blake, D., Hales, D. (2002) School indoor air quality assessment and program implementation. *Proceedings of the 9 International Conference on Indoor Air Quality and Climate*, Monterey, USA

Thompson, B. (1998) Engineers, IAQ, and schools. *ASHRAE Journal*, **June**, 22-26.

Weinläder, H., Beck, A., Fricke, J. (2000) Demand Controlled Ventilation in Schools–Energetic and Hygienic Aspects. *Proceedings 21st AIVC Annual Conference, Innovations in Ventilation Technology*, **September**, paper 6

CHECKING THE COMPLIANCE OF RESIDENTIAL VENTILATION SYSTEMS IN FRANCE

François Rémi Carrié and Daniel Garin

Centre d'Etudes Techniques de l'Equipement de Lyon
46 rue Saint Théobald
F – 38081 L'Isle d'Abeau Cedex, France

ABSTRACT

This paper addresses the issue of the compliance of residential ventilation systems with building regulations. Because the French building code includes requirements on performance as well as on means, the approach adopted by the French government consists in checking both airflow rates and functional measures. This paper gives an overview of the methods used and analyses the results of tests performed on 260 building projects (multi-family buildings and grouped individual houses). Non-conformities are divided into major 8 categories, 4 regarding the type of equipment used, and 4 regarding the measured airflow rates. The non-compliance ranges between 4% and 39%. While the supply of industrial products is well adapted to the requirements, lack of care and coordination at the design, installation, and commissioning phases leads to poor results. Quality management could certainly help improve this situation.

KEYWORDS

Ventilation system, performance check, residential buildings

INTRODUCTION

Regulatory compliance checks on buildings have been initiated in France in the early 70s. These inspections are meant to urge contractors and project owners to build according to the rules set by the building code. They are also meant for the ministry for housing to monitor the application of the regulations.

Today, the compliance checks performed by the CETE network (Technical Studies Centres of the Ministry for Equipment) cover 8 fields : fire safety, balustrades, acoustics, automatic garage doors, stretcher transport, accessibility, energy performance, and ventilation. The controls are ordered by the state as a judiciary police mission on samples taken from the ORTEC (Observatoire de la Réglementation Technique) database managed by CSTB. The inspections are implemented by the CETE network; by law, they can be performed on site within 2 years after the building is declared finished by the owner.

This paper focuses on ventilation checks and the way they are performed in France. The results obtained on a sample of 260 multi-family buildings and grouped individual houses inspected in 2001 are analysed.

BACKGROUND

The French regulation on ventilation in new residential buildings is mostly based on the order dated 24/3/82. It is based on four major requirements:

1. The air renewal must be global and permanent throughout the dwelling.
2. The air circulates from main rooms where the air inlets are located, to service rooms, where outlets are located.
3. New dwellings must be equipped with a ventilation system (the ventilation cannot rely on window opening only). The ventilation system must be able to extract given airflow rates that depend on the dwelling type. Base and boost airflow rates are defined.
4. Airflow rates can be reduced if the indoor air quality is maintained and condensation risks are not increased. Therefore, humidity-controlled systems can be used.

In sum, there are both functional measures and given airflow rates that must be attained in order to comply with the regulation.

INSPECTION METHODS

The ventilation inspection form is divided into 6 chapters: technical characteristics; air renewal and ventilation equipment; extract airflow rates; presence of combustion appliances; general description; comments (open).

In chapter 1, the inspectors report the climatic zone (according to EP regulation), the type of ventilation system, and the presence of chimneys. In chapter 5, information regarding the availability of sizing documents, the contractor that has performed the installation, voluntary commissioning, etc. is included. Chapters 2 and 4 concern functional requirements whereas chapter 3 deals with performance requirements. These two aspects are further detailed below.

Functional measures

The functional measures are controlled through visual inspection—e.g., the location and characteristics of air inlets and outlets, faulty stop-alarm, exhaust air outlet, kitchen hood connected to the system.

Inspectors also report installation defects, including excessively long ducts, torn ducts, impossible maintenance of air terminal devices—e.g., due to the nearby presence of a water heater, etc.

Performance requirements

The performance checks are based on the evaluation of the extract airflow rates. Four requirements are checked:

1. base airflow rate in the dwelling;
2. base airflow rate in the kitchen;
3. boost airflow rate in the kitchen;
4. boost airflow rate in other rooms.

These verifications are performed either by direct airflow measurement or, if calibrated air terminal devices (ATD) are used, by measuring the pressure difference across the ATD. Note that in France, self-balancing outlets are almost systematically used in multi-family buildings.

The airflow rate is considered insufficient if smaller than the required airflow rate with an allowance of 3 m^3/h for a target airflow rate of 15 m^3/h and 5 m^3/h for greater airflows. In that case, the airflow is non-compliant with respect to the ventilation code. Excessive airflow rates are also reported. Although these cannot be considered non-compliant with respect to ventilation, they may affect the compliance of the building with respect to EP regulation. If the airflow rate exceeds the required airflow rates by more than 30%, it is considered excessive.

Reporting

Non-conformities are reported by the inspectors on standard forms for statistical processing. If one non-conformity is found on an item in a building project, all units are considered non-compliant. They are also recorded in minutes that include legal facts as well as observations. The minutes may be forwarded by state authorities to the attorney general. The inspectors also file a report that is sent to the owner. The report describes the non-conformities found; in addition, it includes comments and recommendations mostly on aspects that are known to affect the ventilation performance although not unambiguously covered by regulation (e.g., damaged ducts).

RESULTS AND DISCUSSION

The results of all inspections are compiled by CSTB. Figure 1 summarizes the results in terms of non-compliance rate for height major categories. The results show that 43% of the buildings inspected do not comply with the required functional measures, i.e, there exists at least one non-conformity to the building code. 49% of the buildings do not comply with the minimum requirements on base and boost extract airflow rates.

While the non-compliance rate is relatively uniform for extract airflow rates, there is some disparity regarding the functional measures. There are few non-conformities on the ventilation principle and exhaust air outlets. There is a significant percentage of non-compliance for extract ATDs and stop-alarms. The most frequent non-conformities are reported on air inlets. Common defaults concern the number, installation, and characteristics of the air inlets. In fact, overall for a building, the right types of ATDs are usually on the construction site; however, they are often misplaced. Regarding the extract airflow rates, common defaults that impact the performance are: inadequate ATDs, poor sizing, and poor installation resulting in excessive pressure drops. Based on CETE inspectors field experience, important and critical phases have been reported in Table 1. More detailed quality assurance tools (Garin, 2001) have appeared very promising when tested on pilot projects.

Regarding the type of ventilation system, there are great disparities in non-compliance rates on extract airflows (Figure 2). There are considerably less non-conformities on humidity-controlled extract-only systems (27%) than on standard extract-only systems (56%). Note however that, for humidity-controlled systems, only the pressure drop across the ATDs and compliance of the installation with the technical agreement is checked (no airflow rate measurement). 78% of the buildings with gas appliances connected to the ventilation system do not comply with the regulation. Note however that the sample size is small (18 buildings).

As for the size of the building, the statistics are based on the number of units per building. Trends are difficult to establish although on the sample analysed here, the smaller buildings (less than 20 units) show greater non-compliance rates (Figure 3).

The presence of a technical inspector assigned by the owner to cover ventilation aspects is common. The assignment type may be more or less demanding on the inspection; however, this statistical data on the assignment type is not available yet. The results show that non-conformities remain very frequent when a technical inspector is assigned (40% on functional measures, 46% on airflow rates), although the non-compliance rate is much lower than without such inspectors (Figure 4). Further analyses on the assignment type appear necessary to better understand those results.

Table 1. Example of check list showing the critical steps to avoid non-compliance. Source. Garin and Janody. 2002. Qualité réglementaire des bâtiments d'habitation neufs. Fiche aér. n°1.

Code requirements	Building permit	Call for tender	Field	Commissioning
Global air renewal				
- Principle is met		⌖	✓	✓
Air inlets				
- All main rooms have air inlets		✓	⌖	✓
- Sizing is correct		✓	⌖	✓
Air outlets				
- Principle is met		⌖	✓	✓
Exhaust air				
- Exhaust air re-circulation into dwelling must be avoided		✓	⌖	✓

✓ : Important check point ⌖ : Critical step

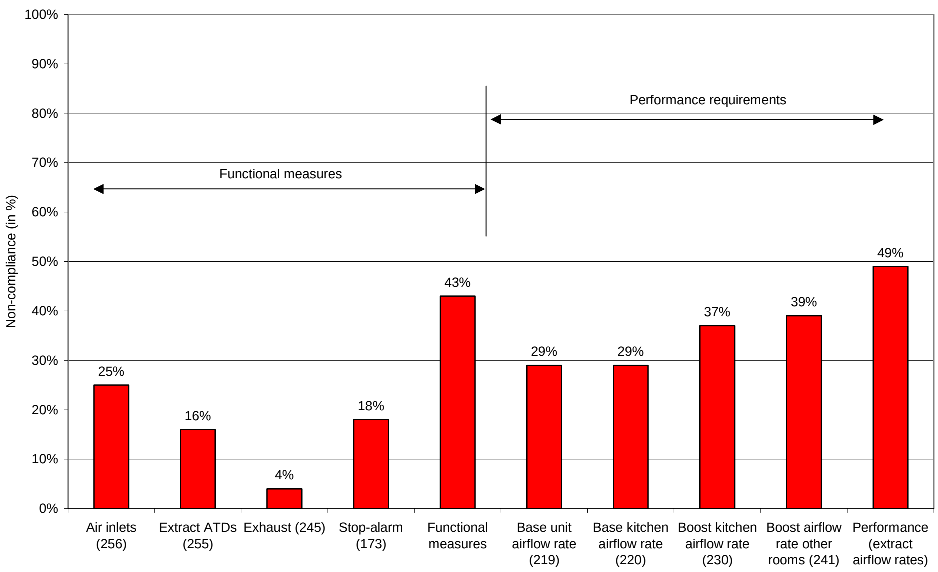


Figure 1. Percentage of non-compliant buildings (based on 260 inspections). By type of non-compliance. Sample size in parenthesis.

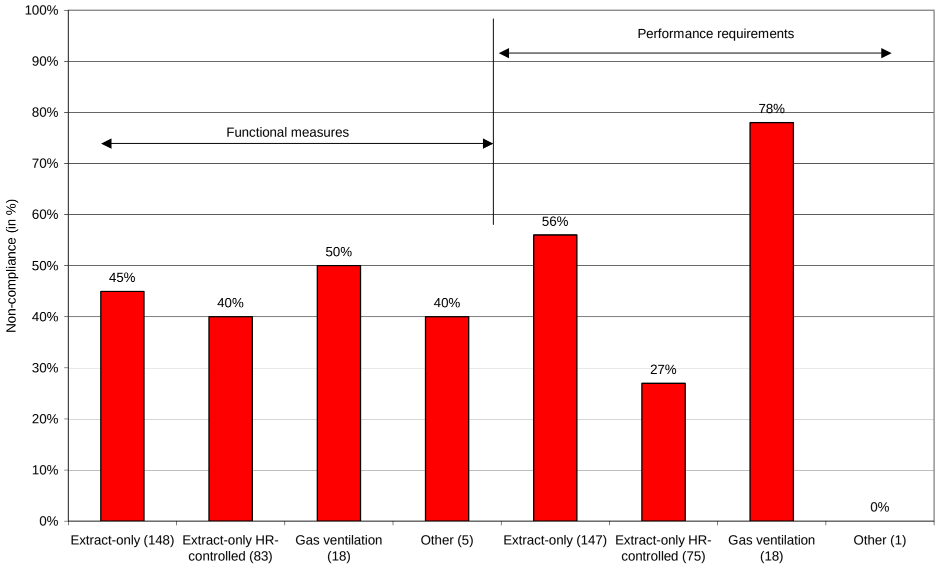


Figure 2. Percentage of non-compliant buildings (based on 260 inspections). By ventilation system type. Sample size in parenthesis.

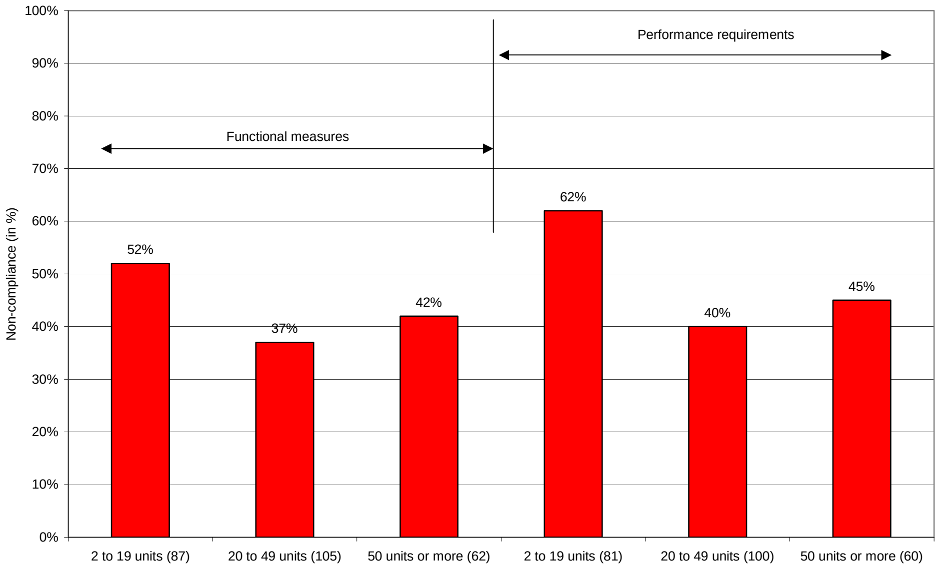


Figure 3. Percentage of non-compliant buildings (based on 260 inspections). By building size. Sample size in parenthesis.

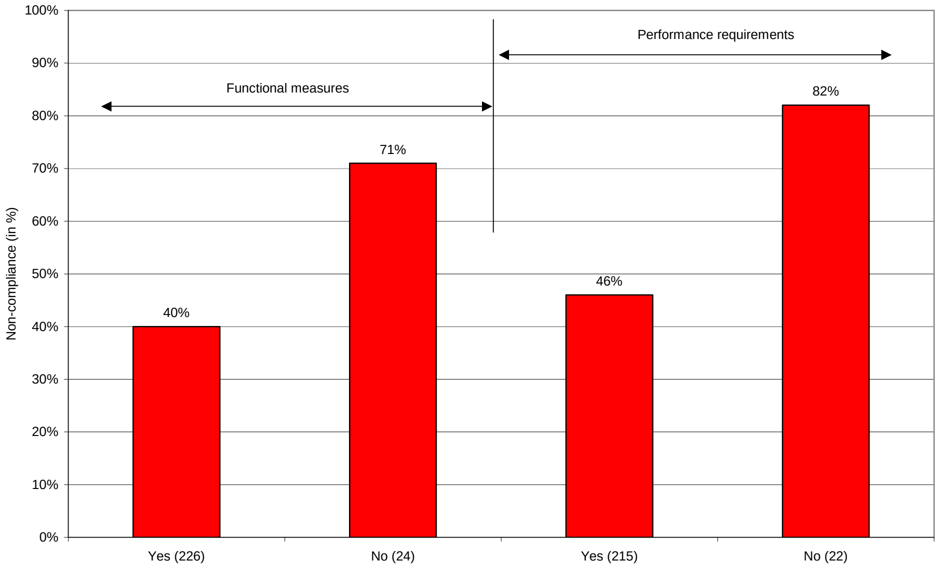


Figure 4. Percentage of non-compliant buildings (based on 260 inspections). By presence of technical inspector assigned by the owner. Sample size in parenthesis.

CONCLUSION

The results show that non-conformities on ventilation are quite common in multi-family buildings and grouped individual houses in France despite the availability of adequate industrial products. Often, the non-compliance results in a lack of care in the installation phase. Most defaults could be avoided should quality control be simply but efficiently implemented for all phases, including commissioning. In fact, voluntary commissioning is rarely done thoroughly with regard to ventilation in France. However, some industries have started stimulating practitioners with quality management, providing simple tools to implement control procedures, commissioning services, as well as guarantees in case of defaults found at commissioning. Also, CETE de Lyon has developed and experimented quality assurance tools to reduce the frequency of non-conformities, and has obtained very promising results (Garin, 2000). Such approaches appear very attractive to operate a market transformation.

ACKNOWLEDGEMENTS

The inspections reported in this paper are funded by the Ministry for Equipment, through General Directorate of Town Planning, Housing, and Construction (DGUHC) and regional infrastructure agencies (DRE). The statistical data is managed by CSTB.

REFERENCES

Garin, D., and Janody, M. 2002. Qualité réglementarire des bâtiments d'habitation neufs. Fiche aér. n°1 et 2. Published by Agence Qualité Construction and DGUHC.

Garin, D. 2000. Réglementation technique des bâtiments d'habitation. Mise en œuvre d'une démarche visant à éviter les non-conformités récurrentes. CETE de Lyon. Report DVT 00 230.

Setting up a database of indoor climate measurements in recently built Belgian dwellings

N. Heijmans[1], P. Wouters[1], F. Dobbels[1], G. Houvenaghel[2], B. Vandermarcke[3]

[1]Division of Building Physics and Indoor Climate, Belgian Building Research Institute (BBRI), B-1342 Limelette, Belgium
[2] Laboratory of Building Physics, Katholieke Universiteit Leuven B-3000 Leuven, Belgium
[3]Sint-Lucas Architectuur Gent, Hogeschool voor Wetenschap & Kunst (W&K) B-9000 Gent, Belgium

ABSTRACT

One of the major sources of problems in dwellings -if not the main source- is moisture, especially due to surface and interstitial condensation on walls and roofs. For this reason, it seems important to evaluate the current standardisation and reference documents dealing with moisture and eventually to develop new assessment methods. This is the goal of the Belgian project "Moisture problems in roofs", carried out by BBRI, KUL, RUG and W&K. The first step is to collect a large number of indoor climate measurements in recently built dwellings built.

A monitoring program is currently carried out. Temperatures and relative humidity levels are measured every 10 minutes in 5 rooms (as well as outside) of 41 dwellings, during several months. CO_2 is monitored in 3 dwellings, in the same rooms and at the same frequency. Pressure differences across the roof are measured in 1 dwelling, at a frequency of 1 measurement every minute. All these collected data are gathered in a database that is presented in this paper. It is intended to make this database available to the scientific community.

KEYWORDS

Indoor climate, dwellings, database, temperature, moisture, humidity.

INTRODUCTION

One of the major sources of problems usually met in Belgian dwellings -if not the main source- is moisture, especially due to surface and interstitial condensation in walls and roofs. The existing standards and reference documents related to moisture in dwellings are mainly based on researches dating from 1974-1980. In the meanwhile, construction techniques and standardisation/regulation have changed a lot. Firstly, most dwellings were not yet properly insulated at that time. Secondly, dwellings were not yet equipped with any kind of ventilation systems. Thirdly, buildings usually were much less airtight; especially the air tightness of window and door joineries has been improved since the 80's. Consequently, dwellings became more energy efficient and more comfortable. The indoor climate is much better controlled than before when ventilation systems are used. On basis of these considerations, it seems necessary to evaluate if the reference documents related to moisture in roofs are still relevant and, if not, to develop additional evaluation methods.

This is the objective of the project "Moisture problems in roofs: impact of the present boundary conditions and construction techniques in Belgium", carried out by the Belgian Building Research Institute (BBRI), the Katholieke Universiteit Leuven (KUL), the Ghent University (RUG) and the Hogeschool voor Wetenschap & Kunst (High School for Science

& Art – W&K), and funded by the Belgian Government. In order to achieve this goal, it is necessary to collect data about the actual indoor climate in dwellings built since 1980; this is one of the project tasks. This paper presents the monitoring that has been set up, the database and some preliminary results.

SETTING UP A DATABASE OF INDOOR CLIMATE IN RECENT DWELLINGS

In order to collect a large number of data, 41 dwellings have been selected all over Belgium. Attention was paid in order to select various types of dwellings. The dwelling stock consists of 19 social houses, 18 single family houses of moderate size and 3 houses with a swimming pool. Other characteristics that were taken into account during the selection are the presence of a ventilation system and the type of structure (heavy versus lightweight constructions).

Until now, measurements are available for 28 dwellings, for periods varying from about 6 months up to 24 months. Measurements will go on until the expected end of the project (April 2005).

In each dwelling, temperature and relative humidity are measured every 10 minutes, at six different locations: outside, in the living room, in two sleeping rooms, in the kitchen and in the bathroom. The measurements are done with HOBO® H8 Pro-dataloggers. The accuracy of these dataloggers is ± 0.2 °C (at 21°C) and ± 3% RH (at 25°C).

Several parameters are calculated from the measured values (formulas are given at the end of the paper):

- for each location: the saturated vapour pressure p_{sat} and the vapour pressure p_v,
- for each indoor location: the indoor/outdoor vapour pressure difference, the critical temperature factor $f_{Rsi,crit}$ (which is a temperature factor with the dew point temperature taken as the indoor surface temperature) and the indoor surface temperature θ_{si} corresponding to a temperature factor f_{Rsi} equal to 0.7,
- and average values for the building.

The database contains therefore 46 parameters by dwelling, for each 10 minutes interval.

This database would not be complete if there was no information available about the dwellings. For this reason, the occupant has to answer a questionnaire. This questionnaire includes questions about the dwelling (type, location, insulation level…), its equipments (heating and ventilation systems…), the occupant's behaviour (number of occupants, time of occupancy …) and humidity (humidity related problems, source of humidity as aquariums…).

As the project team considers that the database could be useful for other research projects, at both Belgian and international levels, it is foreseen to make it available to the scientific community (the precise format has still to be decided). The database could be used for researches related to humidity in dwellings, for building simulations, etc…

FIRST ANALYSES OF MEASUREMENTS

Internal humidity classes

Several methods can be used to assess the internal humidity class on basis of the outdoor temperature and the indoor vapour pressure. A first method is described in the informative annex A of EN ISO 13788 and is based on monthly mean values. Two other methods have been developed by Hens H. (1992) and have been adopted in BBRI Technical Notes (which are considered as reference documents for the Belgian building sector). These methods are respectively based on monthly and annual values for temperature and vapour pressure. Based on the measurements available at the time of writing this article, the internal humidity class has been determined with both monthly methods. An example is given in Figure 1 for one building.

TABLE 1
Humidity class descriptions, according to Hens H. (1992) and EN ISO 13778.

Class	Hens H. (1992) (monthly average)		EN ISO 13778	
	Description	($p_{v,room} – p_{v,out}$)	Description	($p_{v,room} – p_{v,out}$)
1	Buildings with a low humidity production	< 159 – 10*θ_{out}	Storage areas	< 270-13.5*max(0, θ_{out})
2	Well ventilated buildings with a limited humidity production	< 436 – 22*θ_{out}	Office, shops	< 540 - 27*max(0, θ_{out})
3	Moderately ventilated bldgs with a higher hum. production	< 713 – 22*θ_{out}	Low occupancy dwellings	< 810-40.5*max(0, θ_{out})
4	Buildings with a high humidity production	> 713 – 22*θ_{out}	High occ. dwellings, sport halls, kitchens…	< 1080-54*max(0, θ_{out})
5	–	–	Special buildings	> 1080-54*max(0, θ_{out})

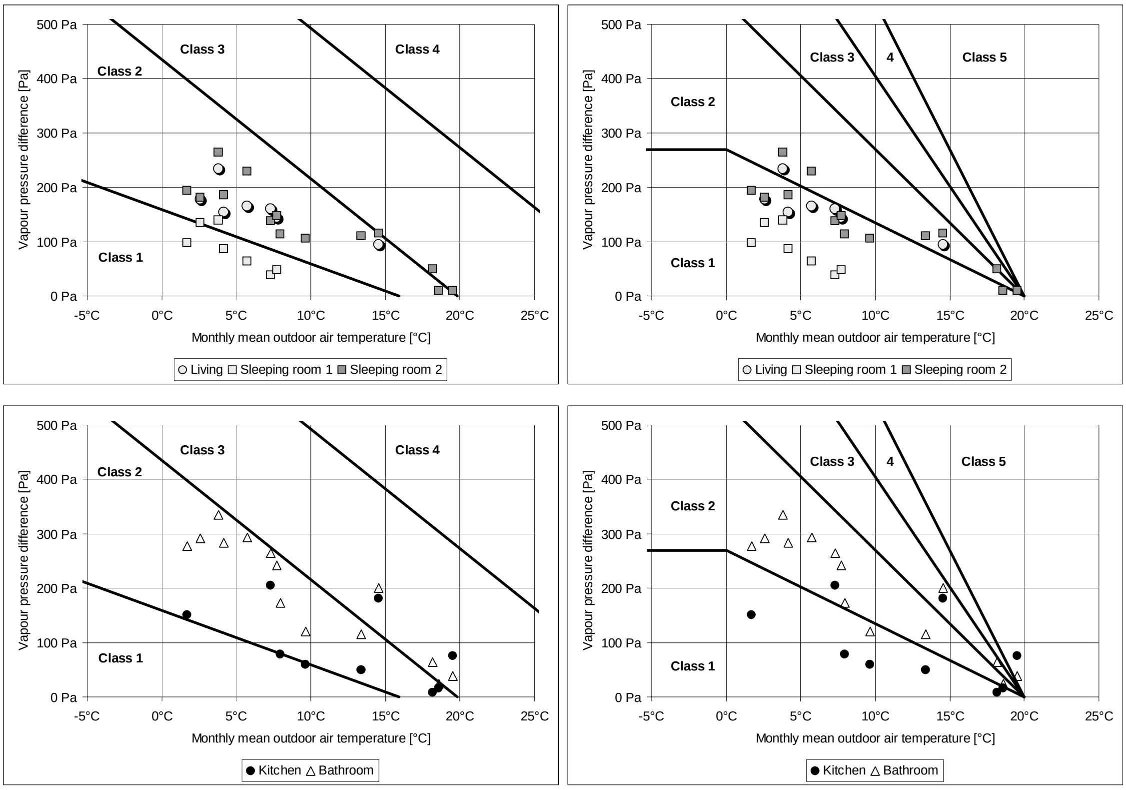


Figure 1: Assessment of the internal humidity class for a building, with methods given in
(left) BBRI Technical Note (Hens H. (1992)) (right) EN ISO 13788

The method proposed by Hens H. (1992) considers 4 classes, whereas the method proposed in EN ISO 13778 considers 5 of them. In the case of the particular dwelling presented in Figure 1, it can be noticed that the sleeping room 1 usually belongs to the internal humidity class 1/1[1], whereas the living and the sleeping room 2 belong to class 2/1 and the kitchen to the class 2/1, and even higher during some time intervals. In this building, the bathroom is the most humid room (mainly class 2/2 but sometimes class 3/≥3).

The impact of some parameters, like for instance the presence of a ventilation system (as far as it is efficiently used by the occupants), could be identified by performing similar analyses on different sets of dwellings. Unfortunately, there are not yet sufficient data available to perform such analysis at this time.

The data will also be used in order to answer some questions: Which method seems to be the most relevant to assess the moisture risk in a dwelling? As the humidity class is different in each type of room, what is a representative procedure for characterising the humidity conditions of a whole building?

Air temperature, relative humidity and critical temperature factor

Measurements from 01/12/2002 (beginning of the monitoring) to 30/04/2003 (end of the heating season) are available for 8 dwellings. From Figure 2a, it appears that the median temperature in the living rooms is about 19.5°C, in the bedrooms 17.5°C, in kitchens 20°C and in bathrooms 19°C. During a small time period, the bathroom is the warmest room of the dwelling.

[1] The first number corresponds to the class given by the method developed by Hens H. (1992) and described in BBRI Technical Notes and the second number to the class described in EN ISO 13778.

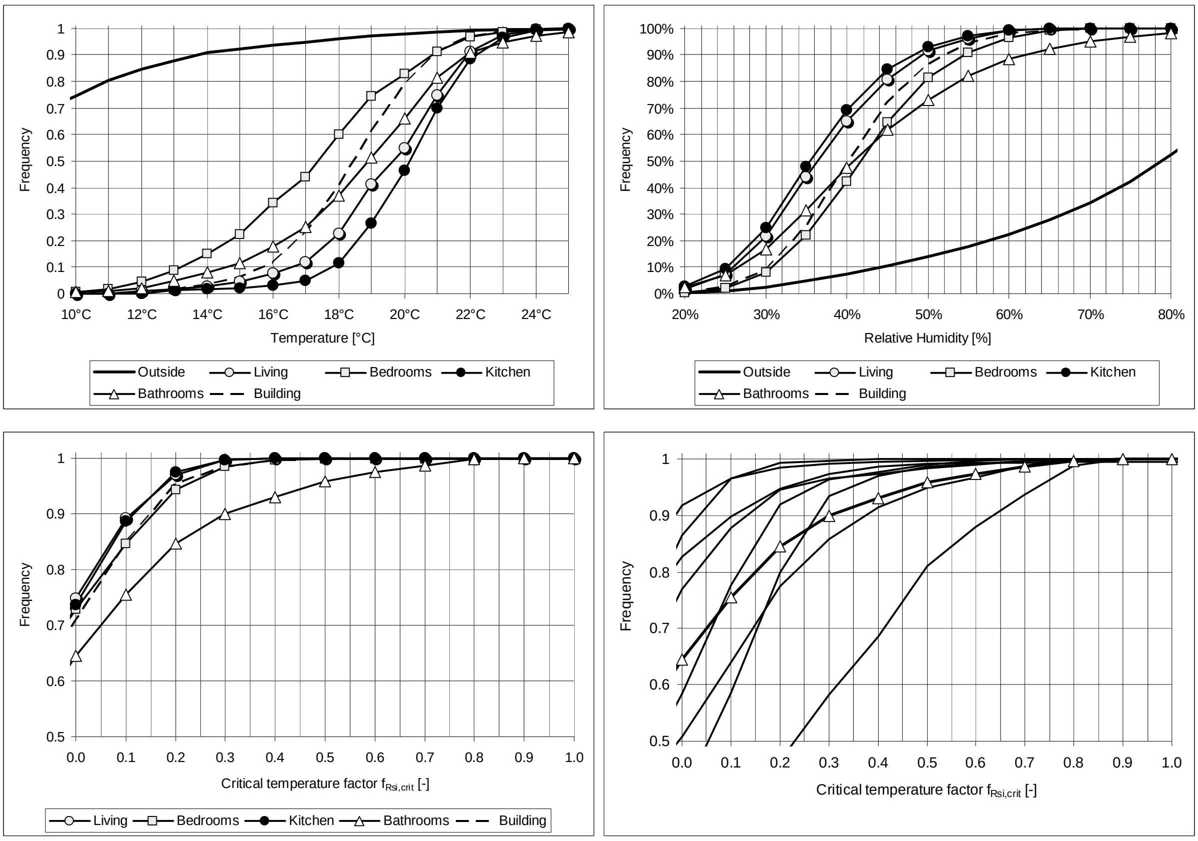


Figure 2: Indoor climate in 8 dwellings, from 01/12/2002 to 30/04/2003
(a) Average temperature and (b) relative humidity by type of room
(c) Average $f_{Rsi,crit}$ by type of room (d) $f_{Rsi,crit}$ in the bathrooms of each dwelling

Figure 2b shows that during 10% of the time, the relative humidity is higher than 49% in the living rooms, higher than 54% in the bedrooms, higher than 48% in the kitchens, and higher than 62% in the bathrooms.

Figure 2c shows that during the major part of the time (±65% of the time in bathrooms, ± 75% of the time for all other rooms), there is no risk of condensation, as the critical temperature factor $f_{Rsi,crit}$ is lower than zero. This means that, if the indoor air temperature θ_{room} is higher than the outdoor air temperature $\theta_{out,}$ the inside surface temperature leading to condensation is lower than θ_{out}, which is of course impossible (in steady-state conditions). Figure 2c also shows that in bathrooms $f_{Rsi,crit}$ is only during 1% of the time higher than 0.7. This of course may vary considerably from one dwelling to another, as can be seen in Figure 2d, according to the building characteristics and the occupant's behaviour. The database, when completed, will allow to evaluate if the criterion $f_{Rsi} \geq 0.7$ is the most appropriate to prevent condensation risk.

It is important to mention that the condensation risk may only be assessed with the help of the temperature factor in steady-state conditions. However, bathrooms are usually only heated just before usage (as illustrated in Figure 2a). The temperature of the wall contacting the outside climate will not rise up as fast as the indoor air temperature. Consequently, the wall surface temperature will be lower than the value calculated in the database and the condensation risk will be higher. It is the intention to study this issue more into detail in the framework of this project.

Indoor air quality based on CO_2 levels

In order to evaluate the indoor air quality and to obtain a better idea of the flow pattern in dwellings, CO_2 measurements have been started in a few dwellings. Five sensors have been installed, in the same rooms as the temperature and humidity sensors.

Pressure differences across the roof

It is commonly stated that dwellings or individual rooms should not be put in overpressure in order to reduce the risk of moisture transport in the building envelop. For this reason, fan assisted supply air ventilation systems (called "system B" in Belgium) are not recommended. However, this statement does not consider that important pressure differences across a roof can also be due to the sole effect of stack and wind, even in the absence of a mechanical supply. This is shown by the measurements carried out in one of the dwellings. The principle of this monitoring is given in Figure 3(a): two manometers are measuring respectively the air pressure differences across the roof (ΔP_1) and between the two external surfaces of the roof (ΔP_2), at a frequency of 1 measure every minute.

Figure 3(b) shows that pressure difference across the roof ΔP_1 was lower than 0 Pa during 4% of the time, higher than 10 Pa during 6% of the time and higher than 20 Pa during 1% of the time. ($\Delta P_1 - \Delta P_2$) gives more or less an indication of the pressure difference due to the thermal effect only. Figure 3(b) shows that $\Delta P_1 - \Delta P_2$ varies between 0 Pa and 5 Pa during 80% of the time, with an average of 2.4 Pa. During this period, the average temperature difference[2] $\theta_{building} - \theta_{out}$ was 8.7°C. As the height of the building is about 15 meters and assuming that the cracks are equally distributed over the building envelop, the pressure difference across the roof due to the stack effect can be roughly estimated to $\Delta P = (0.04*\Delta H*\Delta\theta)/2 = (0.04*15*8.7)/2 = 2.6$ Pa, which is in line with the measurements.

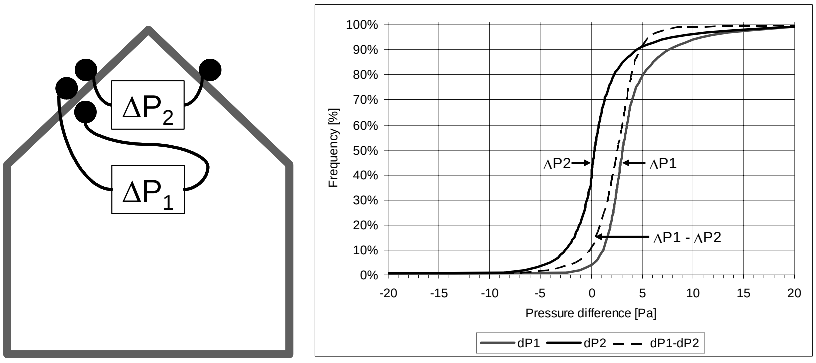


Figure 3: Pressure differences across a roof
(a) Principle (b) Distribution of ΔP_1 and ΔP_2 for the periods
from 29/02/2004 to 20/03/2004 and from 11/06/2004 to 20/06/2004

CONCLUSIONS

In the frame of the "Moisture problems in roofs" project, the indoor climate has been extensively monitored in 41 Belgian dwellings. This monitoring includes temperature and humidity measurements outside and in five rooms of each dwelling. Moreover, CO_2 is

[2] As the measurements were not yet available at the time of data, measurements of 2003 were used for this calculation.

monitored in five rooms of 3 dwellings and 2 pressure differences across the roof are measured in 1 dwelling. The monitoring period varies from 6 to 24 months.

These measurements give a better overview of the indoor climate of Belgian dwellings. In particular, they allow to evaluate the internal humidity classes typically met in dwellings and to select the most appropriate method to assess the moisture risk in a dwelling.

These data could also be used in other researches, both at Belgian or international levels, as the measurement database will be made available to the scientific community.

ACKNOWLEDGMENTS

The authors want to gratefully thank the Federal Public Service Economy, SMEs, Self-employed and Energy of the Belgian Government, which is funding the project "Moisture problems in roofs: impact of the present boundary conditions and construction techniques in Belgium".

FORMULAS USED FOR THE CALCULATIONS

The formulas used for the calculations in the database are given below:

$$p_{sat} = \exp\left(65.8094 - \frac{7066.27}{(\theta + 273.15)} - 5.976 * \ln(\theta + 273.15)\right)$$

$$p_v = RH/100 * p_{sat}$$

$$f_{Rsi,crit} = \frac{(\theta_{dew,room} - \theta_{out})}{(\theta_{room} - \theta_{out})} = \frac{\left(\left(\frac{\ln(p_{v,room}/611)*234.18}{17.08 - \ln(p_{v,room}/611)}\right) - \theta_{out}\right)}{(\theta_{room} - \theta_{out})}$$

$$\theta_{si,room} = \theta_{out} + 0.7*(\theta_{room} - \theta_{out})$$

where θ is the measured air temperature in °C, RH is the measured relative humidity in %, p_{sat} is the saturated vapour pressure in Pa, p_v is the vapour pressure in Pa, $f_{Rsi,crit}$ is the dimensionless critical temperature factor, θ_{dew} is the dew point temperature in °C and θ_{si} is the surface temperature corresponding to a temperature factor f_{Rsi} equal to 0.7. Note that the temperature factor is commonly noted τ in Belgium.

REFERENCES

BBRI (2000), NIT 215 : La toiture plate : composition - matériaux - réalisation - entretien, BBRI Technical Note (available in French and Dutch).

EN ISO 13788:2001 – Hygrothermal performance of building components and building elements - internal surface temperature to avoid critical surface humidity and interstitial condensation - Calculation methods (ISO 13788:2001), CEN.

Hens H. et al. (1982), La méthode de calcul de Glaser, *CSTC Revue n°1 (March 1982)*, BBRI, Brussels.

Hens H. (1992). Indoor Climate Classes. Internal Report IEA-Annex 24 T2-B_92/02. International Energy Agency. Heat air and moisture transfer in insulated envelop parts (HAMTIE).

Janssens A., Hens H. (2003), Development of indoor climate classes to assess humidity in dwellings, *Proceedings of the 24th AIVC conference & BETEC conference - Ventilation, Humidity control and energy, pp 41-46.*.

COOLING IN HOUSING IN SOUTHERN EUROPE WITHOUT CHILLERS.

Simon Burton and Adam Fjearem

Sustainable Development Group, FaberMaunsell Ltd, 23 Middle Street, London EC1A 7JD. UK

ABSTRACT

COOLHOUSE demonstrates the use of passive cooling techniques in southern regions of Europe which are aimed at giving comfortable summer conditions in domestic scale buildings without using mechanical cooling systems. The project focussed on three sites, a private development of houses for sale in south west Portugal, an old people's home in south France and a community centre in mid Italy. All are new buildings and were designed to provide cool internal conditions by passive means such as using solar shading and thermal mass, with the addition in all three cases of ground cooling pipes. This combination of measures was designed, constructed and monitored as part of the project. The ground pipe systems used PVC pipes buried 2-3 metres below ground with air drawn through using electric fans. The results demonstrate that the whole package of measures is successful in providing summer comfort. There is also benefits to the heating of the buildings in winter if the preheated air is used. The project concludes that there are no architectural difficulties in buried pipe system or providing and using internal thermal mass and that the COOLHOUSE package of measures could be replicated in different building types across all southern Europe.

KEYWORDS

Passive, cooling, thermal mass, ground cooling, adobe construction.

BACKGROUND

COOLHOUSE was a European Commission supported Energie Demonstration project which ran for four years from 2000. The project aimed to test the viability of alternatives to air conditioning using passive and low energy construction, cooling and ventilating techniques in Mediterranean and coastal climates and to demonstrate that such strategies can be practical and provide comfortable internal conditions for the occupants. One objective of the Coolhouse project was to reduce the energy demand and the environmental impact of the developments. Another was to provide economic and environmental arguments to justify the cost of the systems and to design and construct ground cooling systems that are easy to replicate at reasonable cost.

The design phase aimed to examine several natural ventilation and cooling strategies, including passive architecture, wind catchers, wind towers, ground pipes, and rock stores. However, the concept of ground cooling systems was common to all three sites. The Coolhouse project finally aimed at the construction, monitoring and publicity of the architectural integration of ground cooling systems with passive architecture in new domestic type developments.

DESCRIPTION OF THE TEST SITES

Three sites were finally included in COOLHOUSE. A new housing development in south west Portugal (Alma Verde), a nursing home in southern France (Frejus) and a community centre in central Italy (Aler Pavia). The developers in each country worked in partnership with energy consultants to achieve the project aims.

A fourth housing site, in Crete was included in the original contract, but was never built. The design work on the project was carried out in 2000 by the University of Athens but no further action was taken by the Contractor ElGreco.

The three sites are different in both location and building type and use and the details of the components and systems finally incorporated into the buildings varies greatly. Each site used its own designers and consultants, though all sites and installations were discussed between the design teams at the regular six monthly meetings. This variety also demonstrates that design of passive cooling systems can take on a number of different forms and the results demonstrate that each can be successful.

There is a general level of innovation in all the buildings which is that they are all designed to optimise the use of the local climate. The majority of new construction in hot countries is not designed to work with the climate and produce sustainable buildings, but rather ignores natural and passive design and, building to current regulations produces buildings that need heating in winter and cooling in summer to make them acceptable to occupants. This is very energy inefficient and very different from the COOLHOUSE building design.

The main technological innovation in all three projects is the use of buried pipes to cool external air and draw this into the buildings to provide cooling. This innovation avoids or at least reduces, the need for conventional active cooling using electrically driven compressor systems. The initial design studies showed that fans were necessary to draw the air through the buried pipes and this uses electricity, though considerable less than air-conditioning systems. It is also thought that buried pipes require less maintenance that air-conditioning systems and certainly have a much longer life.

Site in Portugal

Alma Verde is a 35.3 hectare new residential community with numerous public and private amenities located in the unspoiled western Algarve 8km west of Lagos, Portugal, some 25km east of the tip of Europe. When site design started the first house to be built on the site were the set of 6 detached houses and it was decided to use these to demonstrate the COOLHOUSE principles. Design of the houses and cooling systems started in 2000 and the whole concept of passive cooling, together with the ground cooling systems was developed on a comprehensive basis.

The general design of the houses was passive with external wall insulation, solar shading and internal thermal mass, including adobe internal walls. For the ground cooling, standard PVCu drainage pipework was used for the ground pipes, with the widest readily and economically available diameter being 160mm. With this duct size taken into account, computational analysis showed that a duct air speed of 4m/s running through two ground tubes of 25m length each would achieve an air temperature reduction of 8ºC at the ground tube outlets. This equates to 2500W of cooling energy. Further, computational fluid dynamic analysis showed internal air temperature reductions of 3ºC compared with outside temperatures, which under most circumstances is considered sufficient for thermal comfort.

It also became clear that direct wind power alone would not be adequate to achieve these duct velocities, and that fan assistance would be required. Also, with wind power only, the system would not operate on still days and these are the days when cooling would be most required. Again, analysis showed a separation between pipes of 2m allows heat dissipation and avoids the cumulative build-up of heat from both pipes that would occur if they were closer together. Unavoidable 90º bends in the ground tube layout are formed from two 45º pipe sections to reduce the air resistance encountered with short radius 90º bends, as long radius bends were unavailable locally. Periodic cleaning of the ground tubes is catered for by installing the tubes with a fall from start to end of about 1: 60. This allows jet washing from the intake end of the tubes to the low point at the other end, where a sump enables a temporary pump to remove cleaning fluid.

Site in France

"L'Aubier de Cybelle" is a 80 beds care home for elderly people, which has been built in Fréjus, Southern France. It has been designed to response to high quality standard, in terms of comfort and environmental issues at all levels, inside the building, locally and globally, and to be the very first "green" nursing home available in the south of France, using in particular bioclimatic and passive cooling design. Because of the particularly climatic conditions in Fréjus and the appropriate choice of land, the building is largely open towards the south, allowing the best use of natural conditions for passive heating and cooling, and natural light. The building, on two levels, covers a total surface of 3950 m2.

All the technical systems have been adopted to reach summer comfort without having to install centralized air-conditioning. These include insulation, solar shading, daylighting, thermal mass, natural ventilation, planting and ground cooling. Among these solutions, the most innovative is a ground cooling system for the dining room area of $380m^2$, for which a grid of 11 pipes each of 0,2m diameter has been buried 2m under the ground covering an area of 400m2 outside the building. Solar water heating and passive solar gain are also included in the building.

Site in Italy

The Pietrasana neighbourhood, Vigevano, Italy, is an area of existing social housing undergoing refurbishment. The district consists of 220 dwellings located in 10 buildings. The central courtyard area has been completely re-designed and a new community centre built. The centre, which is the "COOLHOUSE" building, named "CircoLab", is a multi-functional facility with corporate, conference, recreational, cultural and community functions. The minimisation of the running and maintenance costs was of prime importance in the "CircoLab" design. A mechanical ventilation system connected to air solar collectors during the winter season and to the ground cooling duct during summer, provides a reduction of the heating and cooling costs, and an improvement in comfort of users.

The building is a "concrete box", cut by two internal glazed patios along the longest walls, and completely greened by creepers. The visual connection with neighbourhood is given by a large window on the East side, in front of the central courtyard, while a door on the S/E corner which provides the access.

The cooling of the building is provided by connecting the system for the mechanical ventilation with a ground cooling system, of which the core is made of a PVC pipe, diameter 0,4 m, 40 m long buried 4 m under the ground level, taking the outdoor air from a shaded area at the opposite side of the courtyard. An air-to-air heat exchanger provides the connection between the ground pipe and the ventilation system, avoiding any possible air pollution problems. At night, the building is cooled taking the air directly from the roof, when the outdoor temperature falls below the internal one, giving the ground cooling system time to re-charge.

During wintertime, the mechanical ventilation system is connected to a set of glazed air solar collectors of about 36 m^2, placed on the CircoLab flat roof, which provide pre-heating of the inlet air.

RESULTS

Portugal

The monitoring at Alma Verde shows how effective the ground was at removing the peaks and troughs of the external air during hot weather and adding heat to the incoming air during cooler weather. Throughout the monitoring period for house 54 the maximum +DT i.e. heat removed from the incoming air was 11°C and the maximum -DT was 8°C i.e. heat added to cold external air (during winter months or during the evening). For house 56 the maximum +DT was 12°C and the maximum -DT was 8°C.

The temperature of the air leaving the ground pipes varied from 26^0C in August to 15^0C in winter, only one or two degrees different to the temperature of the ground itself. The system achieves the equivalent cooling of fresh ventilation air at a 95% reduction in energy and CO_2 emissions, compared with air conditioning. Useful ventilation pre-heat gains are also available in winter mode. An unexpected benefit from the Alma Verde Coolhouse system when combined with the use of adobe blockwork and vapour permeable external wall construction, is that it is very effective in making significant reductions in internal relative humidity compared to external conditions. Monitoring shows these reductions to be 25% of RH and occasionally up to 30% reductions were recorded.

France

At the nursing home in Frejus, the ground cooling system was monitored during in June and delivered an initial cooling power of 14 kW at 2m^3/s air flow-rate and of 9.5kW at 1m^3/s air flow-rate, which corresponded to expectations. In tests in July and August, cooling power values of typically 5 kW were observed after one to three days of uninterrupted use.

The measured cooling power values are probably lower than values under operational conditions as the soil was backfilled above the pipes in summer conditions of high temperature and low humidity, just before the monitoring started.

Ground temperatures were measured over six months and shown to rise by typically 1 to 2°C per month until the end of August, when decline sets in. At a depth of 2m, earth temperatures ranged between 13 and 28°C.

Based on these results, a one-dimensional finite element simulation calculation predicts annual yields of 2.2 MWh for cooling, 6.7 MWh for heating and an equivalent ventilation coefficient of performance of 16.

Italy

At Vigevano in Italy, monitoring of the whole installation showed that the peak cooling power was 3.2kW with a peak temperature difference 5.0^0C. However the average cooling power was only 0.8kW and the average temperature difference of the air entering the building below external air temperature was 2.9°C. In this particular installation, the earth pipe cooling power seemed too small to overcome solar heating of the duct and heat exchanger located on the roof. In future applications, it is concluded that cooled air should not be brought into the air outside the building in order to keep all the cooling potential inside the building.

The winter monitoring has shown the amount of heating energy generated by the solar panels and the overall building performance, with the solar panels giving 15% of the heating supply, more that 12 000kWh per year.

CONCLUSIONS

COOLHOUSE confirms that several straightforward construction measures are important in providing summer comfort, including solar shading, thermal mass, insulation etc. and that ground cooling pipes can also contribute. Ground cooling pipes work best if they are used in a simple way e.g. air pulled slowly through and used directly as cooled ventilation air. Then they can deliver air at at least 10^0C below outside air temperatures at peak times. At night if the air is cold it can be drawn through to help cool the ground ready for the next day. The pipes can be used only for peak times of the day or for longer periods and also for preheated ventilation air in winter. They can make active air conditioning unnecessary but cannot supply the same blasts of cold air, they work in a slower way and will work best if there is a pre-planned strategy for their use. Ground cooling pipes supply coolth over long periods of time but at a low rate, which is almost the opposite of active chillers. This is very important in understanding and designing a good ground cooling system.

The experience in the community centre in Italy is more difficult, as the ground pipe cool air passes through a heat exchanger first and is integrated mechanically into the heating and ventilating system of the building. The benefits of ground cooling are more difficult to identify and it seems that the particular use strategy was not best suited to the pipe system installed.

We conclude that ground pipe systems work best where the building itself is passively designed to minimise the need for cooling and then a ground cooling system will lop off the peaks of temperature. This generally gives a very comfortable internal environment.

The costs of ground cooling obviously vary with the size but are not expensive, a price per house of about 7500euro was quoted at Alma Verde and a rough estimated payback was 10 years, due to avoided electricity running cost of chillers. From an environmental point of view the energy savings are large at around 5000 tonnes of CO_2 per year per house. This is a very significant conclusion for European energy consumption.

A study on Regional Suitability of the technologies concludes that all technologies are widely applicable across southern Europe where cooling is needed, and could become useful in more northern areas as global warming spreads its effects.

Design of passive cooling measures, including ground pipe systems is not difficult and methods are described in a report on calculation methods used in the project. Computer modelling and calculation methods are available and are tried and tested. The integration of the passive measures into the architecture of a building are not likely to cause any major difficulties, is the conclusion of the Architecture and Passive Design report, but they must be carefully considered from the start of the design process.

Overall it is concluded that occupants like the passive systems but there remains the question as to whether individuals will actually buy in. The Marketability of Passively Cooled Housing report concludes that although passive cooling is low on the list of priorities of prospective purchasers it does have some marketing benefits and has been used as such at Alma Verde (the only private development for sale in COOLHOUSE). The report also indicates that a significant number of purchasers will opt for the optional “COOLHOUSE” system, if offered to them at the current price.

NATURAL VENTILATION OF RESIDENTIAL BUILDINGS IN PORTUGUESE WINTER CLIMATIC CONDITIONS

M. Ferreira[1], H. Corvacho[2] and J. L. Alexandre[3]

[12] *Faculdade de Engenharia da Universidade do Porto, Departamento de Engenharia Civil, Secção de Construções Civis, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal; mce02013@fe.up.pt[1]; corvacho@fe.up.pt[2]*
[3] *Faculdade de Engenharia da Universidade do Porto, Departamento de Engenharia Mecânica e Gestão Industrial, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal; jla@fe.up.pt*

ABSTRACT

In this paper, the current situation of Portuguese residential buildings in terms of ventilation systems is presented. The indoor air renewal is, normally, obtained by providing fresh air exclusively by air leakage of doors and windows and their occasional opening and exhausting the air through ducts placed in kitchens and bathrooms. A recent revision of the Portuguese standard NP 1037-1, concerning natural ventilation of dwellings, is studied and its influence upon heating energy consumption and indoor temperatures is reported. In order to evaluate both thermal and ventilation impact of the adoption of NP 1037-1, a dynamic simulation was undertaken, using Trynsis 15 and Comis 3.1 software. Some results of this study concerning a residential building, located in different Portuguese winter climatic regions, are presented. The relative influence of both wind and thermal stack effect has been evaluated, the cooling effect of ventilation for unheated indoor environments has been quantified and the importance of parameters like the location of the dwelling in the building, its orientation and the opening height have been analysed. Some ventilation devices were simulated, like self-regulated inlet grilles (trickle ventilators). Finally, other strategies of improving ventilation, keeping low heating energy consumption, have been considered, namely demand controlled ventilation.

KEYWORDS

Dwellings, Natural Ventilation, Heating Energy Consumption, Indoor Temperatures.

INTRODUCTION

The most ecological solution to renew indoor room air in dwellings is, undoubtedly, natural ventilation using exclusively the forces of nature to originate differences in pressure, which subsequently generate air circulation. However, during the heating season, the Portuguese climate presents relatively mild weather conditions and the differences between indoor and outdoor temperatures are not as high as in, for example, northern European countries. In this context, it is hard to guarantee that natural ventilation systems are capable of providing an adequate air renewal in buildings by themselves. On the other hand, in order to maintain the ventilation flow rates above the minimum quality standards, ensuring the thermal comfort of the dwellings, it is necessary to consume additional energy to heat indoor spaces (Leal and Maldonado, 2000).

The purpose of this study is to analyze the consequences, in terms of energy requirements for heating and temperatures reached inside the buildings, of the adoption of different natural ventilation systems in a dwelling (Figure 1) with a floor area of 80 m^2, located in three climatic zones in Portugal, with different orientations and opening heights and also with distinct heating regimes. For this purpose, we will use the TRNSYS 15 and COMIS 3.1 programs, which are detailed and dynamic simulation tools. These programs were used together, according to well-defined rules (Dorer and Weber, 2001). The climatic data used for the simulations are included in a climatic database available for the ENERGYPLUS simulation programme (US Department of Energy, 2001).

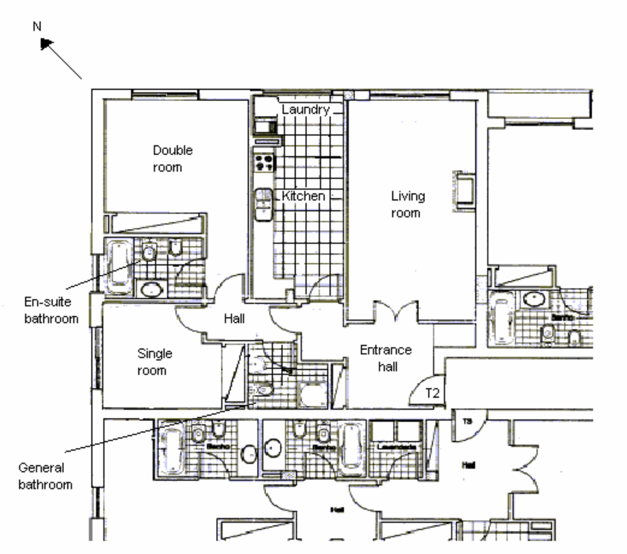


Figure 1: Plan of the Dwelling used in the Simulation

The energy and efficiency analysis is based on three types of natural ventilation systems:
- Air leakage of windows and doors (infiltration), their temporary opening and use of exhaust ducts fitted with cowls. This is a common system in Portugal;
- Natural ventilation using self-regulated inlet grilles located in the various façades. This is the system proposed by the NP 1037-1 Portuguese Standard (I.P.Q., 2002) and can be used not only for the construction of new buildings but also to rehabilitate the existing ones;
- Demand-controlled ventilation.

INFILTRATION AND TEMPORARY OPENING OF WINDOWS

Infiltration Only

In this study, three types of windows were used, belonging to different air permeability classes (I.P.Q., 2002), starting with the less permeable: A2, A1 and non-classified (NC). The building was located in three different cities: Bragança (I3 Zone, Degrees Days (Tb =15ºC) = 1600 ºC day/year), Porto (I2 Zone, DD (Tb=15ºC) = 800ºC. day/year) and Faro (I1 Zone, DD (Tb=15ºC) = 400 ºC day/year) (M.O.P.T.C, 1990) and three heating regimes were used: without heating, permanent heating of the entire dwelling with temperatures of 20ºC, intermittent heating with temperatures of 20ºC only in the bedrooms from 6 p.m. to 22 p.m. in weekdays and from 8 a.m. to 22 p.m. during the weekend. The dwelling faces NE/NW and is located on the 7th floor of a building. Table 1 presents the variations (in percentage terms) of the mean ventilation flows obtained in relation to the figures recommended by the NP 1037-1 Standard, for the entire heating season and for the whole dwelling.

TABLE 1
Percentage of mean flows obtained in relation to the flows recommended by the Standard

%	Without heating			Heating 20ºC			Intermittent heating		
	A2	**A1**	**NC**	**A2**	**A1**	**NC**	**A2**	**A1**	**NC**
Bragança	16	40	60	23	56	88	20	49	76
Porto	19	46	71	23	58	91	21	53	82
Faro	24	57	88	27	67	107	26	63	96

Table 2 presents, in kWh/year, the corresponding energy losses exclusively associated with natural ventilation in the heating season for the entire dwelling.

TABLE 2
Heat losses caused exclusively by natural ventilation

kWh/year	Without heating			Heating 20ºC			Intermittent heating		
	A2	**A1**	**NC**	**A2**	**A1**	**NC**	**A2**	**A1**	**NC**
Bragança	306	580	723	1437	3739	6140	921	2048	2923
Porto	239	460	594	867	2274	3743	599	1348	1943
Faro	142	259	323	534	1382	2380	367	797	1125

It was found that the proportion of this energy in relation to the total energy consumed to heat the apartment with a temperature of 20ºC varies between 30% and 75% according to the city and to the type of windows used, for an insulation level of $U_{Exterior\ Wall}$ = 0,70 W/m^2. ºC and $U_{Windows}$ =1,5 W/m^2. ºC.

Table 3 indicates the mean and lowest temperatures in the double room (Figure 1) and the percentage of hours, in relation to the total number of hours of the heating season, in which the temperature inside the double room is below 16ºC and 8ºC.

TABLE 3
Mean and lowest temperatures in the double room and frequency analysis for infiltration through windows

ºC	Without heating						Intermittent heating					
	A2		**A1**		**NC**		**A2**		**A1**		**NC**	
	Mean	**Lowest**	**Mean**	**Lowest**	**Mean**	**Lowest**	**Mean**	**Lowest**	**Mean**	**Lowest**	**Mean**	**Lowest**
Bragança	11.6	4.3	10.9	3.7	10.6	3.1	17.4	11.4	16.9	8.6	16.4	6.8
Porto	13.9	9.5	13.3	8.8	13.0	8.2	18.1	14.5	17.7	13.5	17.3	12.5
Faro	15.2	11.7	14.7	10.5	14.4	9.6	18.5	15.4	18.1	13.7	17.7	12.2
%	**< 16**	**< 8**	**< 16**	**< 8**	**< 16**	**< 8**	**< 16**	**< 8**	**< 16**	**< 8**	**< 16**	**< 8**
Bragança	83	27	89	31	90	34	29	0	38	0	44	0
Porto	79	0	82	0	85	0	9	0	21	0	31	0
Faro	69	0	74	0	78	0	3	0	8	0	16	0

Infiltration and Temporary Opening of Windows

In many Portuguese dwellings, the dwellers have the habit of temporarily opening windows, especially during the morning, in order to remove excess moisture, pollutants and odours that are released during the night. This procedure, especially in the cases where heating is not a common practice, often leads to a relevant decrease in indoor temperature and to high energy losses caused by the natural ventilation throughout the heating season. These results are presented in tables 4 and 5, for windows with an opening percentage of 1.5% of its total area, from 8 to 9 a.m.

TABLE 4
Mean and lowest temperatures in the double room in a situation of infiltration through windows and an opening percentage of 1.5% from 8 to 9 p.m.

ºC	Without heating						Intermittent heating					
	A2		A1		NC		A2		A1		NC	
	Mean	Lowest	Mean	Lowest	Mean	Lowest	Mean	Lowest	Mean	Lowest	Mean	Lowest
Bragança	11.4	3.6	10.7	2.8	10.5	3.0	17.2	6.2	16.8	5.6	16.4	5.1
Porto	13.7	8.9	13.2	8.5	13.0	8.1	17.9	12.0	17.5	11.3	17.3	10.9
Faro	14.9	9.2	14.5	8.9	14.3	8.7	18.3	11.5	17.9	11.0	17.6	10.6

TABLE 5
Energy losses caused exclusively by natural ventilation for the entire dwelling in a situation of infiltration through windows and an opening percentage of 1.5% from 8 to 9 p.m.

kWh/year	Without heating			Heating 20ºC			Inttermitent heating		
	A2	A1	NC	A2	A1	NC	A2	A1	NC
Bragança	384	631	748	1905	4202	6378	1153	2140	2978
Porto	323	493	612	1199	2523	3916	748	1462	1987
Faro	188	285	332	762	1561	2585	475	848	1152

CONTINUOUS WHOLE-HOUSE VENTILATION ACCORDING TO NP 1037-1

In 2002, the NP 1037-1 Standard was approved, implementing a series of rules concerning natural ventilation in dwellings. This Standard recommends, among other things, the use of continuous whole-house ventilation systems, in which the air inlet consists of special devices placed on the façade. As regards air exhaust, the Standard recommends the use of exhaust ducts, which can be fitted with cowls with appropriate wind pressure coefficients. These ventilators allow for a substantial increase in the inlet and exhaust flows, as well as for a significant decrease in reflux phenomenon. In the simulations that were carried out we used the same apartment, with the same ducts used previously but now with self-regulating inlet grilles on the façades of the main rooms. We also made a comparative study of the use of non-regulated and self-regulated inlets and we concluded that the latter allow for a substantial decrease in the maximum inlet and exhaust flow (sometimes up to 60%), which leads to a reduction of energy losses caused exclusively by natural ventilation, especially in the higher hourly values (up to 30%).

We also analyzed the relative importance of wind and of the thermal stack effect to the ventilation flows, for both heating and non-heating situations. The results of this analysis are shown in table 6 and are related to the dwelling on the 7th floor, in Bragança, facing NE/NW.

TABLE 6
Average air renewal flows for the entire dwelling, according to the different hypotheses (m^3/h)

Without heating		Heating 20ºC	
with wind	**without wind**	**with wind**	**without wind**
165	105	355	320

These data allow us to conclude that thermal stack effect is the most common phenomenon, and that the wind is responsible for just 10% of the flow when the apartment is heated and for about 36% when it is not heated.

We also made an analysis, based on the mean values throughout the heating season, of the impact of the use of self-regulated inlet grilles in terms of energy, according to the different cities, orientations and opening heights. We used the same exhaust ducts and cowls of the previous simulations. For all simulations we assumed that the apartment was heated and had a temperature of 20ºC. Table 7 shows the results for the various situations.

TABLE 7
Energy losses caused exclusively by natural ventilation in systems with self-regulated inlet grilles and its importance in relation to the energy consumed for heating at 20 ºC

(kWh/year)	BRAGANÇA				PORTO				FARO			
	3TH FLOOR		7TH FLOOR		3TH FLOOR		7TH FLOOR		3TH FLOOR		7TH FLOOR	
	NE NW	SW SE	NE NW	SW SE	NE NW	SW SE	NE NW	SW SE	NE NW	SW SE	NE NW	SW SE
Losses caused by natural ventilation	9073	9825	8694	8305	5608	5315	4394	4829	2804	3282	2502	2302
% of the energy consumed	75	85	74	83	75	84	71	82	76	95	74	93

DEMAND CONTROLLED VENTILATION

In order to reduce thermal losses during operation, and at the same time guarantee the necessary flows to allow for a regular use of the dwelling, we decided to reduce the fresh air flows in every grille, in the periods in which the dwelling was unoccupied. The idea was to get minimum values, corresponding to half the flows recommended by the Standard (Viegas, 2001), thus reducing proportionally the operating sections of the self-regulated grilles. For this purpose, we used presence sensors and differential pressure sensors in order to try to further decrease the energy consumption. For example, as regards the simulation of the apartment located in Bragança, facing NE/NW and part of the building's 3rd floor, the use of these two types of sensors, in comparison with the use of the presence sensors on their own, allowed for a reduction of about 30% of losses caused by natural ventilation. Table 8 shows the results obtained in Bragança, with an apartment facing NE/NW.

TABLE 8
Energy losses caused only by natural ventilation in demand-controlled ventilation systems and its importance in relation to the energy consumed for heating at 20 ºC

	BRAGANÇA NE/NW	
	3RD FLOOR	7TH FLOOR
Energy loss caused by natural ventilation (kWh/year)	5534	5227
% of the energy consumed	64	63

CONCLUSIONS

We conclude that the traditional system in which the air intake is made only by leakage through windows, even with heating with temperatures of 20ºC and with windows with large chinks, is hardly enough to guarantee the flows recommended by the NP-1037-1 Standard throughout the heating season. The opening of the windows in the morning is enough to surpass the flows recommended by the same Standard, but it has negative consequences, such as high energy losses and extremely low indoor temperatures.

As regards the study of the system recommended by the NP 1037-1 Standard, we conclude that the use of cowls with adequate wind pressure coefficients is essential for a good operation of the natural ventilation system and that the use of self-regulated grilles, in comparison to the non-regulated ones, allows for a substantial reduction in the maximal flows and, consequently, for a reduction of energy losses caused exclusively by natural ventilation, especially in terms of its maximum values per hour. In addition, it has been shown that the thermal stack effect is predominant in relation to the wind effect, as would be expected. The geographical location, the orientation and the opening height of the dwellings also imply variations both on the resulting ventilation flows and on the energy lost and indoor temperatures. Concerning this ventilation system, we conclude that for all the situations tested, the value of energy losses by ventilation in relation to the total of energy consumed for heating at 20ºC is always higher than 70%. We have also shown that in dwellings without heating or with intermittent heating the flows obtained are always below those recommended by the Standard and the indoor temperatures are significantly low, especially in the first case.

The simultaneous use of presence and pressure differential sensors, in the situation we analyzed, allowed for a reduction of about 40% in energy losses caused by ventilation. This clearly highlights the potential of these types of ventilation systems.

ACKNOWLEDGMENT

This work was co-funded by the Foundation for Science and Technology (FCT - Fundação para a Ciência e a Tecnologia) and by European structural funds (FEDER/EU) in the context of the POCTI/ECM/46877/2002 project.

REFERENCES

I.P.Q.-Instituto Português da Qualidade (2002). *Ventilação e Evacuação dos Produtos da Combustão dos Locais com Aparelhos a Gás – Norma Portuguesa NP 1037-1*. Portugal, Instituto Português da Qualidade.

Leal, V. e Maldonado, E. (2000). Energy Impact of Ventilation in Buildings. *In: Proceedings of Innovations in Ventilation Technology – 21stAIVC Annual Conference.* The Hague, Netherlands, paper 38.

M.O.P.T.C.-Ministério das Obras Públicas Transportes e Comunicações (1990). *Regulamento das Características do Comportamento Térmico dos Edifícios - Decreto-Lei n.º40/90 de 6 de Fevereiro*. Portugal, Diário da República.

Viegas, J. (2001). *Ventilação Natural de Edifícios de Habitação*. Lisboa, Portugal, Laboratório Nacional de Engenharia Civil.

U.S. Department of Energy (2001). *Energy Efficiency and Renewable Energy - Energyplus*. <http://www.eere.energy.gov/buildings/energy_tools/energyplus/weatherdata_html>
(accessed on 6 Oct. 2002).

HYBRID VENTILATION AND USER BEHAVIOUR IN SUMMER

Jens Pfafferott, Sebastian Herkel and Ursula Knapp

Fraunhofer Institute for Solar Energy Systems ISE, Heidenhofstr. 2,
D-79110 Freiburg, Germany, jens.pfafferott@ise.fraunhofer.de

ABSTRACT

Hybrid ventilation is one promising approach to reduce energy consumption in office buildings. On the one hand, a minimum air change rate is supplied to the rooms, even if the windows are closed. On the other hand, the energy demand for ventilation can be reduced if natural forces (wind and buoyancy driven air flow) are used to ventilate the building. The user behaviour has an important but often unknown influence on the thermal building performance and the indoor climate. Thus, an accurate user model should be used in designing hybrid ventilation. This paper focuses on the data evaluation of measurements at the institute building of Fraunhofer ISE [SolarBau:Monitor (2004 a)] concerning user attendance and user behaviour with regard to the use of blinds, equipment and windows in 16 offices. The stochastic user behaviour is derived from a data analysis, is taken into account by a Monte Carlo-simulation and is compared with the assumptions from the design phase.

KEYWORDS

Hybrid Ventilation, User Behaviour, Building Simulation, Thermal Comfort, Summer

INTRODUCTION, BUILDING DESCRIPTION AND MEASUREMENTS

There is a wide knowledge regarding user behaviour in residential buildings for the winter period. Thus, the impact on user behaviour on the heating demand in residential buildings is well known. However, there are only a few investigations regarding the user behaviour in office buildings for the summer period and its impact on the thermal comfort. Furthermore, the user behaviour determines the solar (use of blinds) and internal (attendance and use of office equipment) heat gains. Using monitored data (window and door contacts, occupancy sensors, electricity consumption and status of blinds) from the Fraunhofer ISE building in Freiburg, Germany, the influence of user behaviour and weather on the room temperature can be calculated by building simulation.

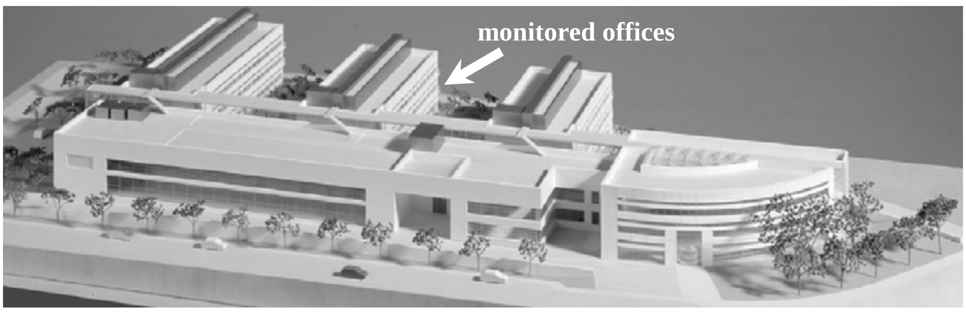


Figure 1: View of the Fraunhofer ISE building from West. The monitored offices are located in the second building wind on the 2nd and 3rd floor (South orientation).

The user behaviour is analysed in 16 office rooms with an floor area of 12 m² or 18 m², respectively. The offices are occupied by 1 – 3 persons. For more information about the building and its use, the reader is referred to Pfafferott (2003).

Availability of controls and their appropriate use is key to better building performance and for improving occupant satisfaction. Raja et al (2001) shows that the use of various controls (e.g. “open windows” and “blinds down”) plays a significant role in modifying indoor thermal conditions. Raja derived strong relationships between these user actions and the outdoor temperature from an extensive survey. The proportion of windows open and blinds closed increases with an increase in indoor or outdoor temperatures. (In most cases the correlation with indoor temperature is similar to that with outdoor temperature. The reason for using the outdoor temperature in analysis is that the outdoor temperature is a part of the input of any simulation, whereas the indoor temperature is an output.)

All data are recorded every minute, whereas the data evaluation deals with hourly mean values. Figure 2 shows the user behaviour regarding the window opening in comparison to a field study in naturally ventilated buildings and measurements in another low-energy office building. Corresponding to the ventilation concept, the mean user behaviour differs from one building to the next. The hourly data at Fraunhofer ISE represent the mean window status of 16 offices for one year and show the high deviation at outdoor temperatures above 10 °C.

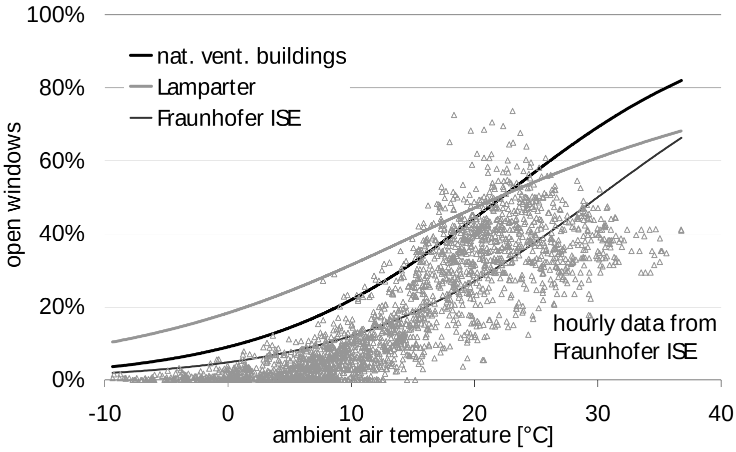


Figure 2: User Behaviour with regard to window-opening during working hours. The model for European naturally ventilated buildings is from Nicol (2001). The Lamparter building [SolarBau:Monitor (2004 b)] (data from 1 office room for 2 years) has a supply / exhaust air ventilation and the Fraunhofer ISE building (data from 16 office rooms for 1 year) an exhaust air ventilation. Both data series are analysed using Nicol’s approach. The correlation coefficient r is 0.6 – 0.8 corresponding to the time period used for data analysis.

In hybrid ventilated buildings, window opening probability mainly depends on the ambient air temperature and the time of day, whereas the time profile differs from season to season. While windows are opened almost as often in winter as in summer, windows are opened longer in summer than in winter. Hence, the user behaviour is analysed from June 12 to July 23, 2003. This period is short enough to carry out many simulation runs in a row and long enough to cover different summer weather conditions. (There are no data gaps within the period considered for data analysis.)

Figure 3 shows that the windows are opened (tilted or turned) in the morning and are closed during the working time. 50 % of all windows are opened during the night. Doors are opened in the morning and the afternoon according to the attendance. The skylight and the ventilation flaps over the door are used unfrequently and most of them are open during the whole day.

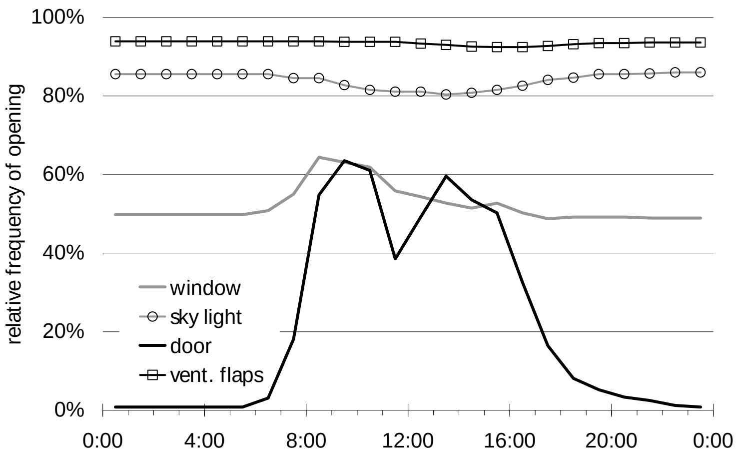


Figure 3: Time dependent user behaviour during 30 working days in summer 2003.

The heat gains are calculated from the occupancy data, the electricity consumption and the status of blinds. Figure 4 shows that heat gains vary from one room to the next and can vary strongly from one day to the next: The daily mean heat gains vary from 219 to 515 Wh/(m² d) and the standard deviation reaches 43 % for solar heat gains, 70 % for equipment and even 93 % for internal heat gains from persons in particular offices. (For simulation studies, the heat gain in the 18 m²-offices are converted into the specific heat gain of a 12 m²-office.)

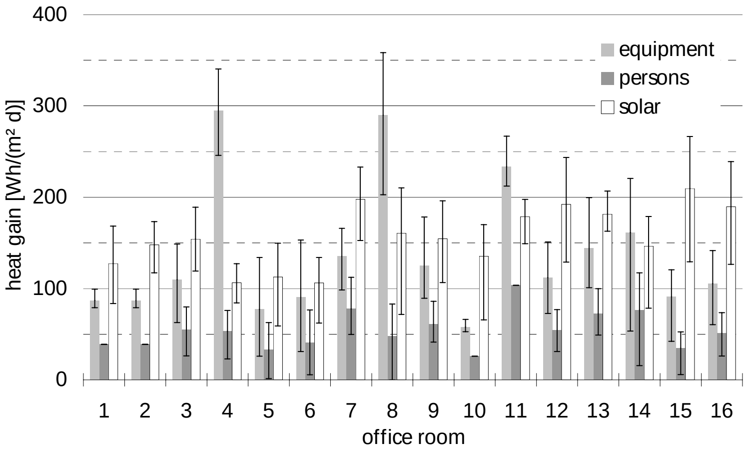


Figure 4: Daily heat gains and 1-σ deviation during 30 working days in summer 2003.

The simulation model has been validated against two data sets from April und July 2002 and is used for Monte Carlo-simulation with the weather data from summer 2003 and the test reference year, which was used for the building design simulation. Pfafferott et al (2004) used Monte Carlo-simulation for model validation with regard to uncertain building physical parameters and material properties. The ESP-r system, version 9 series is used for building simulation, Clarke (2001).

STATISTICAL SIMULATION OF USER BEHAVIOUR

The user behaviour is drawn from the following procedure: (1) Preparation of hourly data for window status, blind status, electricity consumption and attendance. (2) The time series (columns) differentiates working days and weekends. (3) The data are sorted by the time of the day (lines). (4) From this information, relative frequencies of status (i.e. 4 windows in each office) and heat gain (i.e. solar heat gains, internal heat gains from equipment and persons) are calculated for each hour of the day.

The aim is to model the heat gains as close to reality as possible and to investigate the user behaviour with special regard to ventilation. Hence, the information is used for the Monte Carlo-simulation according to the following procedure: (1) The hourly time series of heat gains is taken for one room. At the next time step, the next room is chosen. After 16 simulations, the procedure starts with the first room again. (2) Random determination of mechanical air change according to the statistical distribution of hydraulic resistances. (3) Calculation of window opening. For each hour of the working day / weekend, the status of window, sky light, door and ventilation flap is calculated with the Gauß function. Mean value and standard deviation are known from the data analysis. The opening status increases or decreases over the time but does not oscillate from one hour to the next, i.e. mathematically conservative time series. (4) For each simulation run the hourly room temperatures are saved.

Figure 5 compares the results from 1,000 simulation runs, which cover 10^{18} possible combinations of heat gains and ventilation states, with the monitored room temperature in the 16 offices. For this comparison, the daily mean room temperature and the 16 / 84 % quantile are identified from the monitoring in 16 offices and the 1,000 simulation runs for each day. In this 6-weeks period, the mean monitored and simulated room temperature differ from each other by only 0.2 K, and every day the simulated room temperature meet the monitored temperatures within the standard deviation. Thus, the energy balance and the dynamic building performance are calculated accurately. As expected, the deviation is higher in the simulation than in the monitoring, since the balancing heat transfer between adjacent rooms (in the real building) is disconnected by adiabatic boundary conditions (in the numerical simulation).

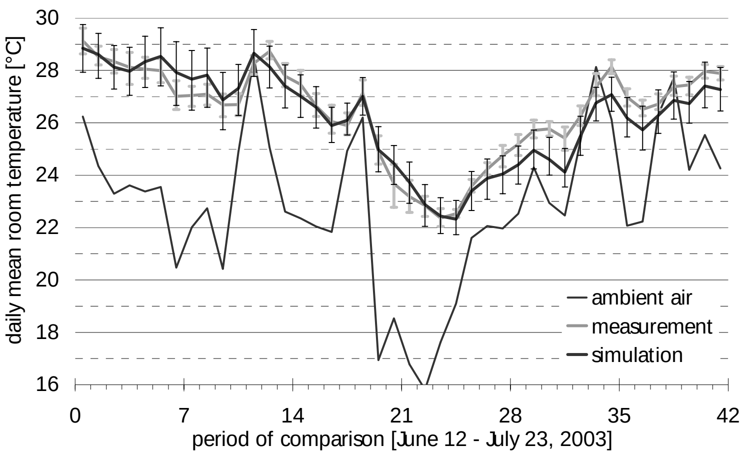


Figure 5: Daily mean room temperatures: The measured mean room temperature is 26.4 °C and the simulated 26.2 °C. The mean ambient air temperature is 22.9 °C.

STATISTICAL SIMULATION WITH DESIGN PARAMETERS

During the design process, the user behaviour regarding ventilation and control of blinds and the internal heat gains had to be estimated or were taken from the available models, respectively. With the statistical simulation, these design assumptions can be checked against the real building operation. Thereby, the different weather conditions has to be taken into account. Figure 6 compares the cumulative frequency of the daily mean ambient air temperature in the typical summer 2002 and the warm summer 2003 with the design weather.

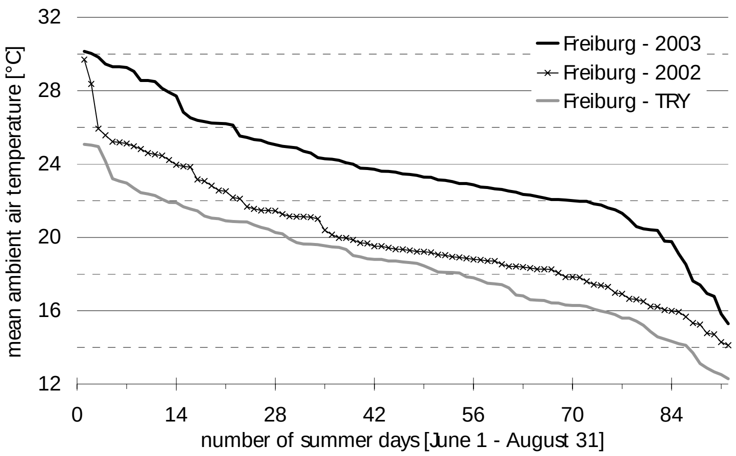


Figure 6: Comparison of ambient air temperature for the summer 2003 and the test reference year TRY 7. The summer 2002 was a typical summer. Obviously, the TRY 7 does not consider high ambient air temperatures. The summer 2003 was 5.2 K warmer than the design weather TRY 7 with long periods of warm weather.

Taking the weather data from test reference year TRY 7 and assuming that users behave in the average summer according to TRY 7 similar to the summer 2003, the predictions from the design simulation can be reviewed by the statistical simulation. Figure 7 shows that the simulated room temperatures follow a similar variation in time to the room temperatures predicted by the design simulation. However, the simulated room temperature is clearly higher: Even the coolest mean room temperature (considering the standard deviation) is 0.2 K higher than the predicted mean temperature, cf. Table 1.

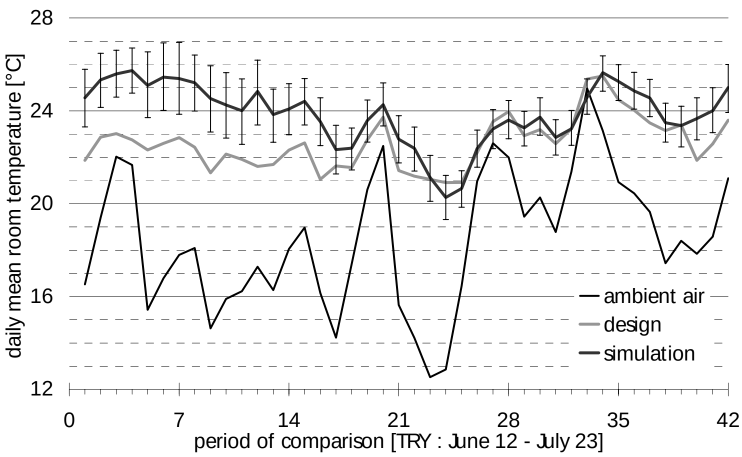


Figure 7: Daily mean room temperature from design and statistical simulation.

Though the statistical simulation is based on a much more complex air-flow network, the mean air change rates are similar in the design and the statistical simulation. Table 1 outlines that the monitored solar and internal heat gains are higher than their estimates according to Zimmermann (1999): (1) The work stations are located in the offices and not in separate IT rooms. (2) As the venetian blinds are mainly used to prevent glare, they are more rarely closed in summer than estimated. Noteworthy, the monitored solar heat gains during the weekends are lower than predicted, as the actually realised g-value of the façade is lower than expected.

Herkel and Pfafferott (2004) show how the energy balance of a room (i.e. heat gain, loss and storage) influence the room temperature using monitored data from 2 years in 3 office buildings. Though an appropriate use of windows can contribute to a lower room temperature, the heat loss due to natural ventilation cannot compensate the heat gains completely.

TABLE 1
Mean room temperature and heat gains from design and statistical simulation.

	mean temperature (with standard deviation)	heat gains (working days)	heat gains (weekend)
ambient air temperature	*18.47 °C*	–	–
room temperature: design simulation	22.61 °C	214 Wh/(m² d)	75 Wh/(m² d)
room temperature: statistical simulation	23.87 °C (+/- 1.01 K)	380 Wh/(m² d)	121 Wh/(m² d)

CONCLUSION

The comparison between the monitoring, the statistical simulation of user behaviour and the design simulation indicates clearly that a statistical user model for window-opening and blind-closing can contribute to a more realistic design of passive cooling concepts.

Though the solar heat gain coefficient through the façade is lower than predicted, the solar heat gains are clearly higher than estimated due to the user behaviour. Only a sophisticated model for the use of blinds can predict the solar heat gains accurately. The internal heat gains are in the same range of or even higher than the solar heat gains. Due to changes in the building use and the user behaviour, the actual mean heat gain is 80 % higher than predicted.

Both the user behaviour and the use of the building influence the thermal comfort in passively cooled buildings strongly. Furthermore, the room temperature in real buildings at given boundary conditions is a distribution rather than a single value. The data analysis suggests that computer simulations of naturally or hybrid ventilated buildings should assume not only an expected room temperature but also a probabilistic variation about it.

References

Raja, I.A., Nicol, J.F., McCartney, K.J., Humphreys, M.A. (2001). Thermal comfort: use of controls in naturally ventilated buildings. *Energy and Buildings* **33**, 235-244.

Herkel, S., Pfafferott, J. (2004). Summer 2003: impacts on the design of active and passive cooling. Proceedings of *EuroSun2004*, Freiburg, Germany, 600-608.

Nicol, J.F. (2001). Characterising occupant behaviour in buildings: towards a stochastic model of occupant use of windows, lights, blinds, heaters and fans. Proceedings of *Seventh International IBPSA Conference*, Rio de Janeiro, Brazil, 1073-1078.

Pfafferott, J., Herkel, S., Jäschke, M. (2003). Design of passive cooling by night ventilation: evaluation of a parametric model and building simulation with measurements. *Energy and Buildings* **35**, 1129-1143.

Pfafferott, J., Herkel, S., Wambsganß, M. (2004). Design, monitoring and evaluation of a low energy office building with passive cooling by night ventilation. *Energy and Buildings* **36**, 455-465.

SolarBau:Monitor (2004 a). Internet platform and project documentation Fraunhofer ISE. http://www.solarbau.de/monitor/doku/proj04/mainproj.htm [2004-July-15]

SolarBau:Monitor (2004 b). Internet platform and project documentation Lamparter. http://www.solarbau.de/monitor/doku/proj07/mainproj.htm [2004-July-15]

Zimmermann, M. (1999). *Handbuch der passiven Kühlung*. EMPA, Dübendorf, Switzerland. (In German.)

Clarke, J.A. (2001). *Energy Simulation in Building Design*. Butterworth-Heinemann.

DEMAND CONTROLLED VENTILATION APPLICABLE FOR ANY AIR TIGHTNESS LEVEL AND OCCUPANCY?

P. Jacobs[1], W.F. de Gids[1] and W. Kornaat[1]

[1] *Healthy Buildings and Systems, TNO Building Construction, Delft, 2600 AA, The Netherlands*

ABSTRACT

The Dutch housing stock consists for about 70% of single family houses with an average N_{50} of about 7-9 ACH and for 30% of apartments with an average N_{50} of about 3-4 ACH.
New single family houses are much more airtight. In the period 1970 to 2000 the air tightness increased to an N_{50} of about 3 - 4 ACH. Apartments have nowadays about the same or a slightly better air tightness then before 1970.

Another trend is the downward tendency of occupant numbers per dwelling. During 1982 to 2000 in the Netherlands the average number of occupants per dwelling decreased from 2.8 with 21% to 2.3 persons per dwelling.

These two trends can have an impact on the choice of a ventilation system when dwellings from a certain period need to be retrofitted. The question is e.g. whether demand controlled ventilation has an added value depending on the air tightness and occupancy of the dwelling.

In the framework of the RESHYVENT project this study comprises COMIS simulations to investigate the relation between occupancy/air tightness and demand controlled ventilation. Based on indoor air quality (IAQ) and energy consumption a comparison has been made between the situation with the exhaust continuously at 21 dm^3/s and all supply provisions closed and the situation that a ventilation strategy such as demand controlled ventilation is applied.

The paper gives a positive answer on the applicability of demand controlled ventilation regardless occupancy and air tightness. Even at low air tightness (N_{50}>16 ACH), from IAQ point of view demand control is interesting. With internal mixing (e.g. open doors and/or air heating systems), in combination with supply provisions closed, pollutants can be reduced to the same levels as with demand control, however this can also lead to a undesired spread of local pollutants. Through a good distribution of the supply air, demand control does not result in an increase of the ventilation compared to the situation with supply provisions closed. On the other hand, depending on the occupants' behavior, significant energy savings are possible.

KEYWORDS

Occupancy, air tightness, indoor air quality, energy use, retrofitting, demand control

INTRODUCTION

Since more than 20 year data from pressurization tests in the Netherlands have been gathered in a database, see Cornelissen et al (1994). At present in total about 700 houses are available within the database. The data about air tightness in this article are derived from this database.
The Dutch housing stock consists for about 70% of single-family houses with an average N_{50} of about 7-9 ACH and for 30% of apartments with an average N_{50} of about 3-4 ACH. New single-family houses are much more airtight. In the period 1970 to 2000 the air tightness increased to an N_{50} of about 3 - 4 ACH. Apartments have nowadays about the same or a slightly better air tightness then before 1970.
Another trend is the downward tendency of occupant numbers per dwelling. During 1982 to 2000 the average number of occupants per dwelling decreased with 21% from 2.8 to 2.3 persons per dwelling in the Netherlands.
These two trends will have an impact on the choice of a ventilation system when dwellings from a certain period need to be retrofitted. The question is e.g. whether demand controlled ventilation has an added value depending on the air tightness and occupancy of the dwelling.
In the framework of the RESHYVENT project this study comprises COMIS simulations to investigate the relation between occupancy/air tightness and demand controlled ventilation based on IAQ and energy consumption evaluation.

MODELLING

Comis

Within COMIS two models have been used. The first model represents a typical single family dwelling, see figure 1. The second model represents the lay-out of a typical apartment, see figure 2.

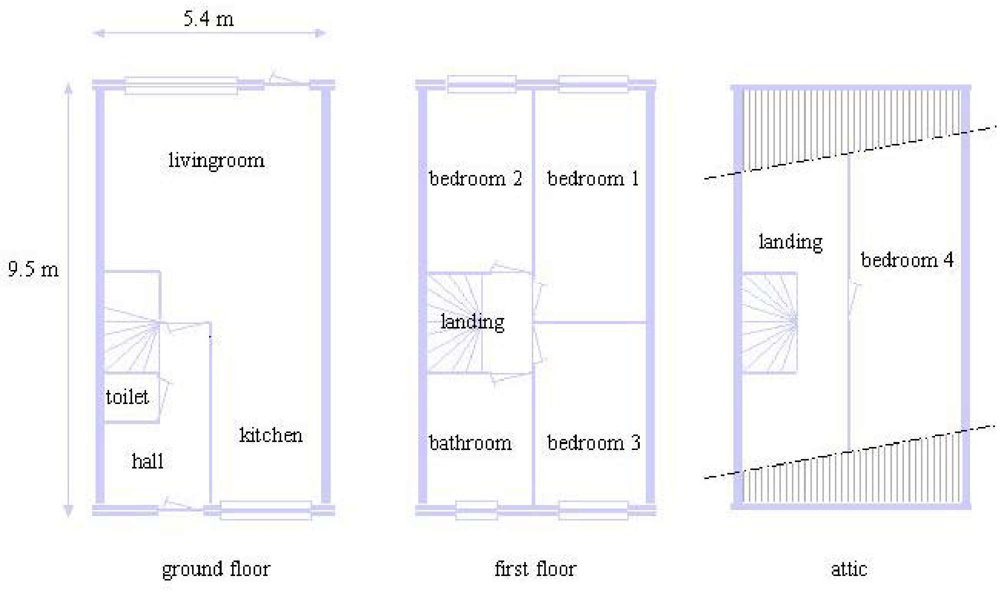


Figure 1: lay-out single family dwelling

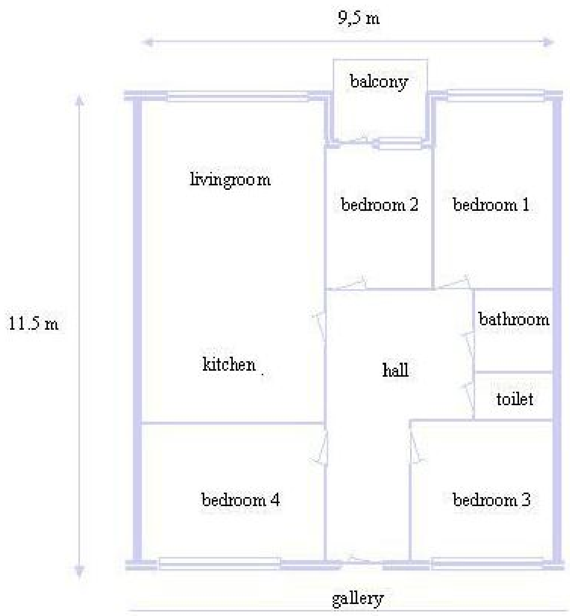


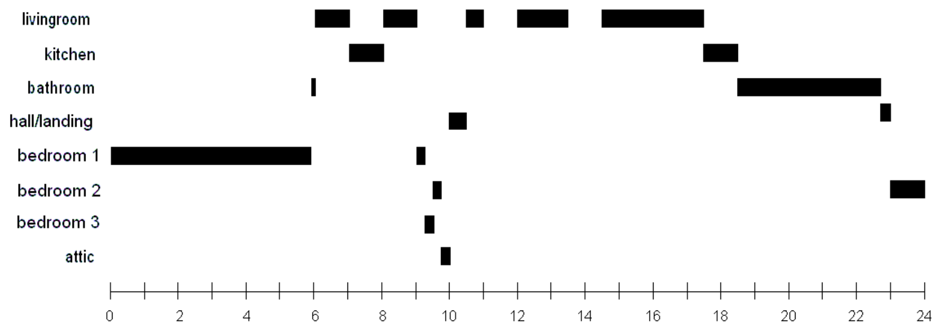
Figure 2: lay-out apartment

COMIS calculations have been executed, coordinated by VentControl. This is a software program that permits the simulation of various control aspects e.g. based on presence, time schedules and IAQ.

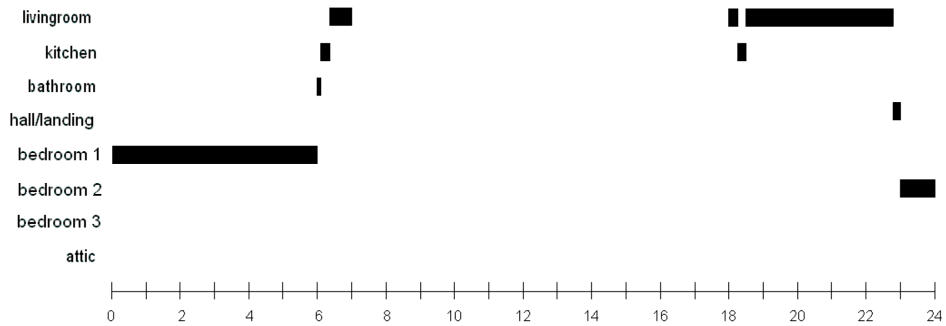
By using the condensed TNO reference year, which consists of 3 days for each season, a typical Dutch heating season (210 days) has been simulated. Table 1 gives the occupant presence distribution schemes used.

TABLE 1
Presence distribution schemes for a 4 persons family

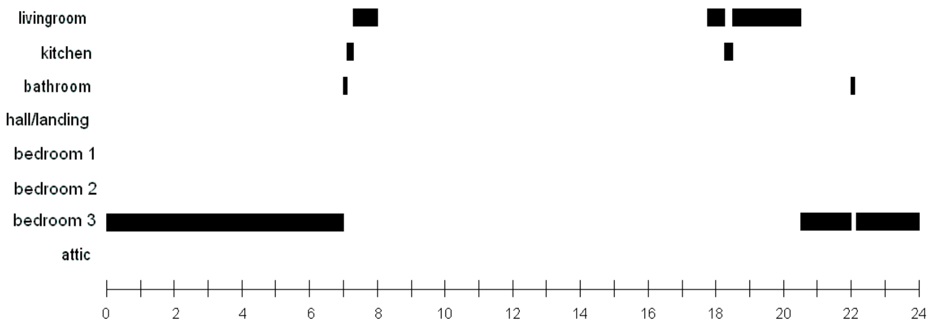
Housekeeping partner



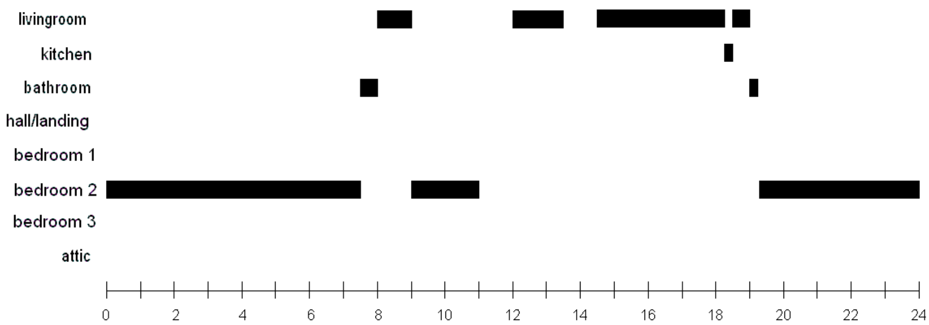
Working partner



Schoolchild



Baby



Air leakages

The distribution of air leakages over the building envelope is shown in table 2. This distribution is derived from de Gids (1981) and Cornelissen (1994). It remains relatively constant for different air leakages. Therefore in all simulations the same distribution of leaks has been assumed.

TABLE 2
Relative leakage of several building elements in the Netherlands

$q_{v,10}$ [dm^3/s]	N_{50} [ACH]	ground floor [%]	Walls [%]	Roof [%]
30	1	17	26	57
100	4	12	28	60
150	6	15	30	55
200	8	17	28	55
400	16	17	26	57

Output

For a broad understanding the results of the COMIS simulations are expressed in (1) time exposed to CO_2 levels higher than 1200 ppm (Dutch standard $\Delta CO_2 < 850$ppm) in combination with the maximum occurring CO_2 level and (2) in the "low ventilation index" (lvi) (de Gids, 1992). The lvi gives an indication of the air quality, the time and extend to which IAQ is insufficient, over a certain time frame, e.g. the heating season. It is defined as the time integration of the normalized ventilation below a value of one. In this paper the normalized effective ventilation is scaled in such a way that at a value of one is equal to a CO_2 rise of 850 ppm above outside. Figure 3 gives an example of a histogram of the normalized ventilation for an lvi of 0.005. During 2% of the time the ventilation is too low. The CO_2 concentration can rise up to two times the boundary limit (q_{en}=0.5). But a lvi of 0.005 could also characterize a situation in which during 4% of the time the ventilation is limited to a normalized effective ventilation of 0.75 (CO_2 concentration maximal 1/0.75=1.33 times the boundary limit). Seen the possible combinations of time and CO_2 levels a lvi of 0.005 can be considered as a good choice for boundary limit.

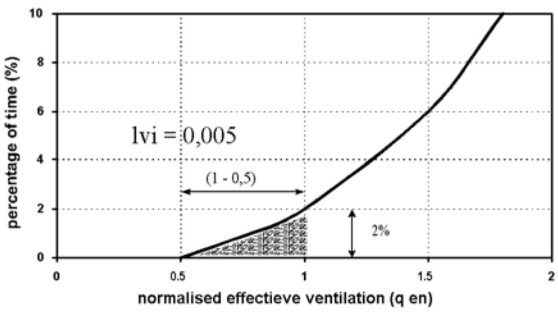


Figure 3: histogram normalized effective ventilation

SIMULATION RESULTS

First the question "Is a ventilation strategy required?" is answered. These simulations have been executed with the supply provisions closed and are compared with demand control. Second the effect of manual window airing is compared with demand control. The following parameter ranges have been used:

TABLE 3
Parameter ranges for simulations

Parameter	Minimum	Maximum
Air tightness N_{50} [ACH] ($q_{v,10}$ [dm^3/s])	1 (30)	16 (400)
Number of persons	1	4
Supply provisions	closed	Open
Exhaust flow rate [dm^3/s]	21(10.5*)	42
Exchange through doors	doors closed	doors open
Control	no	demand controlled

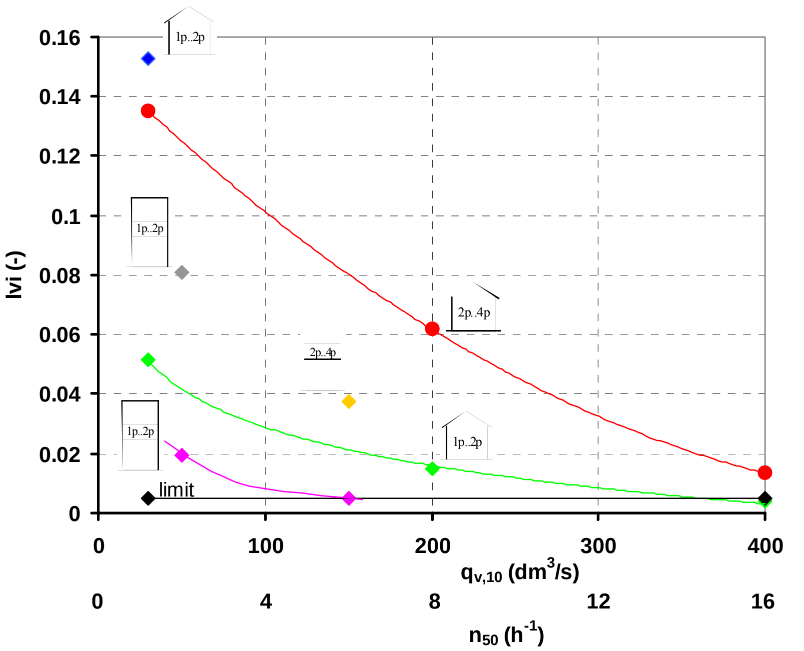
*Demand control can reduce exhaust up to this minimum flow.

Supply provisions closed versus demand control

Indoor air quality

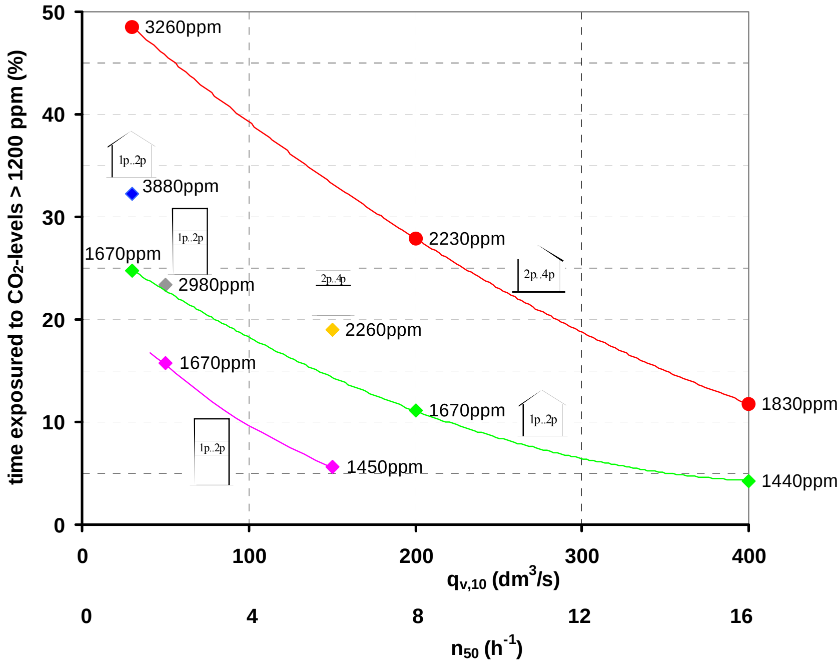
The simulation results for supply provisions closed are shown in Figure 4 (low ventilation index, lvi) and Figure 5 (CO_2 > 1200 ppm). Pictograms indicate whether data concern a single-family house or an apartment. Single points indicate situations with bedroom doors closed, lines with bedroom doors ajar. In Figure 5 the maximum CO_2 levels are listed. These values are reached in the bedrooms and constitute the dominant factor for the lvi. An important conclusion which can be drawn is that ventilation strategies are required to obtain a suitable air quality, even in houses with worse air tightness (up to N_{50} = 16 ACH) and habituated by only one person. Due to the fact that all leakages are localized in the walls, and thus infiltration air flows more

directly through the occupied zones, apartments render a better IAQ than single-family houses with the same air tightness.
In practice the IAQ can differ due to the effect of open doors. Figure 6 shows the effect of mixing between rooms and the landing. By opening the bedroom doors with a few centimeters, which is simulated by an air exchange of 2.3 dm^3/s, the lvi is largely improved (but still insufficient as is shown in figure 4 and 5). This is a result of a better distribution of the infiltration air. With internal doors fully opened a good IAQ can be maintained. This explains also why with an air heating system, with high internal flows, good results concerning IAQ can be obtained. Disadvantage of this system, which is widespread in the US, is the spread of pollutants (e.g. cigarette smoke). Data for demand control are not shown in figure 4 and 5, but are below lvi=0.005.



1p..2p: occupancy by 1 to 2 persons using different bedrooms
2p..4p: occupancy by 2 to 4 persons, of which 2 persons use the same bedroom
lines: situations with bedroom doors ajar
point: situations with bedroom doors closed

Figure 4: supply provisions closed, air quality expressed in normalized effective ventilation (lvi)



1p..2p: occupancy by 1 to 2 persons using different bedrooms
2p..4p: occupancy by 2 to 4 persons, of which 2 persons use the same bedroom
lines: situations with bedroom doors ajar
point: situations with bedroom doors closed

Figure 5: supply provisions closed, air quality expressed in time exposed to CO_2 > 1200 ppm, maximum CO_2 value is listed

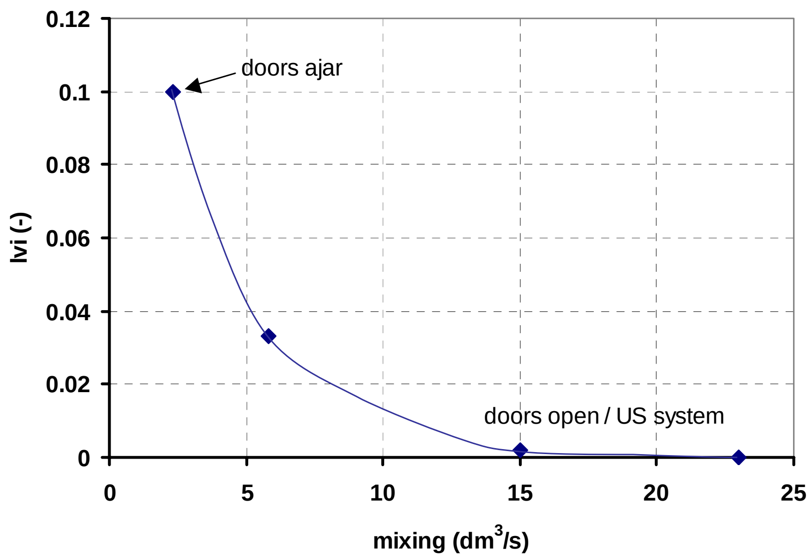


Figure 6: effect of mixing (air exchange) between rooms and the landing on air quality (lvi)

Energy

The energetic consequences are shown in figure 7. The energy use is the energy required to warm up the air with 13 K during the heating season. The figure clearly shows that air tightness is a prerequisite for low energy consumption. The differences between demand control and supply closed are small. Especially a better distribution of the infiltration air is apparently reached.

As an indication it is mentioned that the absolute minimum ventilation requirement for CO_2 removal, for a family with 4 persons and taken the presence and activities in the different rooms as given in Table 1, is about 17 dm^3/s.

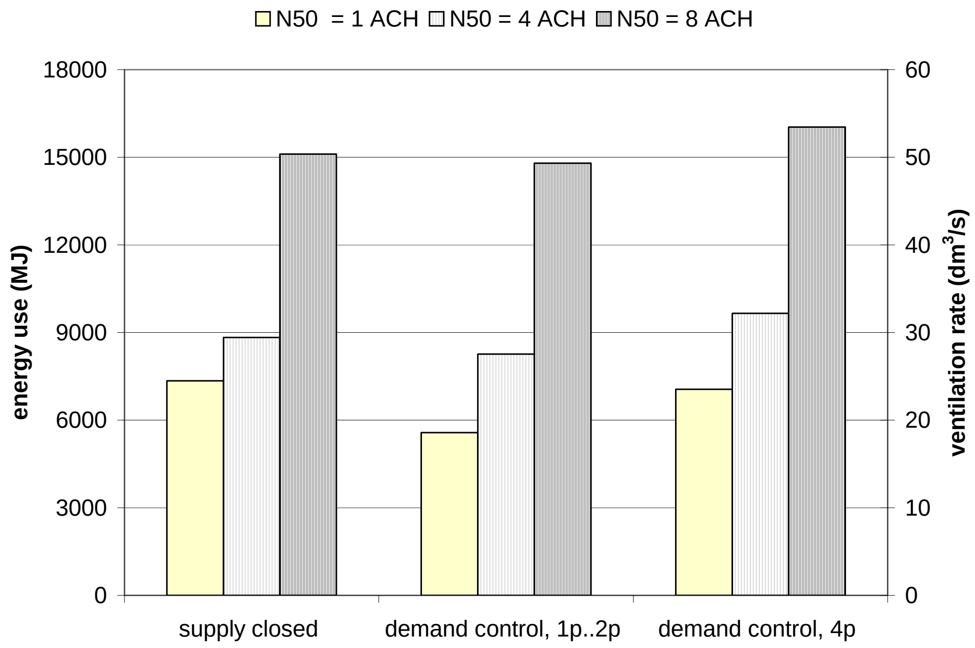


Figure 7: energetic effects of ventilation strategies for different air tightness

Manual window airing versus demand control

COMIS calculations have been made for manual window airing in the bedrooms with exhaust at 21 and 42 dm^3/s during the night. Manual window airing implies here that during the night the bedroom supply provisions are set on the nominal capacity for 1 and 2 persons bedrooms: 7 and 14 dm^3/s respectively at 1 Pa pressure difference. The results are shown in table 4.

TABLE 4
Effect of window airing in bedrooms on average ventilation and lvi (N_{50}=4 ACH, 4 persons)

	Supply closed	**Window airing in bedrooms, exhaust**		**Demand control**
		21 dm^3/s	**42 dm^3/s**	
Heating season average ventilation [dm^3/s]	30.9	36.5	40.7	33.8
lvi	0.1	0.0292	0.0036	0.003

The main improvement of demand control compared to the window airing is that the exhaust during the night is controlled between 10.5 and 42 dm^3/s. Thus a better or comparable IAQ is reached at a lower overall ventilation and corresponding energy use.

CONCLUSIONS

Indoor Air Quality:

- The low ventilation index (lvi), or the amount of hours the CO_2 concentration exceeds 1200 ppm, mainly is determined by the hours spent in the bedrooms.
- Ventilation strategies (demand control, mixing, manual) are required to obtain a suitable air quality even in houses with worse air tightness (up to N_{50}=16 ACH) and habituated by only one person.
- Due to the fact that all leakages are situated in the walls apartments render a better IAQ than single-family houses with the same air tightness.

Energy consumption:

- Air tightness is a prerequisite for low energy consumption.
- Related to a situation in which the inhabitants do not use the supply provisions, demand control results in comparable energy consumption
- Depending on the actual use of provisions by inhabitants with demand control reasonable energy savings can be reached.

REFERENCES

Cornelissen H.J.M., de Gids W.F. Opbouw van het gegevens bestand Luchtdoorlatendheid van woningen.
94-BBI-R1762
Delft 1994

De Gids W.F., Phaff J.C, Kornaat W, Rekenstudie naar de consequenties van minimaal gebruik van ramen en ventilatievoorzieningen. Gevolgen voor toelaatbare emissies uit bouwmaterialen.
B-92-0916
Delft 1992

De Gids W.F. Natural ventilation and energy consumption of dwellings
Report C 482, IMG-TNO.
Delft 1981

IN-SITU PERFORMANCES MEASUREMENT OF AN INNOVATIVE HYBRID VENTILATION SYSTEM IN COLLECTIVE SOCIAL HOUSING RETROFITTING

J.L. Savin, M. Jardinier and F. Siret

Aereco S.A., 9 allée du Clos des Charmes, Collégien
F - 77615 MARNE LA VALLEE Cedex 3

ABSTRACT

To get closer from comfort and energy levels of new buildings conciliating economical viability for the big retrofitting market : the challenge opens the way to the most innovative ventilation systems. In this context was born a new hybrid ventilation system mixing demand-controlled components and low pressure assistance fan. HR-VENT is an exceptional large-scale monitoring launched in France in the suburb of Paris in order to measure the effectiveness of this new system, as well as to improve the knowledge on the hybrid and standard natural ventilation. This monitoring, lead in collaboration with French corporate partners, will favour the development of new solutions for the ventilation of residential buildings.

KEYWORDS

air, hybrid, ventilation, demand-controlled, passive stack ventilation, fan, low pressure, monitoring, Nangis, HR-VENT, humidity sensitive, gas appliance, energy savings, comfort, retrofitting.

INTRODUCTION

HR-VENT is a project which aims at realising an in-situ validation and actualisation of the knowledge on natural and hybrid ventilation. With more than 700 millions data registered on 55 dwellings during 2 years, this large-scale monitoring will show the effectiveness of the new hybrid ventilation system, a humidity sensitive ventilation assisted by a very low pressure fan. Innovative solution in compliance with the retrofitting expectations of comfort, air quality, energy savings and economical viability, the effectiveness of this complete hybrid system is measured by new specific sensors for pressure, airflow, temperature, humidity rates, which are correlated with outdoor climatic conditions. Co-financed by French ADEME (Agence de l'Environnement et de la Maîtrise de l'Energie), HR-VENT is managed in partnership with French CSTB, Gaz De France, SOCOTEC and Logement Français.

EXPERIMENT IN EXPERIMENTS

AERECO has a long life of monitoring to assess innovative and efficient systems. Improvements in means of measurements as well as in ventilation systems : AERECO manages for years projects to follow the aim to assess innovative and efficient ventilation systems :

- **"Passive humidity controlled ventilation for existing dwellings" - Demonstration project EE/166/87 - December 1993.**

This project, in partnership with several important organisms as French CSTB, Dutch TNO and Belgian BBRI, showed on 3 different sites the **effectiveness of the AERECO humidity sensitive extract grilles in pure passive stack ventilation.**

The dilution of a neutral gas was used to measure the extract airflow (instead of measuring the pressure and the opening section of the grille). Measurements were realised in parallel stacks of dwellings to compare passive extract grilles and humidity sensitive extract grilles.

- **"Very low pressure fan - VBP" - Presentation at 2001 AIVC Conference.**

A series of tests assessed the characteristics of a low pressure assistance fan for passive stack ventilation, prototype of what was going to be the future "VBP" used in NANGIS monitoring. These tests and simulations realised in CERGA laboratory showed the **ability of the fan to increase the airflow levels in PSV with a very low energy consumption.**

- **"Monitoring of two natural exhaust grilles in Hokkaido - Japan" - Presentation at 2002 AIVC / EPIC Conference.**

This monitoring of two humidity sensitive extract grilles in an occupied house in the north of Japan lasting one year showed that **the behaviour of the HS grille "GHN" was conform to the announced performances in term of RH / shutter position. It also confirmed the right choice of the relative humidity range for opening** (RH between 30% and 70%).

- **"Hygrothermal behaviour of a humidity sensitive air inlet" - Presentation at 2003 AIVC Conference.**

A special poster presentation was dedicated to explain the important rule of the humidity sensor's temperature in the humidity sensitive air inlet. It was shown that this technology of air inlet needs a real control of the local thermal exchanges to keep the right RH / opening section characteristics, whatever the outdoor climates.

Today, this monitoring is written to be the logical suite of this long-time monitoring experiment, by improving again the means of measurements (see § " Some innovative and accuracy sensors").

PROJECT DESCRIPTION

Buildings choice

No less than 5 buildings representing 55 dwellings have been chosen among a total of 56 social buildings. The choice of the instrumented buildings have been managed by the need of a large scale, pertinent, representative and various project.

- Different locations and disposition (see figure 1) of buildings to show the influence of the wind effect (speed and direction) on ventilation, that means wind influence on the window (air inlets, windows openings) as well as on the duct "natural" pressure (created at the chimney level).
- Different heights (from 3 to 5 levels) chosen to see the variable effects of stack effect (variable heights of ducts) as well as the influence of different wind directions and speeds on duct pressures (created at the chimney).
- Size of dwellings chosen from 2 to 5 mains rooms to see the influence of both the air volume of the dwelling and the number of air inlets.
- Different configurations inside the dwellings (centred or deported technical rooms, one or two grilles on the same duct, etc…) to analyse these influent factors.

The choice of this site, in social housing, is also representative of what can be built in the new, with its "middle" buildings (8 to 20 dwellings in the same building) with "middle" height.

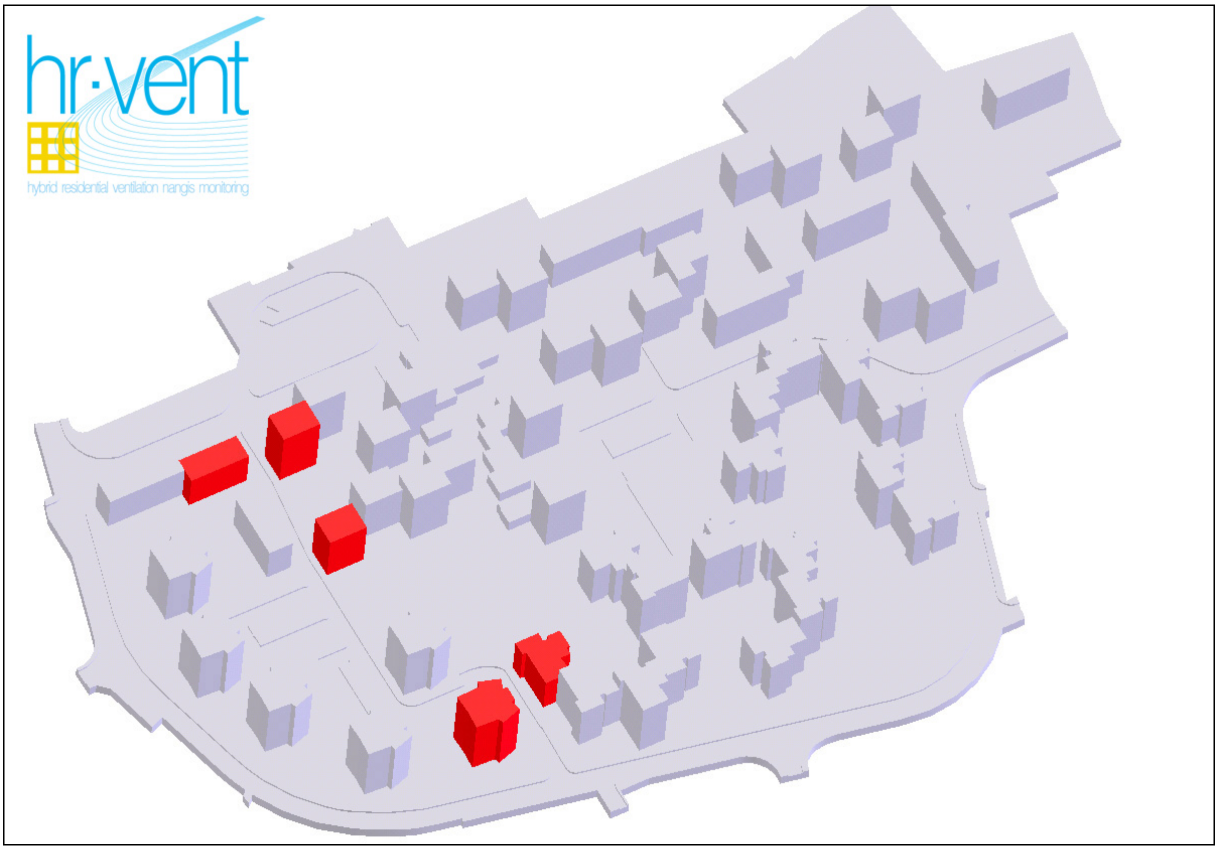


Figure 1 : 3d view of HR-VENT experiment site in " La mare aux Curées", City of Nangis (France). *Note : the experiment buildings are signalised in red.*

Ventilation system

The new ventilation system uses existing natural ventilation ducts. "Classic" humidity sensitive air inlets and extract grilles are installed in the dwelling, while the low pressure fan is installed at the head of the duct. This innovative hybrid ventilation system -the **first one in the world to mix together demand-controlled ventilation with low pressure assistance fan-** is also used in this project to exhaust burnt gas from the gas appliance connected to the ventilation duct in the kitchen. This point reinforces again the interest of this new solution because this co-exhaust (gas and air) is well laid in France (and in some other nations) and needs a real control of the pressure, for obvious reasons of safety.

The new VBP assistance fan (see figure 2) allows to conserve classical PSV ductwork sizing while improving the natural airflow and pressures. Its low electrical consumption and its non-critical breakdown (non significant pressure losses when off) contributes to make it an optimised solution for ventilation, especially in retrofitting when economical aspects are more important.

Inside the dwelling, the humidity sensitive ventilation system, as a "leader" of the demand-controlled systems, contributes to improve the air quality while reducing the heating energy consumption. (see components on figure 3)

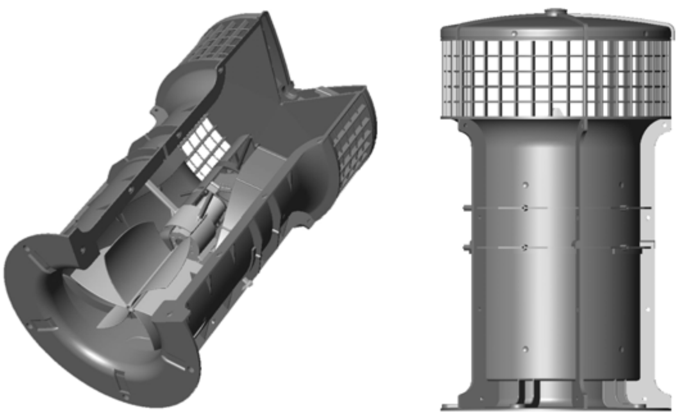


Figure 2 : Very low pressure fan VBP.

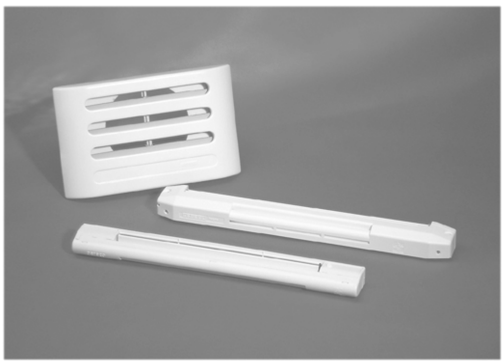


Figure 3 : Humidity sensitive GHN Grille, EHA and EMM air inlets.

Installation

A new monitoring is always a new experiment : a new system to test, with a new method of measurement, on a new architectural environment.

After one year preparation to design the specific low pressure manometer, instrumentation and acquisition system, no less than two months were necessary to install the system on 55 dwellings. The 4 people installation team had to face to the difficult winter meteorological conditions (see figure 6) as well as to structural "surprises" to succeed in installing the whole system.


Figure 4 : Connection to the registering system


Figure 5 : Position of the grille face.


Figure 6 : Setting of the registering system

Equipment

From January 2004 to December 2005, more than 700 million data are going to be registered. The buildings have been equipped by following the scheme presented on figure 7.

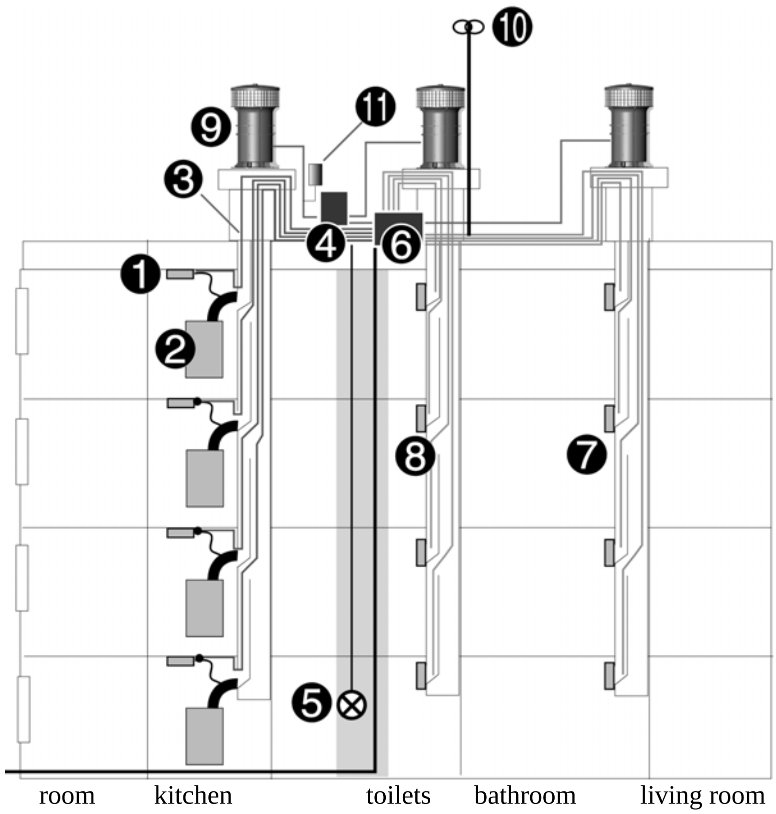
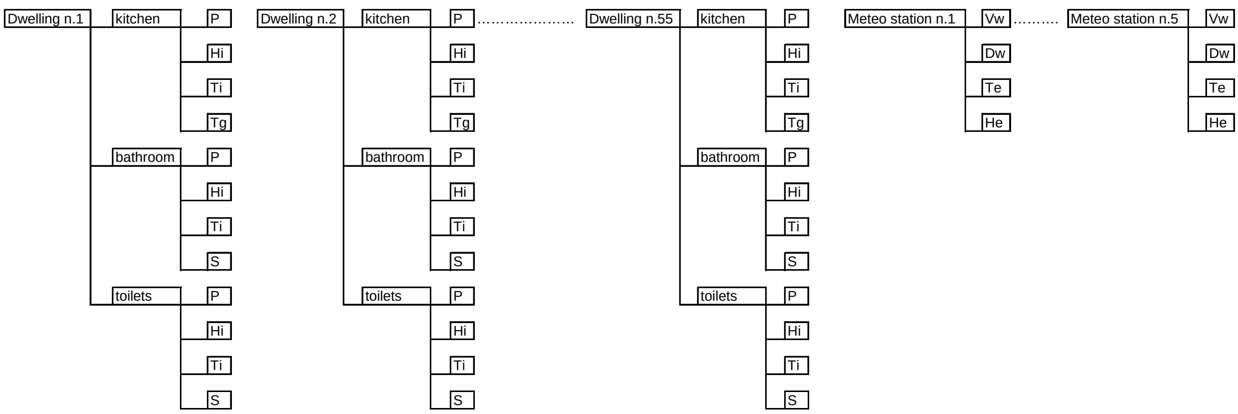


Figure 7 : cut of a schematic view of a building stack (example with 4 levels)

	Component	*Function*
1	**Instrumented grille - Kitchen**	Acquisition of : Pressure / Burnt gas Temperature / Room temperature / Room Relative humidity. Frequency : each minute
2	Connected gas appliance	Hot water production.
3	**Data bus cable**	Carry data acquired by components 1,3 et 8.
4	**Instrumentation box**	Registers data acquired by components 1,3 et 8.
5	Working indicator	Indication of good working of the fans equipping this stack of dwellings.
6	Complete control panel	Transformation of 230 VAC to 15VDC Electrical protection Fan power supply management Simultaneous working of fans management.
7	**Instrumented grille - bathroom**	Acquisition of : Pressure / Grille opening section / Room temperature / Room Relative humidity. Frequency : each minute
8	**Instrumented grille - Toilets**	Acquisition of : Pressure / Grille opening section / Room temperature / Room Relative humidity. Frequency : each minute
9	VBP low pressure fan	Passive stack assistance low pressure fan
10	**Meteorological station**	Acquisition of : Wind speed / Wind direction / External local temperature / External local relative humidity. Frequency : each minute
11	Temperature sensor	Controls the VBP fans speed according to temperature (normal speed / low speed)

Note : Components in charge of registering data are mentioned in bold.

The figures below present the structure of the data registered in the dwellings and in the buildings. The singular quantity of data (more than 700 million) has justified specific means of treatment, with a dedicated server hosting a 20 Gigabytes database. A special tool has been designed to access to statistic results.



Legend :

P : Extract grille pressure (Pa)
S : Extract grille aperture (cm²)
Hi : Relative humidity at the grille (%)
Ti : Temperature at the grille (°C)
Tg : Temperature of gas appliance (°C)
Te : External temperature (°C)
Vw : Wind speed (m / s)
Dw : Wind direction (°)
He : External relative humidity (%)

Some figures :

Buildings	5
Meteorological stations	5
Dwellings	55
Instrumented grilles in dwellings	166
Values per minute per instrument	4
Total values per minute / day / year / 2 years	684 / 984.960 / 359.510.400 / 719.020.800
Database size	20 Gigabytes

Controls

Facing such a huge amount of data requires tools to control validity. From the beginning of the study in January 2004, no less than 1.2 million data were detected to be false due to technical issues : transmission defaults, electronic captors breakdown due to high level humidity, etc… But this amount, when compared to the total amount of data for this period (132 millions), gives a ratio of 0.9% wrong data… **The most important thing is not only to avoid wrong data but to be able to detect them, with the right tools**.

A sharp quality control is also realised by a regular & random take back and test of instrumented grilles in laboratory. Eventual derives of the sensor are rewarded, to increase the reliability of the measurement apparels.

Difficulties

Monitoring, for those who are used to practise this game, is almost always synonymous of difficulties and surprises, moreover when it is realised on a so-large scale. The "short" list below illustrates some of the issues we have had to face to and to solve :

- Data transmission stops
- Bad installation of flexible pressure plug
- Electronic temperature or humidity sensors breakdown (hard climatic conditions with high levels)
- Ducts states and maintenance issues (presence of a bird nest in a duct for more than 7 years !)

Only an appropriate tool (database) and a particular time-spending attention allows to limit the effect of these non-conformities on the data collected. When data continue to be registered, time is counted and the reaction must be the quickest.

Some innovative and accurate sensors

Not only this project is innovative by the fact that a new hybrid system is installed and measured in a large scale ; HR-VENT has also given the opportunity to design a new type of low pressure manometer : more accurate, adapted to the very low pressure range and economically viable for a large implantation. This sensor uses a patented technology based on hot filaments. It is described on the schemes figure 8 and 9.

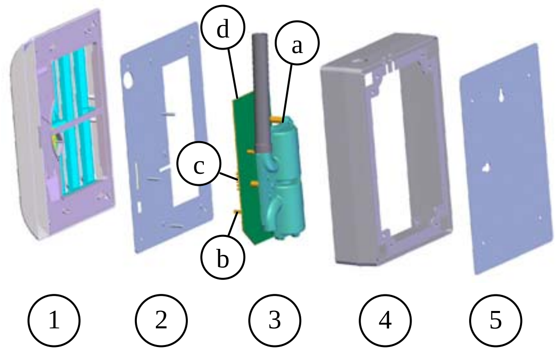
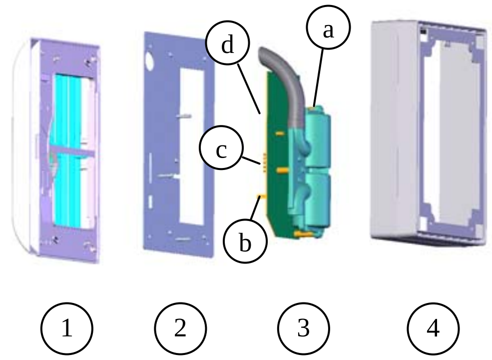
	
	
1 : fix front cover grille 2 : instrumentation support 3 : instrumentation set 3a : low pressure manometer 3b : thermal sensor 3c : humidity sensor 3d : electronic cardboard 4 : protection box 5 : fixation support	1 : humidity sensitive grille + hall effect sensor 2 : instrumentation support 3 : instrumentation set 3a : low pressure manometer 3b : thermal sensor 3c : humidity sensor 3d : electronic cardboard 4 : protection box

Figure 8: Measurement grille in the Kitchen

Figure 9 : Measurement humidity sensitive grille in the bathroom and toilets

RESULTS AWAITED

Results awaited are several types[1]. They aim to assess, according to meteorological, architectural parameters and to events :

- Effectiveness of humidity sensitive passive stack ventilation
- Effectiveness and improvements brought by hybrid humidity sensitive ventilation
- Working of gas appliances with these systems
- Maintenance and exploitation costs of the new system

Some example of these results :

[1] See abstract : Siret, F., Savin, J.L., Jardinier, M. and Bertin, S. (2004). " Monitoring on hybrid ventilation project - first results." *25th AIVC conference.*

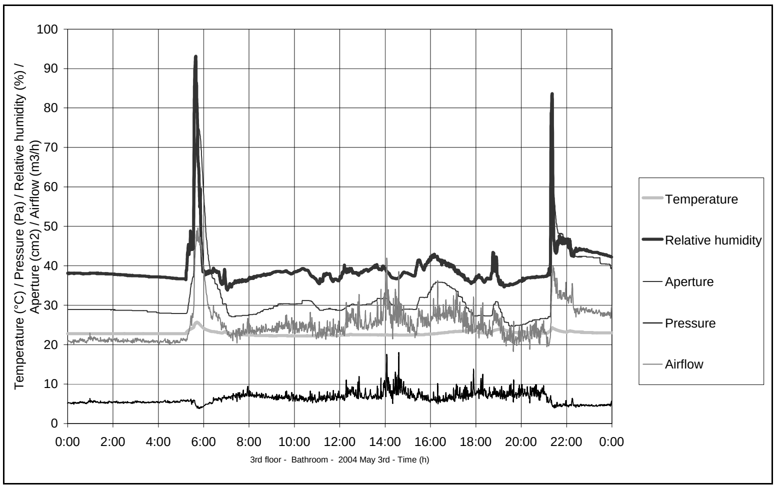


Figure 10 : Variation of parameters registered by a measurement grille during 24 hours.

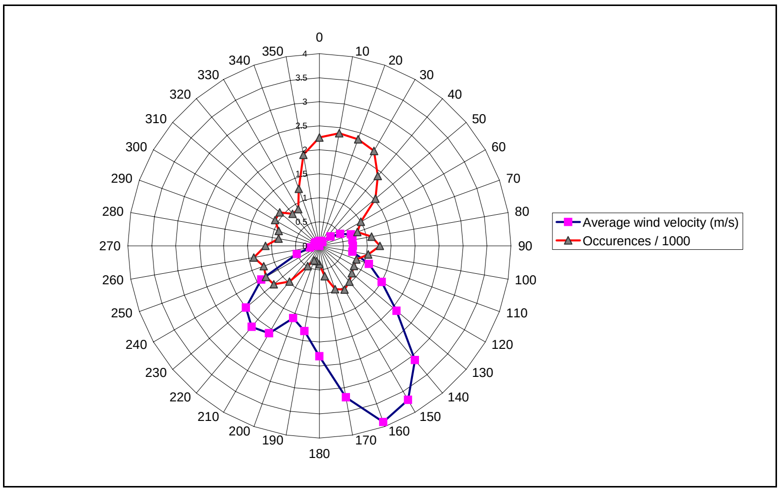


Figure 11 : Repartition of wind speed and direction by frequency on one building terrace, on one month.

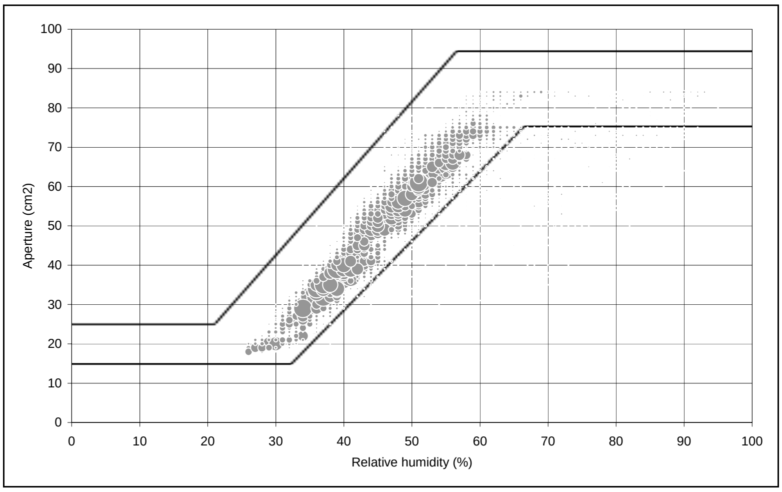


Figure 12 : Repartition of Relative humidity / Aperture couples for one measurement grille, on one month.

CONCLUSION

The first results of HR-VENT project, subject of an other annex article, already show the interest of this monitoring and the richness of the teachings on topics as varied as gas appliance working, wind effect on airflow, etc… The final results publication will bring as many answers to questions often asked on the hybrid ventilation behaviour.

This kind of monitoring must allow to give a place to a new ventilation technology by demonstrating in a scientific and experimental way its performances. Some other monitoring are being studied, like in Malmö (Sweden), to contribute to develop this new technology aimed at answering right to the specific expectations of the residential building retrofitting.

REFERENCES

Siret, F., Savin, J.L., Jardinier, M. and Berthin, S. (2004). " Monitoring on hybrid ventilation project - first results." *25th AIVC conference.*

Siret, F. (2004) and Jardinier, M. (2004). "High accuracy manometer for very low pressure." *25th AIVC conference.*

Wouters, P., Geerinckx, B, L'Heureux, D., Simonnot, J. and Phaff, J. (1993). "Passive humidity controlled ventilation for existing dwellings" - Demonstration project EE/166/87. *December 1993.*

A CZECH DEMONSTRATION HOUSE WITH HYBRID VENTILATION

Miroslav Jicha[1], Pavel Charvat[1], Willem de Gids[2] and Andre Meester[3]

[1]Brno University of Technology, Department of Thermodynamics and Environmental Engineering
Technicka 2, 616 69 Brno, Czech Republic
[2]TNO Building and Construction Research
Schoemakerstraat 97, P.O. Box 49, 2600 AA Delft, The Netherlands
[3] Alusta BV, Penningweg 7, 4879 AE Etten-Leur, The Netherlands

ABSTRACT

An idea to build a demonstration house fitted with a hybrid ventilation system arose when Brno University of Technology joined the RESHYVENT project. There has not been much attention paid to the residential ventilation in the Czech Republic. Window airing and passive stack ventilation are still the most common ways of ventilation in residential buildings. In this context a decision was made to build a house equipped with a demand controlled hybrid ventilation system. The hybrid ventilation system for the moderate climate, developed by the Dutch industrial consortium, has been installed in the house.

KEYWORDS

residential ventilation, hybrid ventilation, CO_2 controlled ventilation

INTRODUCTION

There has not been much attention paid to the residential ventilation in the Czech Republic. Window airing and passive stack ventilation has been the most common way of ventilation in residential buildings. It is true that apartments in multi-storey residential buildings are mostly equipped with manually controlled exhaust fans, but these fans usually run only during cooking or showering. Moreover, there are no air supply openings through which outdoor air could enter the apartments. This is not a problem as long as the windows are not very airtight. A step people usually make when trying to decrease a heat loss of their apartments is sealing the windows or replacing them with more airtight ones. The air change rate in the apartments is then significantly reduced, and the problems associated with poor ventilation arise.

The situation in single family houses (detached dwellings) is similar to the apartment buildings. Window airing and passive stack ventilation are the most common ways of ventilation. Cooker hoods have become quite common in the houses built or refurbished during last decade, but many of them are re-circulation types. Similar to the apartments there are no air-supply openings in the single family houses.

In this context a decision was made to build a house equipped with a demand controlled hybrid ventilation system. The city of Brno has a moderate climate, and so the hybrid ventilation system for the moderate climate, developed by the Dutch industrial consortium, was chosen for the demonstration house. The house will serve for the demonstration, experimental, and educational purposes.

DEMONSTRATION HOUSE

There was not much time available for the construction of the demonstration house. Because of that the house was designed as a well insulated wood-frame construction (this type of construction is not typical for dwellings in the Czech Republic). The demonstration house was built in the Brno University campus within a period of four month. An important requirement was that the total cost of the house should be comparable with the costs of similar size houses built in the Czech Republic. Otherwise the demonstration value of the house would be significantly decreased.

As can be seen in Fig. 1 the demonstration house is a double story building with a flat roof. The usable are of the demonstration house is 100 m^2. The house has quite a low demand for heating (with regard to the housing stock in the Czech Republic). The calculated transmission heat loss is 1.9 kW at -12°C. The ventilation heat loss, in case of demand control ventilation, is significantly dependant on the occupancy and other factors. For the air change ACH = 0.5 $1.hour^{-1}$ the ventilation loss would be 1.7 kW at -12°C.

Fig. 1 Demonstration house with hybrid ventilation

The low-temperature hydronic heating is used in the house. The schematic of the heating system is in Fig. 2. The vacuum pipe solar collectors are expected to cover a significant portion of the energy consumption for space heating and domestic hot water. An air-to-water heat pump is employed for ventilation air heat recovery. The payback time of heat recovery in case of demand control systems is generally much longer than in case of "conventional" systems. It is because the demand controlled systems enable to achieve lower air change rate without negative impact to the indoor air quality.

The living room has radiator heating as well as floor heating. Both means of heating are design to cover the total expected heat loss of the room. The aim of this arrangement is to investigate the thermal comfort in the living room for the combination of hybrid ventilation with radiator heating, floor heating, and combination of both. The hybrid ventilation system supplies fresh air into the rooms without preheating. The ventilation heat loss, therefore, changes quite quickly, and it can be in some moments higher than the transmission heat loss. The floor heating alone may not be able to respond to the changes in the heat loss of the room quickly enough, and it can have negative impact to the thermal comfort of the occupants.

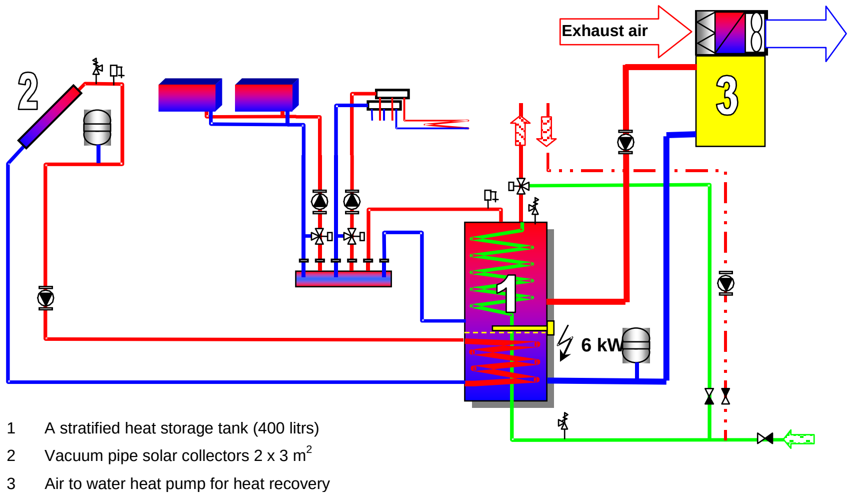


Fig. 2 The heating system in the demo house

HYBRID VENTILATION SYSTEM

The demonstration house is fitted with the hybrid ventilation system developed by the Dutch industrial consortium within the framework of the RESHYVENT project. This ventilation system is primarily intended for the moderate climates. The control of the ventilation system is based on the monitoring of the CO_2 concentration in rooms. The layout of the hybrid ventilation system in the demonstration house is in Fig. 3.

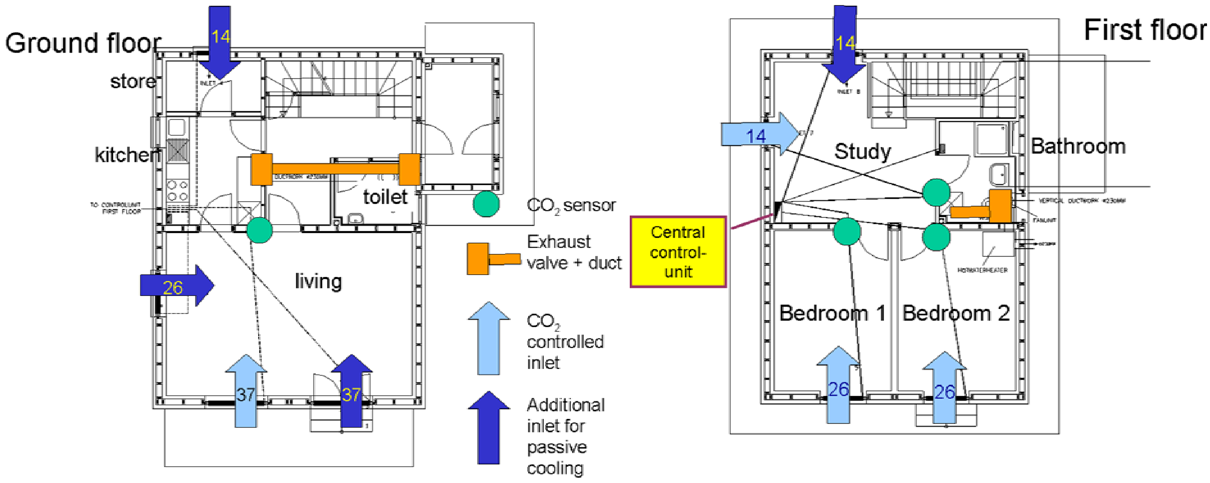


Fig. 3 The layout of hybrid ventilation system

The hybrid ventilation system consists of self-regulating air inlets, CO_2 sensors, central control units (called VENTOSTAT), ductwork, very efficient exhaust fan, motorized damper, and a roof outlet. As can be seen in Fig. 3, there is a self-regulating air inlet in the living room, study and two bedrooms. The self-regulating inlets keep a constant air flow rate when the pressure difference over the inlet is higher than 1 Pa. The control of these inlets (opening and closing) is based on the monitoring of the CO_2 concentration in rooms by means of the CO_2 sensors. When the CO_2 concentration in a room increases to 800 ppm, then the inlet opens to the first position (the first position corresponds to the air velocity of 0.7 m/s in the inlet). If the pressure difference across the inlet is not sufficient to achieve the demanded flow rate, then the fan switches on or increases the speed. If the CO_2 concentration in a room does not decline then the inlet opens to the second position (air velocity 1 m/s in the inlet). This process repeats until the CO_2 concentration in the room begins to decline. Then the inlet will remain in the same position until the CO_2 concentration decreases to 600 ppm. When the concentration decreases to 600 ppm the inlet closes, and the fan (if it is on) either decreases its speed, or switches off. The occupants of the house always have an option to open or close the inlets by means of a remote controller (Fig. 4). There is a switch in the kitchen and the bathroom, which allows the occupants to increase the ventilation rate during cooking and showering.

Fig 4. Air inlets and the remote controller

Fig. 5 shows the exhaust side of the hybrid ventilation system. The flow rate trough the exhaust duct is monitored by means of a flow meter. The motorized damper enables to control the air flow rate when natural driving forces are too high for the demanded flow rate.

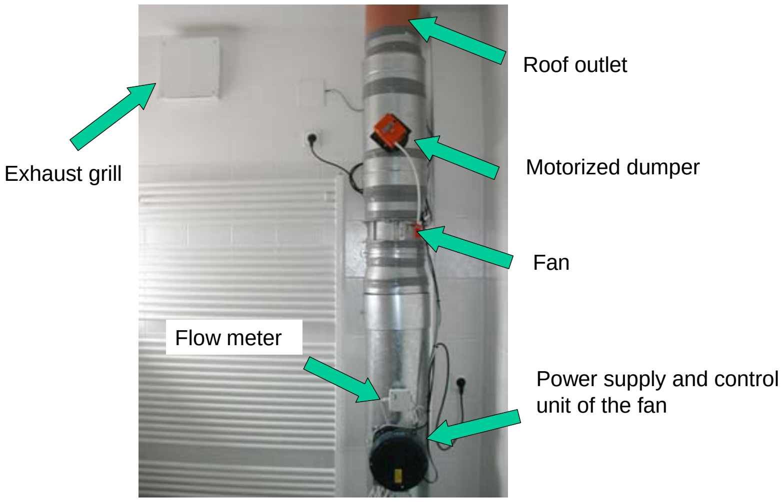


Fig 5 The exhaust side of the hybrid ventilation system

An air-to-water heat pump is used as a heat recovery device. It is actually the only possible arrangement of heat recovery with this ventilation system. The heat pump is connected to the heating system, and so the recovered heat can be used for both space heating and domestic hot water. The ventilation system also has a passive/night cooling mode. In this mode all the inlets open and the fan runs at the maximum speed. There is a solar chimney on the roof, which will assist the ventilation system in passive/night cooling mode. The solar chimney represents the experimental part of the demonstration project, and its performance in cooperation with the hybrid ventilation system is to be investigated.

MONITORING OF THE PERFORMANCE

The central control unit (VENTOSTAT) gathers and stores information about the operation of the hybrid ventilation system. The data file from the VENTOSTAT can be downloaded to a computer and can provide useful information about the ventilation system performance. Beside that another data acquisition system has been installed in the house in order to monitor conditions inside and outside the house. This system involves temperature and humidity sensors in all rooms, heat meters in the heating and solar system and a weather station providing weather data.

Fig. 6 The CO_2 simulation set-up

The demonstration house has not yet been occupied. It has therefore been necessary to simulate the presence of people in order to make the ventilation system respond. The system responds to the increase of the CO_2 concentration, and so the presence of people can be simulated by release of CO_2. Fig. 6 shows a CO2 bottle located in the living room. The bottle is fitted with a manually controlled valve adjustable in the range of 0.1 – 1 l/min of O_2. The variable area flow meters are used to measure the flow rate more accurately, since the CO_2 has different properties than O_2.

The data acquired from the measurements will be used for the evaluation of the performance of the hybrid ventilation system under the climatic conditions in the Czech Republic. The high attention will be paid to the thermal comfort of the occupants. This could be the weakest point of the hybrid ventilation system, which supplies outdoor air to the rooms without preheating. The outdoor air temperature is 20% of year below 0°C in Brno.

Acknowledgements

The financial support from the project No. 222043-4093 granted by the Czech Energy Agency and the Research plan MSM 262100001 granted by Czech Ministry of Education is gratefully acknowledged.

References

Jacobs P., and de Gids W.F. (2003) *Reshyvent - Demand controlled residential hybrid ventilation*, 24th AIVC Conference, Washington, 2003.

Villenave J.G., Bernard A.M. and M.C. Lemaire (2003), *Demand control ventilation systems: performances of CO2 detection*, 24th AIVC Conference, Washington, 2003.

ENERGETIC EFFECTS OF DEMAND – CONTROLLED VENTILATION RETROFITTING IN A BIOCHEMICAL LABORATORY BUILDING

J. Göttsche [1], K. Gabrysch [1], H. Schiller [2], B. Kauert [3], K. Schwarzer [1]

[1] *Fachhochschule Aachen, Solar-Institut Jülich, Heinrich-Mußmann-Str. 5, D-52428 Jülich, GERMANY*
phone: +49-2461-99-3532, fax: 49-2461-99-3570, email: goettsche@sij.fh-aachen.de

[2] *Schiller Engineering, Ulmenstr. 50b, D-22299 Hamburg, GERMANY*

[3] *Forschungszentrum Jülich GmbH, D-52425 Jülich,, GERMANY*

ABSTRACT

The main objective of the demonstration project "LabSan" is the innovative energetic retrofitting of a research laboratory building (3724 m² net floor area) which can serve as an outstanding and guiding example for a large number of existing laboratory buildings.
A scientific monitoring programme, supported by German Ministry of Economics and Labour, is carried out by the Solar-Institut Jülich and the research group STE of Forschungszentrum Jülich. Researchers will analyse the energetic building and HVAC system performance, optimize the operating parameters based on dynamic building simulation, and analyse the retrofitting potential of similar laboratory buildings in Germany. A guide for the retrofitting of laboratory buildings will result.
Due to the high air change rate (25 m³/m²h), and high electric loads of laboratory equipment, the original building consumed about 1235 kWh/m²a primary energy, 65 % of which were due to air heating, air cooling and transport of air. Therefore the largest energy saving potential is related to the ventilation and air conditioning system. The project goal is a 50 % reduction of primary energy consumption, i.e. 600 kWh/m²a, 300 kWh/m²a of which are caused by electricity consumption due to scientific equipment.
First measurements indicate a reduction in primary energy consumption by about 60 %.

KEYWORDS

laboratory building, retrofitting, energy efficiency, variable volume flow, air heat recovery, Air-flow-reduction

INTRODUCTION

Research laboratories belong to the big consumers, even under the energy-intensive buildings for educational facilities. This particularly is because of the high power requirement for the ventilation, the electricity consumption of scientific equipment and lighting. Often operators are missing exact information how much energy is consumed by their laboratory and which possibilities they have to reduce the energy consumption. Many laboratory buildings were established during the creation of research centres in Germany between 1950 – 1980. The use of the buildings for many decades can be recognized: the building structures exhibit numerous defects and the technical equipment is often outdated. In addition, according to changing scientific activities, office space was converted into laboratories and vice versa.

New devices with high heat emissions were added. The retrofitting project serves as an example that will reduce technical and financial uncertainties for future laboratory retrofitting projects.

THE ORIGINAL BUILDING

The building had been established in the middle of the 1960s as chemistry laboratory and had to be modernized in 2002 for a future use by the Institut for Phytosphaerenforschung (see Figure 1 and Figure 2).

Figure 1: Before retrofitting

Figure 2: After retrofitting

After a survey and several short-time consumption measurements a reorganization concept was developed and implemented. The original building needed about 1,200 kWh/m²a primary energy. See Table 1 for some selected building data.

TABLE 1
Selected building data

Building construction style	Concrete carcass structure	
Gross floor area	3,720 m²	
Heated floor area	3,380 m²	
Gross volume	11,420 m³	
A/V ratio	0.30 m^{-1}	
Thermal insulation of external Wall before retrofitting	5 cm polystyrol bonded-system for heat-insulation	
Thermal insulation of external Wall after retrofitting	Rear-ventilated cladding with 17 cm heat-insulation	
	Before retrofitting	After retrofitting
Wall	0.4 – 4.6	0.22
Window	3.4	1.0
Roof	0.6	0.15

In a chemistry laboratory safety and health aspects are of highest importance. Therefore the minimum air exchange rates must comply with DIN 1946-7. Exhaust air was extracted by 55 decentralized ventilation systems without heat recovery. The building was constantly supplied with 45,400 m³/h of fully air-conditioned fresh air. The old ventilation system exhibited function deficits in parts, so that for the evaluation of the possible saving effects a second scenario with values for a fully functional condition of the ventilation system (50,300 m³/h air change) was developed.

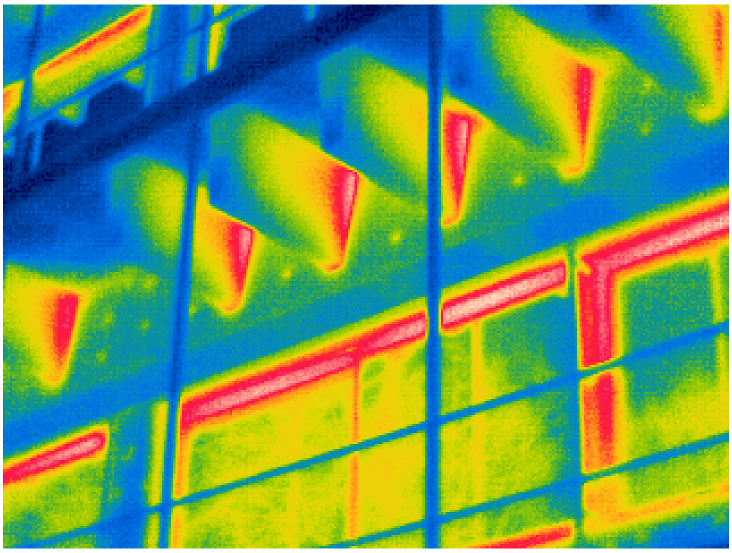


Figure 3: Thermography of the concrete balconies

Concrete balconies projecting from the building front and aluminium window frames formed heat bridges that worsened the energy balance of the building (see Figure 3).

Data basis for the energy consumption were the current consumption measurements of the last six months, individual current consumption diurnal variations, individual measurements of all fans, detailed volumetric air flow measurements and short time heat consumption measurements in the heating season. The annual energy consumption was calculated with the software LACASA under Matlab/Simulink, based on short-time measurements.

An important aspect in a research lab are the internal heat loads. Internal loads were assumed to be up to 15 W/m² by lighting (after the reorganization 9 W/m²), 10 W/m² by office equipment and up to 125 W/m² by scientific equipment. In the simulation computations it was assumed that during the day 2/3 and at night 1/3 of the maximum equipment load was consumed.

THE RETROFITTING CONCEPT

An important aspect were the reorganisation of the space use, the demand-controlled ventilation system with air heat recovery and a differentiated individual room regulation, a complete retrofitting of the building cover and a better daylight use in connection with a lighting system controlled by presence detectors. Supplies of fresh air and cold were completely separated. For the first time a cooling ceiling system was used for the cooling of physical measurement rooms. The sensitivity analysis based on the simulations showed that the largest energy-saving potentials are opened by the reduction of air volumes and the employment of an effective heat recovery system. The past consumption data and the underlying user behavior showed that it is of high importance to optimize the building operation and its usage. Planned energy data are summarized below in table 2.

Restructuring the rooms in use depended groups

Functions as chemical or physical laboratory, office or seminar room were assigned to the individual areas and they were combined within the building into groups, assuring short installation paths. Handling of toxic materials is only allowed in chemical laboratory rooms, thus reducing the number of rooms with increased air change. Areas with high internal loads were positioned at the north-east side of the building.

Centralization of air flow

85% of the exhaust air is led across a central exhaust air system with heat recovery, which can recycle under full load up to 50% of the contained heat. In addition, four decentralized ventilation systems are used for harmful exhaust air.

System separation

In former times laboratory areas were cooled by increasing the air flow. After the reorganization separate cooling systems were installed, either as a recirculating cooler, cooling ceiling or a gravity cooling system. . All systems are appropriate for high inlet temperatures. Cold can be provided either by outside air radiators, river water or a district cooling network.

Volume flow reduction

Variable flow rate controllers are used and provide a single room air balance. The air exchange is reduced at night and on weekends. With the usual laboratory departures a Opening of the front slide gate of extractor hoods leads automatically to an increased exhaust and supply air rate. Only energy-saving, frequency-controlled fans are used.

The volumetric air flow can be reduced by these measures by more than 50%. For example, in former times in a 20 m² laboratory 1,100 m³/h air were exhausted constantly. With the new regulation air change is reduced to a value between the minimum 500 m³/h (as required by DIN 1946-7) up to 1,100 m³/h during the day, while at night and on weekends it is reduced to 340 m³/h. In the library, which serves also as seminar room, the ventilation system is controlled by an air quality sensor.

Building envelope

Concrete balconies (see figure 3) were cut off. Walls and roof were well insulated and windows were replaced with new frames and a double-pane glass with a U value of 1,0 W/m²K. A Blower Door test was carried out at the end of the building phase. The test reached a value of 0,98/h and thus exceeds the value of 1,5 / h as demanded by the German building code EnEV.

TABLE 2: Key building and energy data of retrofitting activity

Energy consumption data			
	Before retrofitting	**After retrofitting (planned)**	**Reduction**
Primary energy demand#	4,600 MWh/a*	2,074 MWh/a	
	1,235 kWh/m²a*	600 kWh/m²a	- 50%
Room heating (District heating)	400 kW	200 kW	
Air heating (District heating)	1,100 kW	246 kW	- 70%
Annual sum of transported air	440 Mio. m³	190 Mio. m³	- 57%
Primary energy demand per air volume	6.7 Wh/m³	3.5 Wh/m³	- 48%
Installed electrical achievement of the fans	41 kW	33 kW	- 20%
specific transmission heat losses [W/K]	4,030	2,030	- 50%
Net heated floor area	offices	ventilated area	other
m²	663	1,527	1,190

conversion factors primary energy: Electr. power = 3,0; district heating and cooling = 1,1

* according to ventilation scenario II – 50,300 m³/h constant air flow

Daylight use and lighting system

For an improved daylight use external blinds with reflecting coating were installed at the south-west facing offices. Corridor doors were equipped with daylight openings. The effect of the light guidance lamellas on the space impression and the appropriate shading situation was examined by Solar-Institut Juelich with daylight simulations. Also the distance of the escape balconies improved the daylight situation. The new lighting system is characterised by energy-savings lamps and a require-fair control with operational readiness level alarm units, stage circuits and automatic density of light regulation as a function of the external beam of light.

FIRST RESULTS

A summary of energy consumption data is given in table 3.

TABLE 3
Characteristic values and energy consumption

Details							
		Before retrofitting		**After retrofitting (planned)**		**After retrofitting$ (measured)**	
		End-use energy MWh	**Primary energy# MWh**	**End-use energy MWh**	**Primary energy# MWh**	**End-use energy MWh**	**Primary energy# MWh**
Electricity	Fans	373	1,119	112	336	216	648
	Lighting	72	216	43	130	339	1,017
	Equipment	344	1,031	344	1,031		
Heat	space heating	350	385	140	154	209	230
	Central air preheating	1,298	1,428	220	242	195	215
Cooling	space cooling	0	0	119§	131§	§	§
	Central air conditioning	383	421	45§	50§	§	§
Sum		**2,820**	**4,600**	**1,023**	**2,074**	**1,123**	**2,291**
	Volume flow	**day**	**night/WE**	**day**	**night/WE**	**day**	**night/WE**
	m³/h	50,300	50,300	28,800-36,600	12,000	26,000 – 29,000	17,600

conversion factors primary energy: Electr. power = 3,0; Long-distance heating and cooling = 1,1
* after ventilation scenario II – 50,300 m³/h constant air flow
+ for the prognosis an identical equipment use in the laboratories and offices before and after the reorganization were assumed.
$ Annual energy requirement on the basis of G20 heating degree days and the test basis year TRY 02
§ at this time a computer forecast on the annual cooling demand is not possible)

First results of the heating season 2003/04 are available. The heating energy consumption (133 kWh/m²a) exceeds the expected value slightly. The ventilation system is not yet challenged to its full capacity. However, at night and on weekends, volume flow rates should be further reduced to reach the targeted values. 88,4% of the exhaust air passed through the central system with heat recovery. Statements about the actual cooling power requirement are only possible after the summer 2004.

The electricity consumption of the building is a major concern as it contributes to about 50 % of the primary energy consumption. At present the building is not yet fully equipped with scientific equipment. Therefore the present peak consumption (average of laboratory area) is only 13 W/m². The electricity consumption of laboratories is displayed in a sorted graph in Figure 4. The total peak power based on hourly averages is 78 % of the sum of the single maximum values of the single sub-grids in the different floors (Ground floor: EGUV1 and EGUV2, First Floor: 1OGUV1 and 1OGUV2, Second Floor: 2OGUV1 and 2OGUV2). As can be seen in Figure 4, there is not yet any single consumer which dominates the electricity consumption.

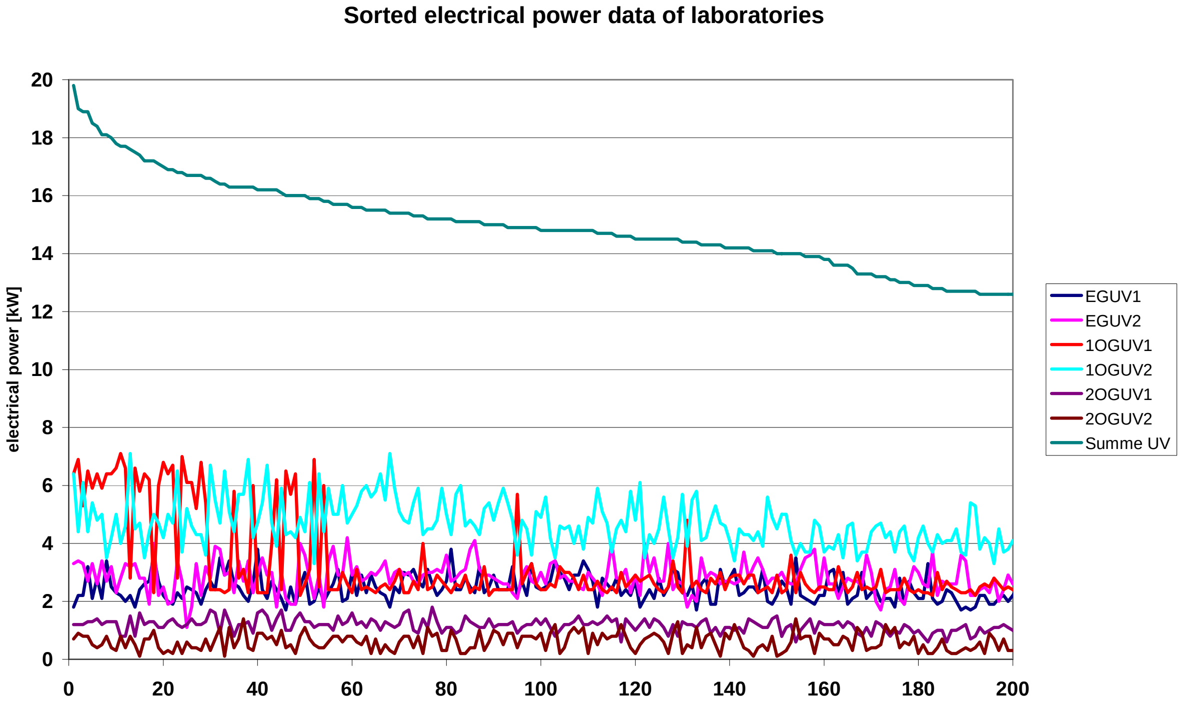


Figure 4: Electricity consumption data of laboratories, sorted by sum value ("Summe UV")

CONCLUSION

A laboratory building with a primary energy consumption of 1,200 kWh/m² was retrofitted with the aim of 50 % reduction of energy consumption. An intensive monitoring programme was carried out by Solar-Institut Juelich. According to extrapolated measured data, this aim has just been achieved. Further optimization will be necessary when the laboratory usage is intensified and data of cooling energy consumption is available. For example, the optimization of supply air temperature may result in a 27 % reduction of total energy consumption /2/.

REFERENCES

/1/ Milles, U., BINE Projektinfo 02/2004, Fachinformationszentrum Karlsruhe, ISSN 0937-8367

/2/ Engdahl F., Johansson D., Optimal supply air temperature with respect to energy use in a variable air volume system, Energy and Buildings 36 (2004), p. 205-218

ACKNOWLEDGEMENTS

The project was supported by the German Ministry of Economy and Labour (BMWA) through its "Zukunftsinvestitionsprogramm" ZIP.

THE RETROFIT OF EXISTING VENTILATION AND AIR TREATMENT UNITS: AN EXPERIMENTAL AND METHODOLOGICAL APPROACH.

Dario Bozzolo (**)(***), Luca Pietro Gattoni (*)(***), Giovanni Laube (***)

(*) Politecnico di Milano
Dipartimento di Scienza e Tecnologia dell'ambiente costruito (BEST)
Building Envelope Group
Via Bonardi 15, I-20133 MILANO
T. +39.02.2399.6014 F. +39.02.2399.6020
luca.gattoni@polimi.it

(**) Scuola Universitaria Professionale della Svizzera Italiana (SUPSI)
via Cantonale, CH-6928 Manno
T +41 91.610.85.80 F +41 91.610.85.81
dario.bozzolo@supsi.ch

(***) IFEC Consulenze SA via Cantonale, c.p. 505 CH-6802 Rivera
T +41 91.935.97.00 F +41 91.935.97.09
dario.bozzolo@ifec.ch, giovanni.laube@ifec.ch, luca.gattoni@ifec.ch

ABSTRACT

Recent studies in Switzerland showed that in large non residential buildings, witch can be compared for typology and ventilation needs, the consumption of electricity for mechanical ventilation can vary considerably from case to case. Moreover in such a building it represents a percentage not negligible of the whole consumption of electricity. We had a confirmation of that behaviour with a study we made during 1999-2000 on a set of eighty air treatment units of the Civic Hospital in Lugano (Southern Switzerland). In the case in point the consumption for the electrical engines for switching on the fans came to 15% of the whole consumption of electricity (this figure does not include the electricity consumption for the air treatment -post heating, humidification, etc.-).

The analysis pointed out high possibilities of energy savings (40-60%) for many air treatment units both by the mean of simple and cheap measures of retrofitting of the plants, and thanks to a review of the ventilation needs in each interested room. In some cases it was possible to implement the proposed solutions and confirm, within experimental error and according to control measurements, the effective improvement estimated on paper.

KEYWORD

Air treatment unit, electricity saving, fan engines, energy saving, hospital building, electrical motor

THE STARTING POINT

The high electricity consumption of the plants

Various research carried out during past few years demonstrated how the electricity consumption due to the mechanical ventilation and air conditioning plants for the treatment and movement of the air is very large and cannot be ignored.

For the case described here, the Civic Hospital in Lugano (~350 beds), has been demonstrated that the annual costs for electricity consumed to run all the fan engines amounts to about 150'000 Fr. This quantity represents 15% of the global costs spent for the electricity (See Fig. 1)

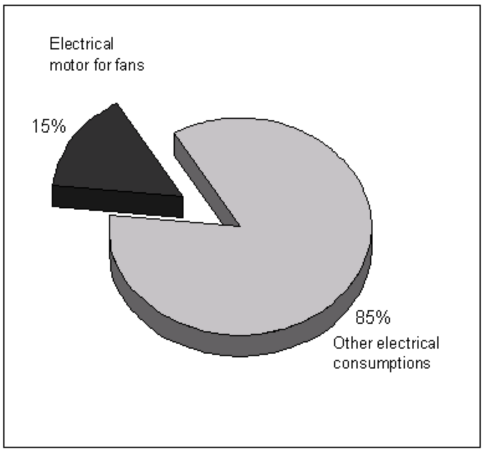


Fig. 1 Consumption of electricity in the Civico Hospital - Lugano

The limited efficiency of the plants

An experimental analysis made on a set of eighty air treatment units showed that the measured efficiencies are far below referring to the values suggested from the Swiss technical codes (SIA 382/3), especially in the case of lower air flow volume rates.

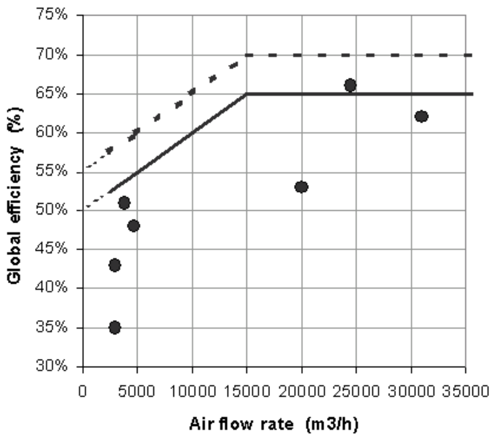


Fig. 2 Comparison of measured efficiency (black dots) and suggested value from Swiss standards

The Fig. 2 explains what mentioned above: investigated plants with small air flow rate(< 5000 m^3/h) have an efficiency lower than 50%, in some cases lower than 30%, clearly below the values suggested from the technical codes (the continuous line represents the normal efficiency requested, while the hatched line indicates higher requirements). In the case of Civic Hospital was evident the possibility to reach high energy savings.

THE RESEARCH GOAL IN THE FRAME OF E2000

The research goal was to propose a methodology easy and fast that allows the HVAC manager to plan the right measures in order to lower significantly the electricity consumption of the hospital ventilation plants both from the energetic and economic point of view.

Even if the research interested the air treatment units of an hospital building all the actions pointed out can be applied usefully in mostly of HVAC plants.

MAIN ENERGY DEFECTS

In the following chapters we present the main defects that were identified during this research.

Insufficient management and control

Very often the running of the mechanical ventilation system does not fit the real needs and usage of the rooms. The Fig. 3 shows that the global electricity consumption varies according to the needs (it is lower both during the night and the weekend days). On the same diagram we can see that the power used for running the fan keeps fairly constant. This means that a lot of plants run even if the rooms are unoccupied.

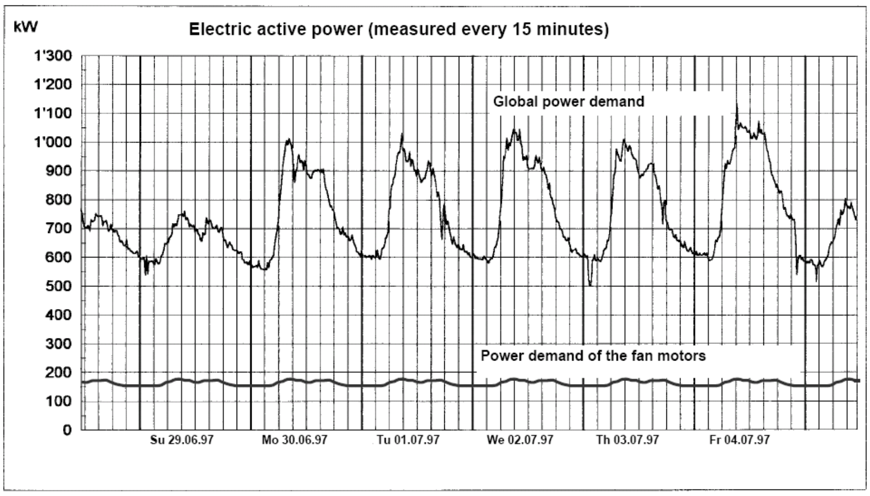


Fig. 3 Measured electricity consumption over a week

Air treatment units with useless components

Very often the air treatment units have components unnecessary, no longer used or overstated.

The following cases are some examples:

- The filters were not corresponding to the needs of the rooms;
- The humidifiers, even if installed, were never used;
- The ducts can have unjustified extension and curves.

At the same time air flow rate if an additional component is installed, we have an additional resistance to the air flow leading to an higher consumption of mechanical energy and electricity.

Unsuitable air flow rate

The air flow rates are often unsuitable to the real needs of the room according to the new standards and in many case the is a lack of efficient control systems. For high performance buildings, the trend during last years is to reduce the ventilation losses at the minimum air flow rates that allows a good indoor comfort (~15-25 m^3/h.pers). From the energetic point of view this topic is very important because the engine power is proportional to the third power of the air flow rate. Lowering the air flow rate of 20% leads to an energy saving of 50% in electricity consumption.

Overstatement of the engines

From the measurements came out that more than 50% of the engines are overstated with a factor 2 or higher (See Fig. 4). The effects of this behaviour are very negative on the electricity consumption because the efficiency of the motor decreases sharply when the engine runs at a partial charge lower than 25 – 50% of the nominal value. This aspect has a double negative consequence for the plant manager because he pays more to buy an engine too big for his purpose and he spends yearly more electricity.

The overstatement ε came from Eqn. 1

$$\varepsilon = \frac{P_{n,out}}{\eta \, P_{e,in}} \qquad \text{Eqn. 1}$$

Since $\eta = f(\varepsilon)$ it is possible, even without know the nominal efficiency η_n (or $\cos\varphi_n$) to estimate the maximum value of η and then the minimum value of ε referring to the database of electric motors EuroDEEM 2000.

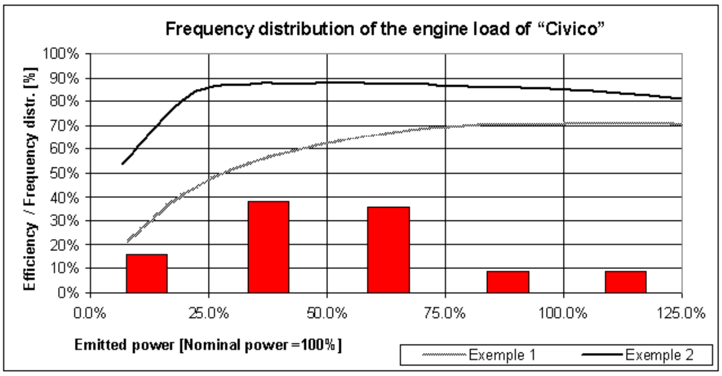


Fig. 4 Frequency distribution of the engine load of Civico Hospital - Lugato

METHODOLOGY

As usual in other sector, the methodology is divided in two main parts: a “Brief Analysis” and a “Detailed Analysis”.

Brief Analysis

During the first phase in order to evaluate a possible overstatement, to list the first measures of energy improvement and their cost, and to select the air treatment unit witch should be analysed in detail afterwards, all the data of the ventilation plants and of the ventilated rooms are collected and the electric power of each air treatment unite are measured (See Fig. 5).

In detail the answer to the following questions has to be found:

- Which sort of plant are we dealing with? And which need it has to satisfy?
- Which elements compose the air treatment unit? And how they are maintained?
- Which are the rooms served by the plant and their dimensions?
- How many hours and when the rooms are occupied? And which are the working hours of the system?
- How big is the designed air flow rate?
- Which control system are installed?
- How much energy spend each air treatment unit yearly?

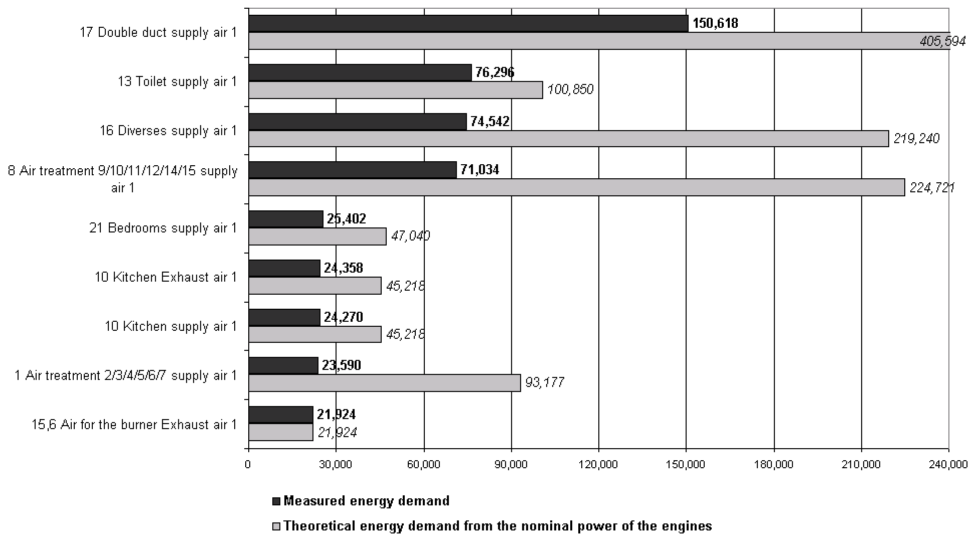


Fig. 5 Theoretical and measured yearly energy demand (kWh) for the Civico Hospital

In this context it is essential to measure for each treatment unit the electric power absorbed by the engine. In fact the real energy consumption can be notably lower than the theoretical value obtained from the nominal values of the installed engines. This can happen because of the overstatement of the motor.

To know the exact figure of the energy consumption for each air treatment unit is important to evaluate the profitability of the actions and to state which units have to be studied in detail furthermore.

Detailed Analysis

During the second phase in order to have a comprehensive description of the starting situation all the efficiencies of the selected air treatment units are measured.

In detail the following physical quantities has to be measured:
- air flow volume rate;
- the global pressure drop across the fan;
- the frequency of rotation on the fan and of the engine;
- the pressure losses related to the various component of the air treatment unit;
- the electric power absorbed by the engine.

Then, according to the ventilation and air treatment needs of the rooms, by the means of an audit and an optimisation of the plant in each component, it is possible to find out a schedule of retrofitting procedure (short, medium and long term).

The possible strategies for energy savings must focus on:
- reduction of number of working hours of fan;
- minimization of air flow rate;
- minimization of pressure resistances in the plant;
- increase of the efficiency of the system “fan-transmission-engine”.

CONCLUSIONS

The suggested procedure should represent a good starting point to manage the problem of retrofitting of existing air treatment units taking into account both the energy savings and the economical resources even if it is under a continuous improvement phase (See Fig. 6), from the collection of new experiences during the practical implementation by the means of courses and seminars running in some region of the Switzerland.

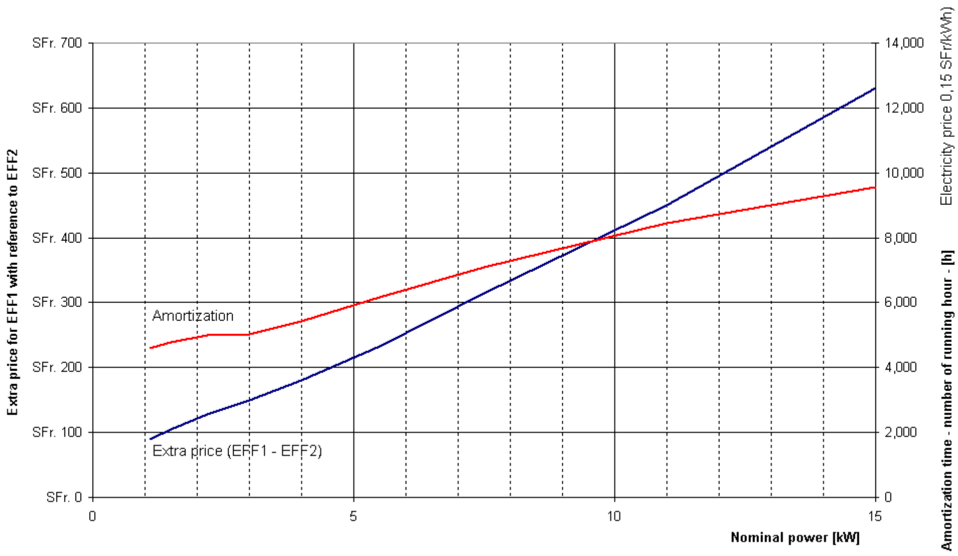


Fig. 6 Profitability of a 4 poles motor with an higher efficiency (EFF1)

EXAMPLES

During our experimental research we had the occasion to test some simple actions of energetic upgrade for some air treatment units.

Example 1: air treatment unit of supply air for the Chapel (Lugano Hospital)

For the case of the Chapel we choose three different actions.

Reduction of number of working hours
Originally the plant was switched on continuously at low velocity. Considered the scarce use of the chapel, a timer to switch off the fan from 22:00 to 6:00 was installed. By the mean of this simple measure it was possible to reduce the yearly consumption of electricity (less 33%)

Adjustment of the transmission-gear to the engine speed
The analysis showed that the efficiency of the engine was better at higher velocity (~85% instead of ~70% for small velocity). The solution was to move the engine to high velocity and to change the sheaves in order to assure the same air flow rate: the electricity savings was around 20%.

Replacement of the fan
The fan was removed because the efficiency was very low and replaced by another fan, with a good characteristics for the plant, from a disused air treatment unit. With this action and the adjustment of the transmission-gear to reach the aimed air flow rate the energy savings were around 21%. All these measures together allow to save around 43% in energy consumption referring to the base case.

Example 2: treatment unit for the supply air in the kitchen (Lugano hospital)

The easy action in this case was to reduce the air flow rate by 20% simply with the replacement of the sheaves, because the measures showed that the flow was overstated. This measure alone reduced the energy consumption of 43%

Example 3: air treatment unit for therapy rooms (Sursee Hospital)

In this case the analysis showed the presence of an unnecessary filter: without this filter and adjusting the transmission-gear in order to reach the correct air flow value the reduction in consumption was around 30%.

REFERENCES

Bozzolo D. and Laube G. (2000). *Energiesanierung der Monoblöcke von RTL-Anlagen,* Energieschweiz energho

EuroDEEM 2000, *The European Database of Efficient Electric Motors,* http://iamest.jrc.it/projects/eem/eurodeem.htm

SOLUTIONS FOR MVHR IN EXISTING DWELLINGS

Peter Op ‘t Veld, Erwin Roijen

Cauberg-Huygen Consulting Engineers bv Maastricht, the Netherlands

ABSTRACT

For retrofitting of existing dwellings MVHR is seldom applied, despite the potential in energy saving and improving thermal comfort and indoor air quality. Major barriers and limitations for application are lack of space, especially for the supply ducts and the MVHR units as well as the complexity of execution. Also initial costs are an important barrier. Limiting supply ducts could be beneficial for application in single family dwellings. In a study some configurations with simplified air supply with MVHR in single family dwellings have been investigated. The main principle is supplying air only on the first floor and internal air transport by overflow provisions to the exhaust points.
Simulations with COMIS show the CO_2 levels in habitable rooms for different configurations and the Low Ventilation Index (Lvi) in relation to a reference situation with natural supply and mechanical exhaust. Good quality overflow provisions are crucial in this concept. Simulation show a Lvi < 0.005 which is equal (and in some cases even better) then the reference situation. In a number of field experiments ventilation efficiency of different configurations have been measured with tracer gas.
In collaboration with the company Agpo BV some industrialised prefab solutions for simplified air supply have been developed and tested in retrofitted dwellings.

KEYWORDS

Mechanical ventilation with heat recovery, retrofitting, dwellings, ventilation efficiency

INTRODUCTION

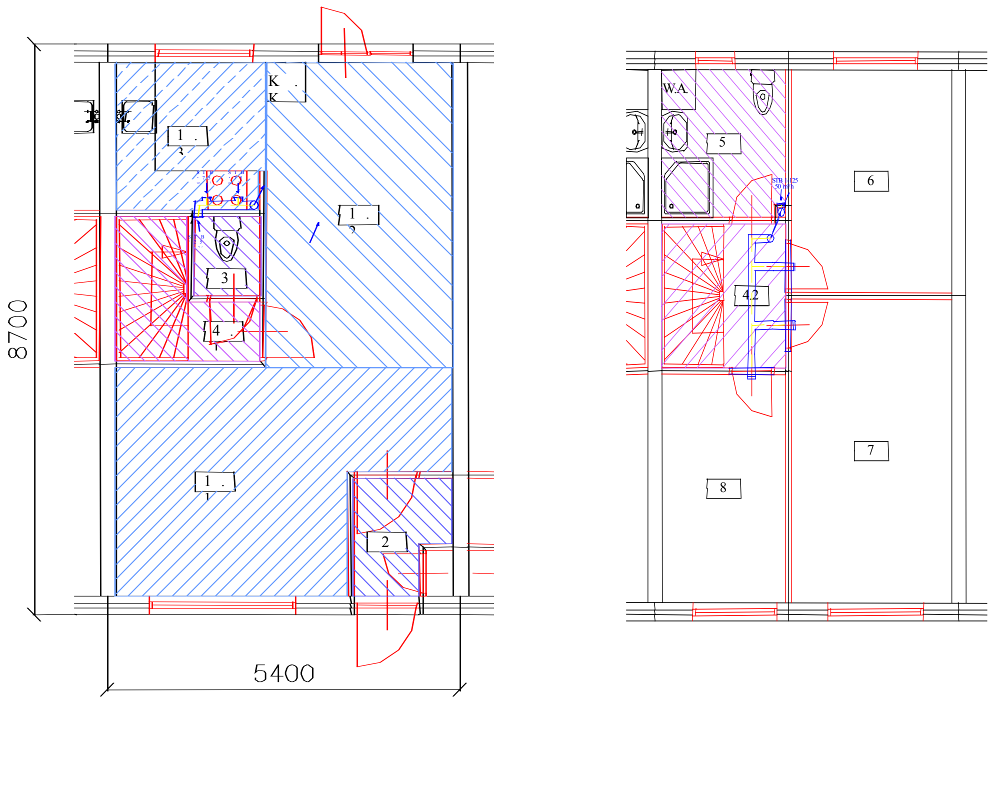
Since the introduction of the Energy Performance Regulations in the Netherlands in 1996 the market share of mechanical ventilation with heat recovery (MVHR) increased from 0.5% in 1995 to 50% in 2003 in new dwellings. The main driving force in the market is the building regulations, especially the Energy Performance Regulations, introduced in 1996 and sharpened in 1998 and 2002. In 2006 the allowable energy consumption will be sharpened to half of the level of 1996. The Dutch Energy performance regulations are only mandatory for new buildings. For retrofitting of existing dwellings MVHR is seldom applied, despite the potential in energy saving and improving thermal comfort and indoor air quality. Apart from the lack of standards and regulations as a driving force also other barriers occur. Major barriers and limitations for application of MVHR in existing dwellings are lack of space, especially for the supply ducts and the MVHR units as well as the complexity of execution. Also initial costs are an important barrier. Limiting supply ducts could be beneficial for application in (common) single family dwellings.
Therefor the feasibility of a simplified supply ductwork is investigated for single family dwellings. The main principle for this simplified ductwork is supply of air only on the first floor (bedrooms and landing). Exhaust of air takes place in kitchen and toilet (ground floor) and bathroom (first floor). The idea is that the supplied air on the first floor will flow from bedrooms and landing through internal overflow provisions to the exhaust points on the ground floor. There are 4.2 million single-family dwellings in the Netherlands; about 2.2 million single-family dwellings have a lay out of the ground floor with a so-called open kitchen, i.e. a kitchen adjacent to the living room. For these dwelling types there are no restrictions. The air will flow from the first floor through the living room to the exhaust points

in the kitchen. These dwellings will need a certain level of air tightness to avoid cross flow ventilation.
The Dutch building regulations state that the supply of air to habitable rooms must come for at least 50% directly from outside. In other words, the proposed solution does not comply with the building regulations. However, using the Principle of Equivalence, it is allowed to apply this solution if it is proved that this solution gives an equal performance (in terms of indoor air quality).
This equal performance is assessed as follows:

- by simulating the air flows and indoor air quality, assessing the Low Ventilation Index (Lvi);
- by ventilation efficiency measurements.

SIMULATIONS

Simulations have been carried out with the multizone ventilation modelling programme COMIS. For the simulations a typically Dutch standard reference building was used, see figure 1.



ground floor first floor

Figure 1 Dutch Reference dwelling used for simulations

Three situations have been modelled:

1. traditional ventilation system:
   - natural supply by ventilation provisions in facade;
   - mechanical exhaust in kitchen, toilet and bathroom;
   - internal airflow to living room/kitchen by overflow provision in door to living room.

2. simplified MVHR
   - mechanical supply in bedrooms and landing (42 – 63 dm^3/s);
   - mechanical exhaust in kitchen, toilet and bathroom;
   - internal airflow to living room/kitchen by overflow provision in door to living room.

3. simplified MVHR with improved overflow
   - mechanical supply in bedrooms and landing (42 – 63 dm^3/s);
   - mechanical exhaust in kitchen, toilet and bathroom;
   - internal airflow to living room/kitchen by improved overflow provisions in door to living room an extra overflow grille in wall (between zone 4.1 and 1.1, see figure 1).

All modelled situations have same boundary conditions for occupancy patterns and behaviour, use of airing provisions and the mechanical ventilation. CO_2 production is calculated by COMIS. The performances of the three situations are assessed by the Low Ventilation Index. The Low Ventilation Index is determined as follows:

1. calculation of the effective ventilation by
   $q_{en} = C_{target}/C_t$

   q_{en} = effective ventilation; ($q_{en} \leq 1.0$)
   C_{target} = target concentration ppm ($C_{CO2} > 1200$ ppm)
   C_t = occurring concentration in ppm

   For example: for dwellings target concentration CO_2 = 1200 ppm

2. plotting a histogram of the effective ventilation during the simulated period

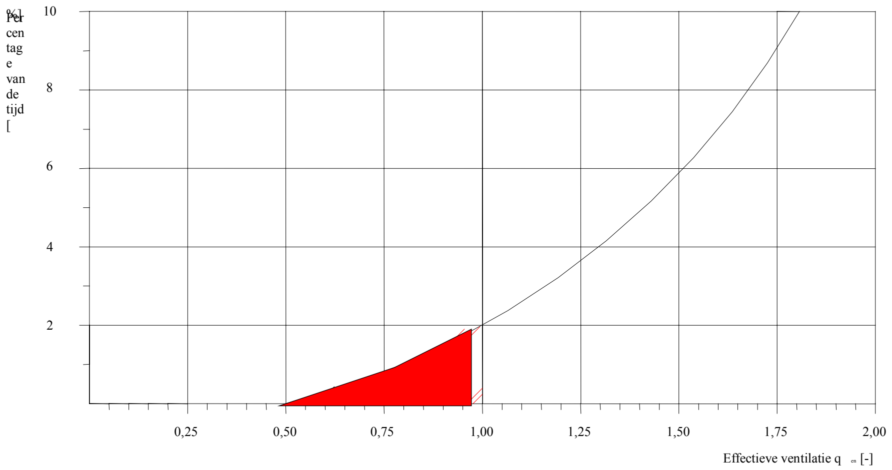


Figure 2 Example of histogram for determining the Low Ventilation Index

The Lvi is the marked part of the histogram for $q_{en} < 1$ and the corresponding time interval.

For dwellings (in the Netherlands) the maximum value of Lvi is 0.005 (-)

In table 1 a comparison is given of the Lvi values for the 3 situations in the living room.

Table 1. Lvi living room for 3 situations

Case	**Lvi**
1 traditional system (natural supply, mechanical exhaust)	0.1054
2 simplified MVHR supply 1st floor	0.1437
3 simplified MVHR supply 1st floor with improved overflow	0

For the traditional system a peak concentration of CO_2 in the living room of 4200 ppm occurs between 20.30 and 21.00 h (all occupants in living room). For case 2 the peak value is even 8700 ppm between 22.00 and 22.15 h. For case 3, simplified MVHR with supply on the 1st floor and improved over flow to the living room, the maximum CO_2 concentration of 1200 ppm is not exceeded. In figure 3 the time related CO_2 concentrations for this situation is given for all rooms for a number of classes of CO_2 concentrations.

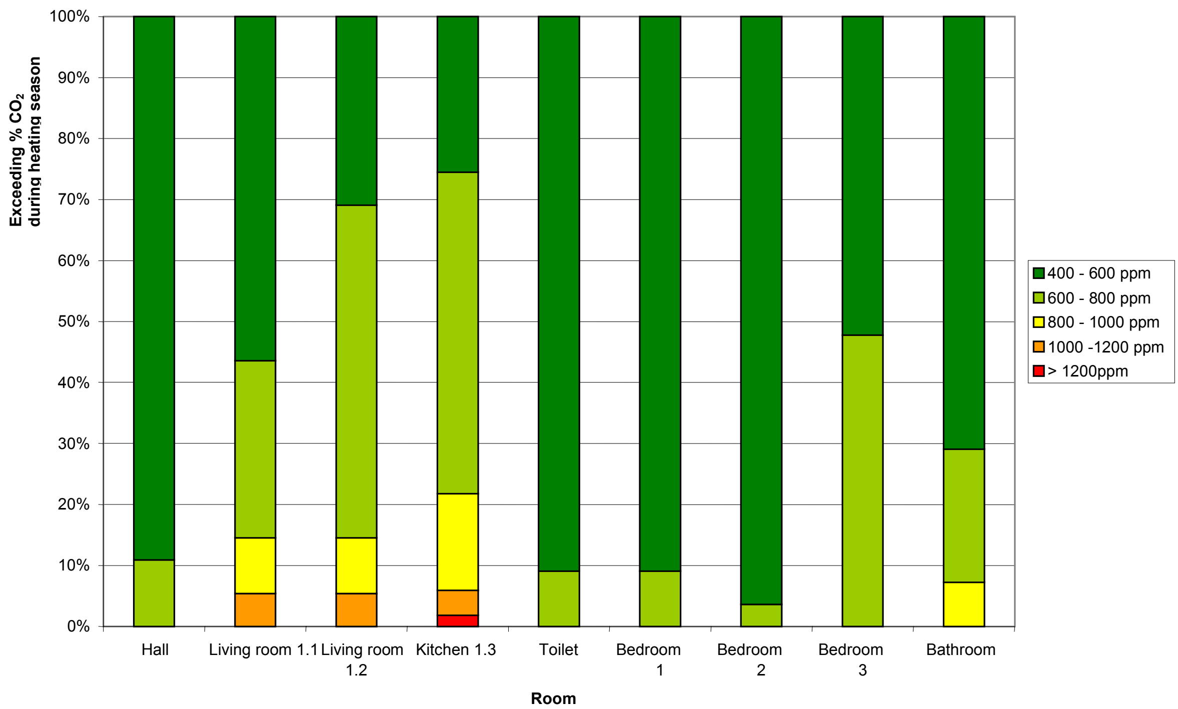


Figure 3 Time related CO_2 concentrations for MVHR with simplified supply and improved overflow

In the kitchen the target concentration of 1200 ppm is exceeded for 2% of the time. This is due to the fact that the exhaust point in the kitchen is the “end-point” of the total air flow path in this dwelling. However, the maximum CO_2 concentration in the kitchen occurs at 19.00h. At that time there are no persons present in the kitchen.

VENTILATION EFFICIENCY MEASUREMENTS

The feasibility of a MVHR system with simplified supply was also tested in a single family dwelling (with open kitchen) by measuring and comparing the ventilation efficiency and local air change rates in the living room for following situations:

- a reference situation with mechanical supply in the living room;
- situation with simplified supply on the first floor and overflow provisions.

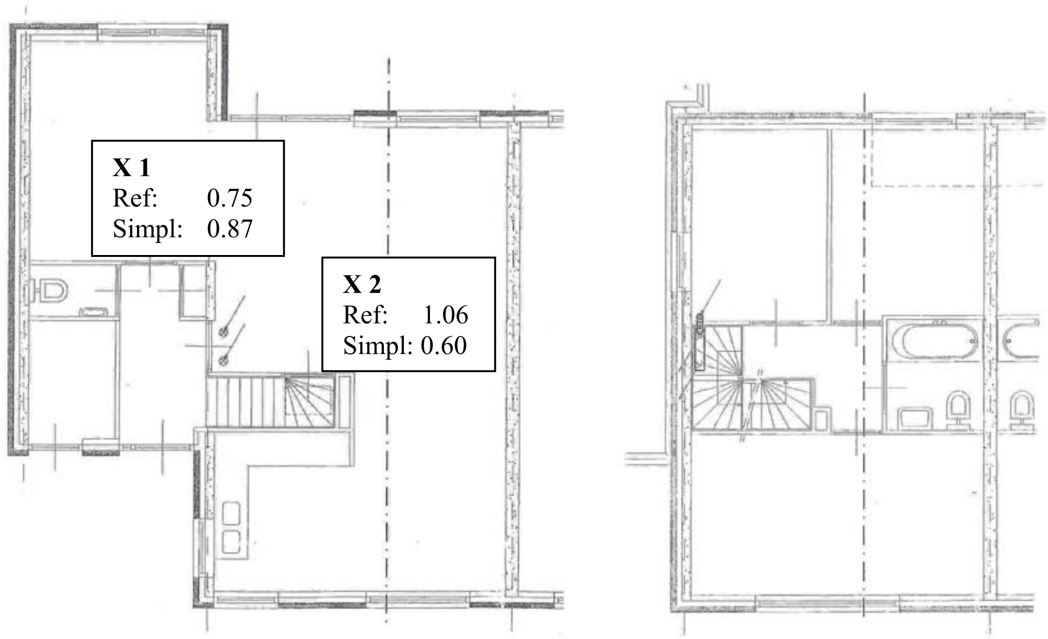


Figure 4 Measured dwelling in situ

The measured local air change rates are given in table 2

Table 2. Measured local air change rates in situ

Position	Reference supply in living room	Simplified supply 1st floor
1	0,75	0,87
2	1,06	0,60
average	0.91	0.74

Position 1 is a measuring point situated in a "dead corner" of the living room, but near to a door with an overflow provision. Position 2 is situated in the middle of the room near two supply grilles (in the reference situation). For position 1 the local air changes rate increases while for position 2 it decreases. However, for both situations and both positions the local air change rates satisfy the minimum rates conform the building regulations. Again, as in the simulations, the position of the overflow provision(s) is very important. No tests have been performed with an improved overflow for position 2 but it can be expected that this will increase the ventilation efficiency on this point.

INDUSTRIALISED SOLUTIONS FOR SUPPLY AIR

One of the problems with application of MVHR in existing dwellings is design and mounting of the ductwork (supply and exhaust). In many cases only natural ventilation with passive stacks is present. This means that for the application of MVHR supply ducts as well as exhaust ducts have to be installed. Often the dwelling lay out is such that supply and exhaust ducts have to cross. This can be a problem when the ceiling height is limited.
In collaboration with Agpo BV, the Netherlands, some industrialised solutions for the simplified supply ducts have been developed. These solutions are based on a prefabricated plenum for the supply air (height 150 mm) that fits to the ceiling of the first floor landing. From this plenum connections can be made to the bedrooms. The plenum has also extra grille supplying the landing. With the fan in high position 50% of the air is supplied to the bedrooms and 50% to the landing. During the nighttime the fan runs at 50% of its capacity with 100% supply to the bedrooms. This has the advantage of supplying the full amount of air to the bedrooms without needing the fan switched in the high position (less noise). In case the grilles to the bedrooms are closed all air is supplied to the landing. If necessary exhaust ducts can be placed within the plenum thus avoiding crossings with supply ducts.

CONCLUSIONS

Both multizone ventilation simulations as well as measurements in situ show that a good ventilation and indoor air quality can be achieved by applying MVHR with a simplified supply system, supplying air only on the first floor. This application has following boundary condition:
- lay out of the ground floor must be suitable, i.e. there must be a logical air flow path from the staircase via the living room to the exhaust points in the kitchen;
- position and dimensions of overflow positions are critical;
- air tightness must be good ($n50 < 3$).

Advantages of this simplified supply system are:
- very short and limited supply duct systems or even no supply ducts when applying the prefabricated supply plenum;
- very limited pressure losses;
- low noise levels due to the low pressure losses and due to the fact that during night time the fan can run at lower speed but still providing the bedrooms with the nominal air flows.

Disadvantages of this simplified supply system is
- only applicable (without major limitations) in single family dwellings with open kitchen (approximately 50% of the Dutch single family dwellings);
- for single family dwellings with closed kitchens additional overflow provisions are necessary.

REEFERENCES

Etheridge D., Sandberg M., Building Ventilation, 1996
Schild P., Air-to-Air Heat Recovery in Ventilation Systems, AIVC Ventilation Information Paper VIP 06, 2004
De Gids W., Kornaat W., Revision NEN 5128, formulas for calculating heat loss by ventilation and infiltration, TNO-Bouw, 1998

ESTIMATION OF THE EFFECTIVE FRESH AIR SUPPLY RATE ON TWO STOREY DWELLINGS EMPLOYING STACK EFFECT VENTILATION

M. Tajima[1], T. Sawachi[2] and M. Okabe[3]

[1] *Housing Department, National Institute for Land and Infrastructure Management*
1 Tachihara, Tsukuba, 305-0802 JAPAN
[2] *Building Department, National Institute for Land and Infrastructure Management*
1 Tachihara, Tsukuba, 305-0802 JAPAN
[3] *Tsukuba Building Test Laboratory of Center for Better Living*
2 Tachihara, Tsukuba, 305-0802, JAPAN

ABSTRACT

This study deals with the ventilation performance of two storey dwellings employing stack effect ventilation to satisfy the overall ventilation requirement. The SRF (Supply Rate Fulfillment) index was used as a ventilation performance index. The experiments were implemented to measure effective fresh air rate by using tracer gas in a test house. Following are the results of the experiments and the theoretical calculations.

- The measured air change rate and the SRF value were fairly close to the theoretical calculation.
- The ventilation factors such as the ventilation rate, the effective fresh air supply rate and the SRF value were measured by using two tracer gases in transient conditions.
- The relationships among the equivalent leakage area of dwellings, the total ventilation rate and the overall SRF value are quantified on the basis of the measurements and theoretical calculations.

KEYWORDS

Ventilation performance, Measurement, Network air flow model, Tracer gas, Stack effect

INTRODUCTION

It is not easy to estimate ventilation performance of multi zoned building, because of the existence of the transferred air among the zones. The transferred air from other rooms contains effective fresh air when it has a potential to dilute contaminants. On the other hand, the transferred air is categorised as a contaminant source when it has higher pollutant level compared with acceptable concentration. From the viewpoint of the effective fresh potential of the transferred air, the authors defined the Supply Rate Fulfillment (hereinafter referred to as SRF (Sawachi et al. 1998)) index. The index has been used for the evaluation of ventilation performance of multi zoned dwellings employing mechanical ventilation systems as well as natural ventilation systems. This study, focused on whole house ventilation performance on two storey dwellings employing a stack effect ventilation system, has the following objectives.

- Measurement of the SRF value and the direct fresh air supply rate by using tracer gas methods in transient condition.
- Verification of the accuracy of the calculated rate by using a network air flow model, which is used as a tool for ventilation design, based on the measurement.
- Clarification of the relationships among the temperature difference, total fresh air supply

rate and the SRF value by the field measurement.

METHODS

Ventilation Performance Index SRF

The SRF index is used to evaluate the ventilation performance. This terminology is based on the theory of conservation law of fresh air rate. The index is given by Eqn.1 and defined as the ratio of the effective supply rate S_i (Eqn.3) to the substantial required fresh air supply rate P_i'. The SRF value ranges from 0 to 1 and SRF=1 means the referenced room has sufficient effective fresh supply air rate comparing to the P_i'. The S_i and the P_i' are calculated by using the α_i (surplus fresh air supply rate of the zone i, which is obtained by solving Eqn.2). The α_i can be calculated when all airflow rates among zones in a building are known. The maximum value of α_i, 1.0 represents purely fresh air like outside air, and the negative means no fresh air quantity included in the air. The OSRF (Overall Supply Rate Fulfillment) is defined as the geometric mean of SRF values of rooms as shown in Eqn.4. The OSRF value is used to evaluate the whole house ventilation performance. As mentioned above, the SRF value can be derived by theoretical calculations like as network air flow model. Furthermore, the value can be measured by using two tracer gas techniques which are the constant injection method and the constant concentration method (Tajima et al. 2003).

$$\mathrm{SRF_i} = \frac{\mathrm{S_i}}{\mathrm{P_i} - \sum_{j=1}^{n} \min(0, \alpha_j \cdot \mathrm{Q_{ij}})} = \frac{\mathrm{S_i}}{\mathrm{P_i}'} \tag{1}$$

$$\mathrm{A_i} + \sum_{j=1}^{n} \alpha_j \cdot \mathrm{Q_{ij}} - \alpha_i \cdot \left(\sum_{j=1}^{n} \mathrm{Q_{ji}} + \mathrm{B_i}\right) - \mathrm{P_i} = 0 \tag{2}$$

$$\mathrm{S_i} = \mathrm{A_i} + \sum_{j=1}^{n} \max\left(0, \alpha_j \cdot \mathrm{Q_{ij}}\right) - \sum_{j=1}^{n} \max\left(0, \alpha_i \cdot \mathrm{Q_{ji}}\right) - \max\left(0, \alpha_i \cdot \mathrm{B_i}\right) \tag{3}$$

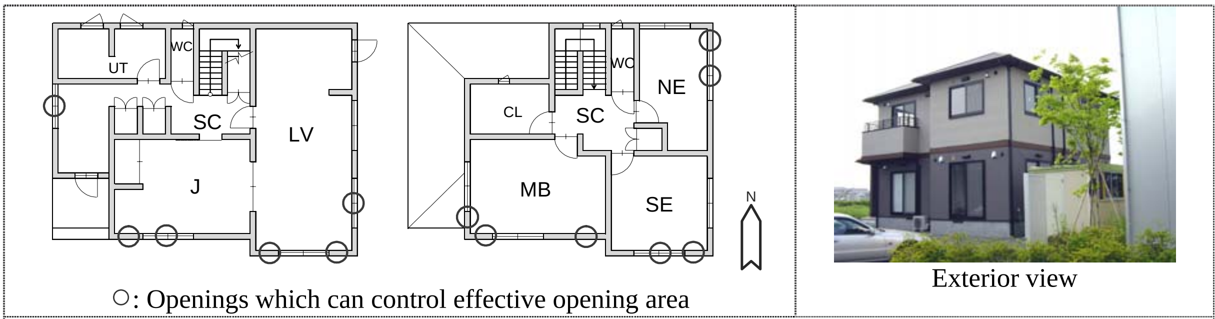
$$\mathrm{OSRF} \equiv \left(\mathrm{SRF_1} \times \mathrm{SRF_2} \times \cdots \times \mathrm{SRF_M}\right)^{1/M} \tag{4}$$

where

A_i	direct fresh air supply rate, the rate of air that is supplied directly from outside to room i [m^3/h]
B_i	rate of air exhausted directly to the outside from room i [m^3/h]
M	numbers of rooms for which the required fresh air supply rate is specified
P_i	required fresh air supply rate for room i [m^3/h]
P_i'	substantial required fresh air supply rate of room i [m^3/h]
Q_{ij}	transferred airflow rate, rate of air flowing from room j to room i [m^3/h]
S_i	effective fresh air supply rate of room i [m^3/h]
n	number of rooms
α_i	surplus fresh air supply rate contained in the air exhausted from room i

Experimental Conditions

To verify theoretical total ventilation rate and the SRF value, the experiments were implemented by using two tracer gases in a two storey test house employing a stack effect whole house ventilation system and heating equipment (Figure1). The dwelling can vary its air tightness by openings on the external wall. By using the constant injection and constant concentration methods with tracer gas, the ventilation aspects were measured and estimated. At the same time the wind direction, wind velocity, pressure differences between internal and external walls and temperatures of each zone were measured. Table1 and Table2 show the experimental conditions and Table3 shows the setting values of P_i (required fresh air supply rate) to measure the SRF value. One was based on the required fresh air supply rate of the Japanese Energy Conservation Standard of 1999 (hereinafter referred to as ECS99) and the other is based on formaldehyde concentration at a hypothetical room temperature of 20^{o}C and relative humidity of 50%RH as winter condition.



Location: TSUKUBA(warm region in Japan) Structure: Timber(ZAIRAI)
Floor area:131m^2 Air volume:315m^3 Air tightness: 1.6cm^2/m^2 at 9.8Pa

Figure1Configurations of the two storey test house

Table1 Experiment conditions

Temperature of outside	-5.4 to 23.3 ^{o}C (wintertime)
Temperature of internal zone	20^{o}C (controlled by heat pump heater)
Equivalent leakage area ($ELA_{9.8}$)	5 or 8 cm^2/m^2 at 9.8 Pa (controlled by additional openings)

$ELA_{9.8}$ is defined as Total leakage area of envelope / Floor area at 9.8Pa [cm^2/m^2]
$ELA_{9.8}$=5 equals n_{50}= 8.4, $ELA_{9.8}$=8 equals n_{50}=13.4

Table2 Experiment settings

CASE	$ELA_{9.8}$	Setting value of P_i
EX-08-E	8	ECS99
EX-08-H	8	HCHO(20^{o}C 50%RH)
EX-05-E	5	ECS99
EX-05-H	5	HCHO(20^{o}C 50%RH)

ECS99: fresh air requirement of Japanese Energy Conservation Standards of 1999
HCHO (20^{o}C 50%RH): Fresh air requirement derived from the area and Formaldehyde emission rate of plywood in prevailing condition.
The P_i values are shown in Table3.

Table3 Conditions to measure SRF values

	ECS99			HCHO(20^{o}C 50%RH)		
	P_i m^3/h	q_i ccm	σ_c ppm	P_i m^3/h	q_i ccm	σ_c ppm
J	20	20	60	9.6	12	76
LV	50	50		17.9	23	
MB	40	40		9.5	12	
SE	20	20		7.9	10	
NE	20	20		7.0	9	
SC	0	0		27.1	34	
Σ P_i	150m^3/h (0.48ACH)			79m^3/h (0.25ACH)		

P_i: Required fresh air supply rate (designing rate) q_i: Tracer gas injection rate (constant Injection)
σ_c: concessionary tracer gas concentration (for constant injection method)

RESULTS AND DISCUSSION

The condition of air leakage openings of envelope for theoretical calculation is different from the real situation (Table4). The measured values averaged 30 minutes data even though they include affection of transient condition. Beside, the effective temperature differences between indoor and outside are defined as Eqn.6 for the purpose of considering the wind pressure and temperature differences simultaneously.

Table4. The conditions of air leakage openings distribution on envelope

Real situation	Theoretical calculation
Existing on roof, external walls, floor, Window and so on	Existing on only external walls hypothetically

$$\Delta T_E \equiv \Delta T + \frac{T_r \Delta Cp_E \mathbf{V}^2}{2gh} \qquad (5)$$

where

T_r	indoor temperature [K]
g	gravity [m/s^2]
h	height of storey [m]
v	wind velocity [m/s]
ΔCp_E	effective wind pressure coefficient
ΔT	temperature difference between indoor and outside [K]
ΔT_E	effective temperature difference between indoor and outside [K]

Figure2, 3, 4, 5 show the results of the experiments and theoretical calculations. Over 0.6ACH air change rate is required to comply with the Japanese energy conservation standard of 1999 perfectly, judging from the results of theoretical calculations (Figure2). On the other hand, only 0.3ACH is required to satisfy HCHO (20^{o}C 50%RH) condition. In addition, the required air change rate is less than 0.2ACH where the absorption rate (0.1m/h) of plywood was considered. The measured total fresh air supply rates are distributed closely along the calculated rate. Its mean rates are a little lager than theoretical values which means the hypothesis of the distribution of openings on external walls contributes to less fresh air supply rate than real situation (Figure3). The calculated air change rate indicates sufficient value from the viewpoint of ventilation designing. The measured OSRF values close to the calculated rate, and mean values are a little larger than the calculated rate (Figure4 and Figure5).

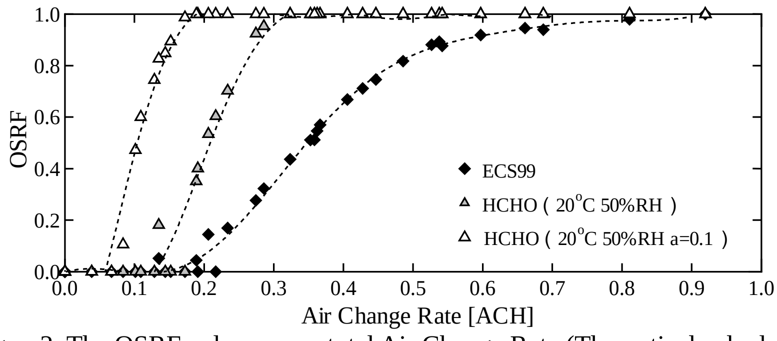


Figure2. The OSRF value versus total Air Change Rate (Theoretical calculation)

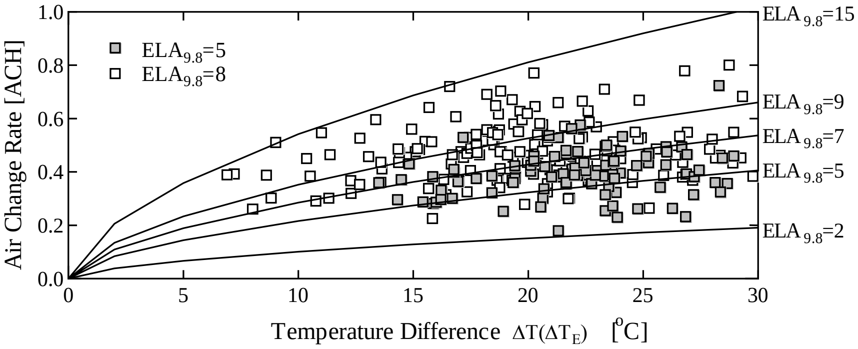


Figure3. Relations between ΔT and Air Change Rate
(Solid lines: theoretical value, Dots: measured value)

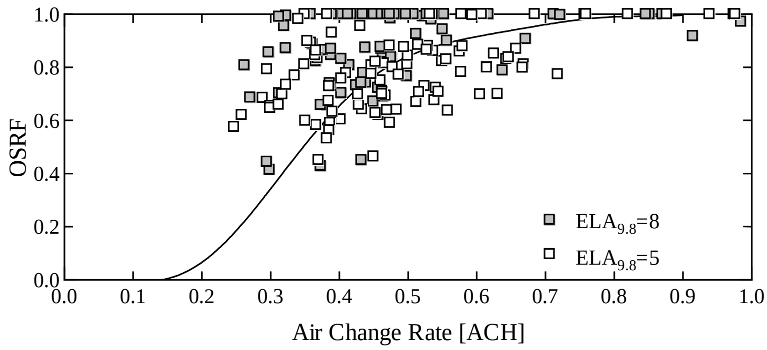


Figure4. The OSRF value for ECS99 versus Air Change Rate
(Solid line: theoretical value, Dots: measured value)

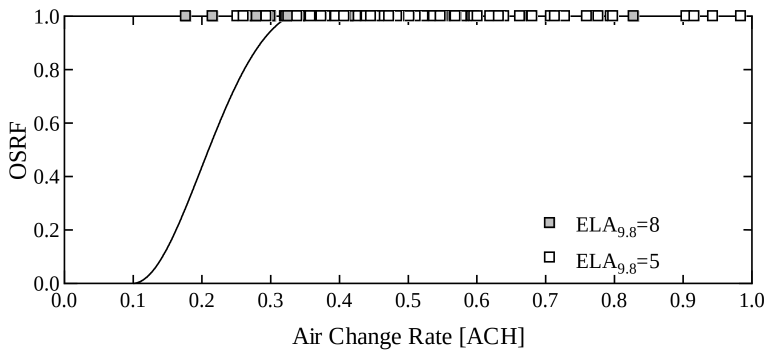


Figure5. The OSRF value for HCHO conc. versus Air Change Rate
(Solid line: theoretical value, Dots: measured value)

CONCLUSIONS

The ventilation aspects such as the whole house ventilation rate and the SRF values were measured by using two tracer gas techniques in transient conditions. The relationships among equivalent leakage area of the envelope, the total ventilation rate and the OSRF value are shown on the basis of the measurements and the theoretical calculations. This method allows the required effective leakage area of openings for sufficient fresh supply and the SRF values in two storey dwellings employing stack effect systems to be easily determined. These results can make it easy for designers to build structures by giving them a way to know the necessary effective leakage area of envelope to comply with required fresh air rate.

REFERENCES

Claude - Alain Roulet, Luk Vandaele. (1991). *Technical Note AIVC34 Air Flow Patterns within Buildings Measurement Techniques*, Air Infiltration and Ventilation Centre.

Takao Sawachi, Yoshinori Taniguchi, Shigeki Ohnishi, Haruki Ohsawa and Hironao Seto. (1998) A new experimental approach for the evaluation of domestic ventilation systems, *ASHRAE Transactions: Research*, pp.570-611.

Masaki Tajima, Takao Sawachi, Hironao Seto and Hitoshi Takeda. (2003). Presumption experiment of supply rate fulfillment sing tracer gas, *Healthy building 2003* **volume2**, pp.422 426.

VENTILATION –THE CHALLENGES AND ACHIEVEMENTS

Martin W. Liddament
Editor: International Journal of Ventilation
VEETECH Ltd, Ventilation Energy and Environmental Technology
7a Barclays Venture Centre, University of Warwick Science Park
Sir William Lyons Road, COVENTRY, UK CV4 7EZ. mliddament@ijovent.org

ABSTRACT

Major ventilation developments covering systems, measurements and design methods have taken place over the last 25 years. Our understanding about the impact of ventilation on the indoor environment and energy use has also evolved. This paper outlines these developments. Many future challenges are considered including minimum ventilation rates, energy efficient cooling, cost effective heat recovery and the development of calculation techniques.

BACKGROUND

The 1970's marked a decade of energy crisis resulting in doubt about the sustainability of existing energy supply. To provide a common framework for addressing this issue, twenty-one of the world's leading economies formed the International Energy Agency. Its task was to develop a strategy for security of future supply. To evolve this process, key areas within the supply and end-use sectors were separated into Implementing Agreements (IA's). Since approximately 40% of primary energy use was identified as being associated with buildings, this area was assigned its own IA, named Energy Conservation in Building and Community Systems (ECBCS). Aware of the considerable yet uncertain impact of air change on energy use, the ECBCS inaugurated the Air Infiltration Centre in 1979 with the stated aim of encouraging joint international research and to increase the world pool of knowledge on infiltration and ventilation. The overall objectives of the Centre were: standardisation of techniques, the validation of models, the cataloguing and transfer of information and the encouragement of research. Within this framework the AIC initiated the development of a model validation programme and an information dissemination service. The Centre initially operated from the offices of the Building Services Research and Information Association in Bracknell, England under the headship of Peter Jackman. The founding member countries were Canada, Denmark, Italy, the Netherlands, Sweden, Switzerland, the United Kingdom and the United States of America. Since then many other countries have taken part in the success of the Centre including: Belgium, the Czech Republic, Finland, France, Germany, Greece, New Zealand and Norway. In recognition of the important impact of ventilation in the energy equation, the Centre was renamed the Air Infiltration and Ventilation Centre in 1986.

The purpose of this paper is to outline the ventilation achievements and associated challenges over the proceeding 25 years.

THE EARLY CHALLENGE: VENTILATION, ENERGY AND AIR QUALITY

Energy Impact and Building Airtightness: In its early days the challenge of the Centre concerned the energy impact of infiltration. This is because evidence pointed towards poor air tightness and associated uncontrolled air-driven losses from buildings as a source of significant energy waste. Achieving air tightness was a major goal in many countries and a task of the Swedish participant of the Centre was to produce a handbook entitled "Air Infiltration Control in Housing - A Guide to International Practice" (Elmroth et al 1983). This reviewed airtight construction methods in the AIC Member Countries and provided guidelines for improving construction techniques. In 1980 Sweden became the first country to introduce a quantifiable building airtightness requirement. This initial regulation covered dwellings and specified the maximum number of air changes per hour allowable at a test pressure of 50 Pa. This 50 Pa reference pressure is now almost universally applied for air leakage evaluation on the basis that:

- It is practical to achieve by fan pressurisation;
- Under calm conditions results are not affected by ambient driving forces;
- The 50 Pa reference pressure is not so high that it artificially distorts the size of leakage openings.

The air change rate specification, however, is now steadily giving way to a specific leakage value defined as the leakage in m^3/s for each m^2 of envelope area. Also, an equivalent leakage area is applied in some countries. Assessing the energy impact of airflow (and related fan energy) from buildings remained a major task of the Centre that culminated in a publication on the energy impact of air change (Orme 1998).

Ventilation and Air Quality: Although energy was of prime concern, within the context of an IEA activity, air quality issues were addressed at an early stage. At the 2nd AIVC Conference, Wanner (1981) outlined the results of odour tests carried out in a test chamber and the use of metabolic CO_2 as an indicator of acceptable IAQ. This provided some early guidance on how much ventilation could be cut back as a means of reducing energy consumption. At the same time it was important to distinguish between both the need for ventilation and the need to inhibit uncontrolled infiltration losses. Arne Elmroth emphasised these differences in the August 1980 issue of Air Infiltration Review where he introduced the concept of “Build Tight - Ventilate Right” - an expression that is still widely used today.

Discussion on minimum ventilation rates is also very much a topic of the moment, especially when ventilation impacts on capital and operational costs. Typical minimum values are 8 - 10 L/s.p (sometimes much lower) although values as high as 25 L/s.p are being recommended (Wargocki et al. 2002). The setting of a universally agreed minimum ventilation rate is therefore an uncompleted task. A possible reason is that there is a lack of clear understanding by policy and decision makers. In many instances these see health as an issue combined with the need for cost cutting and energy reduction. From the perceived evidence, minimising cost favours lowering ventilation rates and putting less emphasis on providing peak comfort ventilation. Only by linking lower ventilation rates with tangible health consequences (e.g. increased spread of illness, poor reaction time and an increase in work-place accidents etc.) will policy makers begin to take note. Thus issues such as odour intensity and CO_2 concentration must be equated with identifiable adverse health and efficiency effects rather than with comfort alone.

Outdoor Air Quality: While ventilation plays an important role in securing good indoor air quality, it is ineffective if the supply (outdoor) air itself is not clean. It is not practicable to imagine that contaminated outdoor air can be suitably cleaned by artificial means on a population wide basis. Within Europe air quality requirements are covered by European Air Quality Framework Directive 96/62/EC (and subsequent ‘daughter directives), which is aimed at securing a cleaner environment. A further key issue includes the siting of air intakes to avoid local sources of contaminant. This aspect is now covered by various codes and standards.

THE DEVELOPMENT OF CALCULATION TECHNIQUES

Calculations form a fundamental part of any prediction or design activity. It is therefore essential that such tools function correctly and that users understand how to apply them. An important early task of the Centre was to make an assessment of available ventilation tools. Calculation techniques include:

Zonal (Network) Models: By the end of the 1970’s various multizone type network models had been developed as well as simplified single zone approaches. Such models are used to quantify the flow rate of air through openings and can thus predict the passage of air as it enters and flows through the building. They are therefore invaluable for calculating energy dissipation due to air change and may be used for basic air quality assessments. Due to lack of field data, evaluation of these models had not been possible. To overcome this, AIVC member countries pooled their data together to develop common datasets that could be used to assess model performance. Initial model results showed over sensitivity of calculated air change with wind speed and this was tracked down to inappropriate wind pressure coefficients, used to convert the impact of wind impinging on a building to wind induced pressure. Published data of the day largely related to wind loading values for isolated buildings whereas the observation buildings were all surrounded by adjacent buildings and structures. To overcome this, a search for more appropriate wind pressure data was made. This revealed the work of Bowen (1976) and Wirén (1985). Subsequent modelling results were promising. These results were published as a Technical Note (Liddament and Allen 1983). From this beginning the ECBCS supported further work on improving the applicability of network models through the development of the COMIS multizone program (Allard et al 1990). Complementary work took place and is still on-going at NIST (2004). This work includes a fully downloadable model. Recent new research is focussing on the development of more accurate numerical expressions for flow through large openings and for flow through openings at oblique angles to the wind (IJV 2004). Currently multi zone models are used by specialist organisations to evaluate ventilation design, however, their use is not widespread in the design office.

Computational Fluid Dynamics: CFD methods are used to calculate airflow, contaminant and temperature fields within a defined space. They may also be used to predict the external flow field. The ECBCS has taken a strong role in determining the applicability CFD models for building air flow studies through Annexes 20 and 26 (Moser 1992, 1998). Without these collaborative tasks it would be unlikely that the performance of CFD methods in building studies would have been as well understood. CFD has now captured the imagination of design offices throughout the world. This, certainly in part, is because much use has been made of graphical processing to produce vivid output. There is no question that they provide a valuable insight into flow behaviour, representing one of the greatest design advances over the last 25 years. However, there are still questions about their validity under all circumstances. Perhaps the greatest difficulty is the representation of turbulence since computational time and size limitations restricts the general ability to represent turbulence directly. Instead, various turbulence models need to be applied. Other issues concern reliable representation of boundary conditions - especially of flow from diffusers, and the simulation of thermal transfer from surfaces.

Combined Thermal and Ventilation Modelling: Modelling the thermal behaviour of buildings is well established but, even today, ventilation and infiltration may be incorporated in these models as a single value or simple schedule. Because this component can account for up to 50% of the energy loss, it rather devalues the level of detail used in complex thermal models to predict the remaining components of heat loss. Similarly, ventilation models make simplified assumptions about the temperature conditions. There is therefore a strong attraction to combine the two approaches. This is an area that the AIVC investigated and facilities to provide a coupled solution are beginning to become available (e.g. ESRU 1997).

THE DEVELOPMENT OF MEASUREMENT TECHNIQUES

Tracer Gas Techniques: Measurement techniques formed the topic of the Centre's first conference held in 1980. This early assessment was of importance because it provided the framework for acquiring data for the Centre's evaluation of calculation techniques. Many of the techniques presented at this conference are still in use today. For ambient monitoring, SF_6 tracer gas, multi tracer analysis, electron capture detection and computer controlled automation had been developed and validated. Subsequent to this conference developments have included long term averaging (using passive emitter and sample tubes) and monitoring of metabolic carbon dioxide. In the 1980's, measurements in occupied spaces using nitrous oxide as a tracer gas was not uncommon. Also SF_6 was sometimes used in the relatively high ppm range required for infrared detection equipment. While not known to be toxic at the concentrations used, SF_6 is a significant greenhouse gas while nitrous oxide is an anaesthetic. More recently, regardless of toxicity issues, the use of alien gases at any concentration, in occupied spaces, is becoming less acceptable to the public. Thus frequent use is now made of metabolic CO_2 concentration monitoring. In fact CO_2 sensors are becoming so reliable and inexpensive that they are beginning to be installed on an almost routine basis in some buildings as part of a demand controlled ventilation approach.

Pressurisation Techniques: Pressurisation techniques, in the form of blower doors as well as high capacity fans for large buildings, were also introduced at the first conference. Since then pressurisation testing has become common. For example, in the UK, Building Regulations requires that all non-residential buildings of $1000m^2$ floor area and above be pressure tested for air leakage.

Wind Tunnel Measurements: The use of wind tunnel models has evolved to keep pace with theoretical and design demands. Not only are wind tunnels used for wind pressure assessment but also they are now used to measure flow through simple building structures and to observe the characteristics of flow through openings of varying size. This work has improved our understanding and representation of flow through openings. Wind tunnels are also used to determine the pattern of pollutant concentration arising from traffic and other pollutant sources.

Flume Models: In addition to wind tunnels, salt bath or flume models have become important tools to evaluate the performance of complex naturally ventilated structures.

DEVELOPMENTS IN VENTILATION STRATEGIES

In the 1970's, ventilation was essentially divided between natural and full mechanical systems. Often natural ventilation meant little more than relying on air infiltration combined with openable windows and, perhaps, vents. Scandinavian and some other countries, however, had quite a sophisticated stack driven approach to natural ventilation.

Mechanical systems were common in larger buildings, especially in severe climatic regions characterised by low winter temperatures and high summertime temperature and humidity. Because the primary purpose of mechanical ventilation was thermal conditioning, relatively large volumes of well mixed air, (compared to occupancy needs) were required. To avoid huge losses of conditioning energy, therefore, a significant proportion of air was recirculated. Since this recirculation technology was well developed it was rapidly imported to large buildings in many other climate zones and is still widely used today. However the high energy, maintenance and capital needs of these systems, combined with inherent air quality concerns about air recirculation has brought into question its suitability for milder climates where high outdoor temperature and humidity is less of a problem. There has hence been a large transformation in the implementation of ventilation systems.

Ventilation Effectiveness: A groundbreaking paper was presented by Mats Sandberg (1982) at the Centre's third conference. This work provided a mathematical representation of the mixing of ventilation air and the distribution of pollutant concentration in a space. It also enumerated the age of air at individual locations and the average age of air within a space. Once these parameters had been defined, by means of equations, it then became possible to develop and understand the performance of alternative ventilation strategies.

Displacement Ventilation: An outcome was the development of displacement ventilation systems, aimed at minimising mixing and, instead, directing fresh supply air directly to occupants. As a consequence, for a given ventilation rate, it was possible for occupants to receive less polluted air than was achievable by conventional mixing ventilation. Developmental research was aimed at meeting the heating and cooling needs in buildings serviced by displacement ventilation. As a consequence conventional ventilation driven air conditioning systems gave way to chilled beams and ceilings.

Natural Ventilation, Mixed Mode Ventilation and Passive Cooling: Throughout the 1980's there was, perhaps, a movement away from natural ventilation in favour of a totally mechanically controlled environment. Where climates were less severe, occupant reaction tended to be negative. Also there were concerns over poor comfort and sick building syndrome. As a consequence, purpose designed natural ventilation systems began a renaissance. Key studies included the European NatVent Study (Kukadia et al 1998) while, within the ECBCS, Annex 35 "HYBVENT" was initiated on hybrid ventilation systems (Heiselberg 2002). These projects also explored the role of thermal mass and night cooling to provide a measure of daytime cooling. These developments have had a fundamental impact on questioning the need for full mechanical ventilation. In many climates, by meeting the majority of cooling needs by passive means, central mechanical air conditioning can give way to localised and/or intermittent cooling.

Heat Recovery: A promise of the 1980's was exhaust air heat recovery. Demonstrated systems showed recovery rates in excess of 90% while latent heat recovery was also possible. In severe winter climate countries, such as parts of Scandinavia and Canada, there is growing popularity in heat recovery. In Finland, for example, a measure of heat recovery has become compulsory. Elsewhere, the promised benefit has yet to be fulfilled. Capital, running and maintenance costs are the primary issues that still need to be resolved.

Demand Controlled Ventilation (DCV): The potential of DCV formed the work of ECBCS Annex 18 (Mansson 1997). DCV has subsequently had a major impact on air quality and energy performance. CO_2, humidity, PIR, temperature and other detectors, when used appropriately, can all assist in securing a healthy and comfortable indoor environment. The controls technology necessary to secure DCV hardly existed in 1979 but are now widely available.

CONCLUSIONS

The AIVC has presided over a period in which air change accounts for approximately half of the energy dissipation from buildings in industrialised countries and as much as 20% of total primary energy consumption. Above all ventilation is the final arbiter of indoor air quality.

The original rationale of the Centre was concerned with energy efficiency, especially in relation to air infiltration. Over the intervening years airtightness standards and construction practice has evolved to ensure reduced uncontrolled loss of air. Equally ventilation systems and control methods have developed to the point that energy efficient ventilation can be provided to meet the varying loads imposed by occupants. Also monitoring equipment has become relatively inexpensive, hence routine monitoring of CO_2, foe example, to ensure maintenance of minimum ventilation requirements, is becoming a reality.

Many challenges still remain however; these include:

Policy and Education:

- There is a need to educate the policy and decision maker, especially in relation to how much ventilation is required. This should entail definitive research into the impact of ventilation on occupant health and efficiency rather than purely on odour and comfort;
- Ventilation design in practice can still be poor. There are many examples of poor ventilation design and resultant lack of climate achievement. The necessary knowledge exists within the domain of the specialists but is lacking in various areas of general practice.

Technical Challenges:

- Multizone modelling: Network models have not captured the same enthusiasm by the design office as CFD yet they are very definitely used in support of design work by specialists. Commercial equivalents need to be developed that offer comparable interfaces and output graphics as the current generation of CFD models;
- Model Boundary Conditions: For CFD and network models alike, there are still many uncertainties about boundary conditions. These include turbulence parameters, wind pressure values, and the characteristics of flow through openings;

- Ventilation Strategies: Ventilation systems should be designed to utilise the outdoor environment to its full potential;
- Heat Recovery: Despite the promise, the market has not yet judged these systems to provide a good return, particularly in less severe climates. Effort is needed to reduce the operational cost.

REFERENCES

Allard, F., Dorer, V.B and Feustel H.E. (1990) Fundamentals of the multizone air flow model – COMIS. AIVC Technical Note 29.

Bowen, A.J. (1976). A wind tunnel investigation using simple building models to obtain mean surface and wind pressure coefficients for air infiltration estimates. LTR –LA-209 NRC, Canada.

Elmroth, A. and Levin, P. (1983) Air infiltration control in housing: a guide to international practice". Report D2:1983 Swedish Council for Building Research.

ESP. (1997). The ESP-r system for building energy simulation. User Guide 9, ESRU Strathclyde University.

Heiselberg, P. (2002). Principles of Hybrid Ventilation. IEA-ECBCS Annex 34 Report Aalborg University Hybrid Ventilation Centre, ISSN 1395-7953 R0207.

IJV Special Edition. (2004). First International Workshop on Natural Ventilation. Proceedings of Workshop held at Tokyo Polytechnic University, Japan, 31st October 2003 IJV **2:4.**

Liddament, M. and Allen, C. (1983). The validation and comparison of mathematical models of air infiltration. AIVC Technical Note 11.

Kukadia, V. and Perera, M.D.A.E.S. (1998) NatVent: Overcoming technical barriers to low-energy natural ventilation in office-type buildings - an overview. Proc. CIBSE National Conference 18-20 October 1998, pp 165-173.

Mansson, L-G. Svennberg, S.A. (1997). Technical synthesis report: a summary of IEA ECBCS Annex 18 - Demand controlled ventilating systems. TSR No. 02 IEA ECBCS.

Moser, A. (1992). Numerical simulation of room thermal convection, review of IEA Annex-20 results. Proc. International Symposium on Room Air Convection and Ventilation Effectiveness – ISRACVE.

Moser, A. (1998). Energy efficient ventilation of large enclosures. ECBCS Technical Synthesis Report. IEA ECBCS Annex 26.

NIST. (2004). CONTAM Multizone Model. http://www.bfrl.nist.gov/IAQanalysis/default.htm.

Orme, M. (1998). Energy impact of ventilation: estimates for the service and residential sectors. Technical Note 49, Air Infiltration and Ventilation Centre.

Sandberg, M. (1982) Definition of ventilation efficiency and the efficiency of mechanical ventilation systems. Proc. AIVC Third Conference London 20-23 September,1982.

Wanner, H.U. (1981). Indoor air quality and minimum ventilation, Proc. 2nd AIC Conference Stockholm 21-23 September 1981.

Wirén B.G. (1985). Effects of surrounding Buildings on Wind Pressure Distributions and Ventilation Losses for Single Family Houses. The Swedish Institute for Building Research Bulletin M85.

Wargocki, P., Sundell, J., Bischof, W., Brundrett, G., Fanger, P., Gyntelberg, F., Hanssen, S., Harrison, P., Pickering, A., Seppänen, O. and Wouters, P. (2002). Ventilation and health in nonindustrial indoor environments. Report from a European Multidisciplinary Scientific Consensus Meeting, *Indoor Air*, 12, pp113-128.

The Air Infiltration and Ventilation Centre was inaugurated through the International Energy Agency and is funded by the following seven countries:

Belgium, Czech Republic, France, Greece, The Netherlands, Norway and United States of America.

The Centre provides technical support in air infiltration and ventilation research and application. The aim is to provide an understanding of the complex behaviour of the air flow in buildings and to advance the effective application of associated energy saving measures in both the design of new buildings and the improvement of the existing building stock.

Air Infiltration and Ventilation Centre
Operating Agent and Management
INIVE EEIG
Boulevard Poincaré 79
B -1060 Brussels - Belgium

www.aivc.org

Tel: +32 2 655 77 11
Fax: +32 2 653 07 29
inive@bbri.be
www.inive.org