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P. HARTMANN, I. PFIFFNER AND S. BARGETZI

RESULTS OF AIR-CHANGE-RATE MEASUREMENTS IN SWISS RESIDENTIAL BUILDINGS

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ROBERT SERRÉ

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Authors/Auteurs: P. Hartmann, I. Pfiffner and S. Bargetzi

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Canada Institute for Scientific and Technical Information

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RESULTS OF AIR-CHANGE-RATE MEASUREMENTS IN SWISS RESIDENTIAL BUILDINGS

1. INTRODUCTION

Studies carried out at the Swiss Federal Laboratories for Materials Testing and Research (EMPA)[1] and elsewhere[6,7,8] have shown the great significance of heat losses due to natural ventilation in buildings. Since there were practically no data available on air change in buildings, the Division of Building Physics of EMPA undertook, in 1975, a research project aimed at:

- gathering measurement data on air change from a selection of representative residential buildings, so as to provide improved methods of calculating ventilation losses as a function of climate, design and user data.

Results obtained so far have been published in two reports[3,4] and one journal article[2].

All measurement results refer to non-air-conditioned residential homes in Switzerland, a few of which had additional exhaust systems in interior toilet facilities or kitchens.

The reports of EMPA do not discuss the preferability of natural ventilation as opposed to forced-air systems in terms of the Central European climate. On the other hand, the results could be used as a solid basis for comparing the energy requirements and cost effectiveness of natural and forced-air systems.

PREFACE

There is very little information available on air change rates in residential buildings that have some windows open to provide ventilation: the published data are usually for buildings that have the windows and doors closed. This paper reports the results of some studies that were conducted in Switzerland on small apartment buildings. The air change rates were measured using a tracer gas technique both with the windows closed and with some partially open. The air change rate increased by a factor of 4 when the windows on one facade were opened only a few centimeters. This shows how difficult it is to achieve adequate ventilation without increasing excessive heat loss when windows are used as the ventilators.

The Division of Building Research is grateful to Mr. Robert Serré for translating this paper and to Dr. D.G. Stephenson of this Division who checked the translation.

Ottawa
April 1980

C.B. Crawford
Director

2. EXPERIMENTAL PROCEDURE FOR DETERMINING THE AIR CHANGE IN BUILDINGS HAVING CLOSED OR PARTLY OPEN WINDOWS AND DOORS

A comprehensive overview of measuring techniques was published in 1967[16]. Since then, however, there have been further developments in measuring methods. Recent measurements have also been carried out and published at a number of research institutes. There are some shortcomings, however:

- there are compatibility gaps between the techniques and results of the institutes involved;
- measurements for buildings having closed envelopes are often described in every detail, but in many cases the ventilation heat losses caused by occupants are predominant; very little is known about their causes and effects;
- ventilation heat loss computation rules based on theory and verified experimentally as a function of all essential parameters are to be found only in models.

A survey of the actual research work which forms the essential portion of the literature cited here indicates that the tracer technique (decay method) has become widely accepted for buildings with and without an occupant parameter[2,3,16]. This technique provides data for extreme wind condition, which are important in the layout of heating installation, as well as data for boundary condition in terms of residential hygiene (e.g., under minimum wind and heavy use), and forms the basis for computing transient heat losses needed for dynamic energy requirement computer programs. Very useful results are also provided by measuring the air permeability of building components or of the entire building envelope[2], and by model investigation in wind tunnels. Unfortunately, tracer gas measurements can only be carried out in special cases, e.g., for buildings with warm-air heating[10] or in ventilated and air-conditioned buildings. New approaches are being made by various authors who investigated user-oriented ventilation patterns. The problems involved are very complex and would best be studied by a team of engineers, architects, behavioural scientists and physiologists. Brundrett[15)] and De Gids[11)] have published reports of prolonged observation of buildings including climatic data. We know of few other English and American studies on the subject. Pilot EMPA studies have shown that meaningful user-parameter investigation must meet the following conditions:

- observations should be as unobtrusive as possible (e.g., automatic camera);

- extensive indoor and outdoor climatic measurement should be carried out simultaneously;

- users should subsequently answer detailed questionnaires;

- additional air-change measurements should be made in suitable areas of the building under study.

3. OVERVIEW OF THE TEST BUILDINGS AND OF THE EXPERIMENTS CARRIED OUT

A variety of test buildings were needed to provide a comprehensive survey of the situation in existing buildings. Except for a few buildings serving other purposes, we tested the residential buildings described in Table I. Test building properties differed in terms of age (from 2 to about 70 years), occupancy (single-family or multi-family homes), design, construction and wind exposure.

The measurement techniques used by EMPA are fully described in references 2 and 3. Air-change measurements using tracer gas (N_2O) were carried out in each case. Furthermore, air permeability was often determined for individual building components, though not as yet, for the entire building envelope. Certain user parameters were also studied for buildings A-C and F.

TABLE I

Outline of test building; air change measurement results in residential units

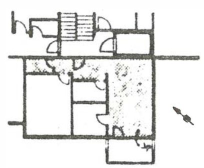
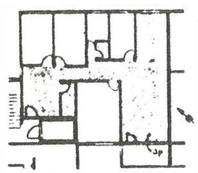
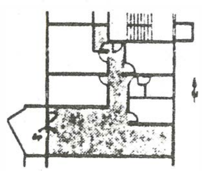
Test building									Measurement results						
No.	Type of building	Age in years	Building exposure	Structure (building envelope)	No. of floors/ test point (floor)	Floor plan, living area shaded	No. of rooms in test unit/ furnished	Comments	Outside walls of test unit with windows or doors	Area of test unit (m^2)/ vol. (m^3)	Wind Velocity (m/s)	Wind Direction	ΔT (T_1-T_a) [K]	Δp (p_1-p_a) [Pa]	n_L [h^{-1}]
A + B	MFH	4	partially exposed	- wood window with double glazing - double-shell concrete member walls - flat roof	8/ 7 8/ 8		2/ no 2/ yes	Floor plan & elevation staggered	SW wall	28.5/ 71.5	1.2 3.5 5.5	E/SE NE N/NE	17.0 20.5 14.5	0 1.5 - 0.5	0.09 0.17 0.2
C	MFH	4	partially exposed	analogous to A + B	9/ 7		5½/ no	Floor plan & elevation staggered	NE wall + SE wall + NW wall	46.6/ 117	1.3 2.0	NE/SE NW	19.5 11.5	1.0 ± 0.2	0.06 0.07
D	MFH	3	fully exposed	analogous to A + B	8/ 5		5/ no	Elevation staggered	E wall + W wall	47.1/ 118	2.2 8.5 8.5	N/NE SW SW	12.5 17.0 14.0	- 2.0 -28.0 -32.0	0.33 0.97 1.12

Table I (cont'd)

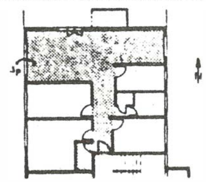
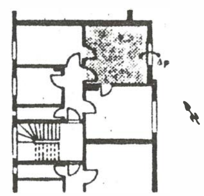
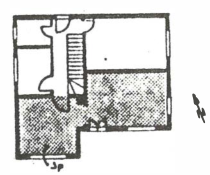
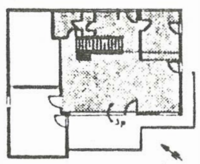
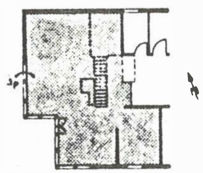
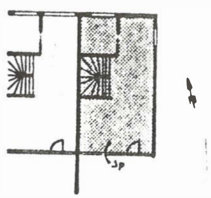
Test building										Measurement results					
No.	Type of build-ing	Age in years	Building exposure	Structure (building envelope)	No. of floors/ test point (floor)	Floor plan, living area shaded	No. of rooms in test unit/ furnished	Comments	Outside walls of test unit with windows or doors	Area of test unit (m^2)/ vol. (m^3)	Wind Velocity (m/s)	Wind Direction	ΔT (T_1-T_a) [K]	Δp (p_1-p_a) [Pa]	n_L [h^{-1}]
E	MFH	3	fully exposed	analogous A + B	7/ 7		5/ no	Elevation staggered	N wall + E wall + W wall	47.1/ 118	2.0 2.5 4.5	SW SW NE/NW	3.0 1.5 17.5	- 4.0 - 4.0 - 3.6	0.63 0.68 0.67
F	MFH	68	protected	- wood win-dow with single glazing (+ double window) - double shell masonry - gable roof with tile covering	5/ 3		3/ no		SE wall	17.7/ 46	1.0 0.7 1.5	W/SW S/SW W/SW	16.5 15.5 18.0	- 1.1 - 1.5 - 1.7	0.42 0.49 0.72
G	SFH		partially exposed	- wood win-dow with double glazing - double shell masonry - gable roof with tile covering	2/ 1		5/ yes		SE wall + SW wall	33.3/ 81	2.2 0.6	NE/SE NE	3.5 14.0	0 - 0.5	0.23 0.26

Table I (cont'd)

Test building									Measurement results						
No.	Type of build-ing	Age in years	Building exposure	Structure (building envelope)	No. of floors/ test point (floor)	Floor plan, living area shaded	No. of rooms in test unit/ furnished	Comments	Outside walls of test unit with windows or doors	Area of test unit (m^2)/ vol. (m^3)	Wind Velocity (m/s)	Wind Direction	ΔT (T_1-T_a) [K]	Δp (p_1-p_a) [pa]	n_L [h^{-1}]
H	SFH	11	fully exposed	- wood win-dow with double or insulating glazing - double shell masonry - gable roof with Eternit covering	3/ (with basement)		8/ yes	Open stairwell between basement and residential floor	NE wall + SE wall + SW wall	67/ 335	1.1 1.2 3.4	SW/W SW W	4.0 9.0 12.5	- 1.5 - 5.0 -12.0	0.13 0.55 0.86
I	SFH	2	partially exposed	- wood win-dow with insulating glazing - wood pre-fab con-struction - broach roof with Eternit covering	3/ (with basement)		7/ yes	Open stairwell between basement and residential floor	NW wall + SW wall	74/ 450	2.4 2.8 4.0	W/NW W/NW NW	7.0 8.5 8.0	- 2.5 - 3.6 - 9.0	0.42 0.52 0.6
K	SFH (row house)	2	protected	- wood win-dow with insulating glazing - one-leaf masonry (external insulation) - gable roof with Eternit covering	4/ (with basement)		4/ yes	Open stairwell between basement and residential floor	NW wall + SW wall	38/ 139	1.2 0.8	S/SW SW	13.0 17.0	- 0.5 - 0.6	0.35 0.44

4. RESULTS AND DISCUSSION

4.1. Results for buildings with closed windows and doors

Table I contains the results of measurement of natural air change in the living areas of all test buildings (some with adjoining areas, e.g., corridor, attic) for various wind conditions and differential temperatures. The values of air change rates are relatively low throughout, but are confirmed and supplemented by similar results from other authors[13,17]. Certain boundary conditions such as light wind, wind parallel to the main axis of the building, relatively small gap length or "tight" construction led to the extremely low air change rates. Even the values for less tight construction, such as older buildings, do not exceed an air change rate of about 0.6 h^{-1} for closed windows at the prevailing wind velocities for the Central European winter climate. This indicates that natural ventilation does not meet the requirements for residential hygiene in spaces of high occupancy when the building envelope is relatively airtight.

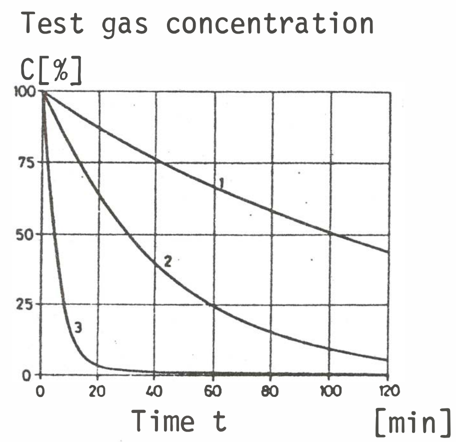
We ran a series of measurements to determine what amount of air leaving a space was replaced directly or indirectly by air from outside, and from adjoining spaces. In these investigations, doors were closed, usually with a gap of several millimeters at the doorstep. By comparing the air change rates of each space measurement with the "total space measurement" of the living unit, we were able to make an evaluation with relative ease. Depending on the circumstances, the air in each space was replaced from 10 to 50% by the air from adjoining spaces. This confirms the principle that air change measurements, from an energy point of view, should always encompass the entire residential unit (so-called total space measurement).

In terms of possible heat load variations within a building, it is important to know to what extent natural ventilation losses may vary at extreme weather locations. We therefore determined the ratio of air change rates in conditions of heavy wind blowing directly against the windows, as well as at locations of light wind. This ratio, as a characteristic for "wind sensitivity" of a residential unit, fluctuated in our observations between roughly 2-5 for locations sheltered from the wind and especially airtight structures, and 5-8 for structures in exposed location or of less airtight construction and designed according to the open concept.

4.2. Studies of the effect of occupants on air change

It takes only a few results to show the complexity of determining the effect of occupants on ventilation losses.

Figure 1



The effect of window aperture on the air change in a residential unit (test building D in Table I) under uniform wind conditions (north wind v_{mean} about 3-4 m/s) and for an indoor/outdoor temperature difference of 15 K.

1) Windows and doors closed $n_L = 0.4\ h^{-1}$

2) W-side windows open 10 cm $n_L = 1.5\ h^{-1}$

3) One sash open 45^{o} on both W and E sides $n_L = 11\ h^{-1}$

Measurements for fixed position of windows and doors provide a first look at the scope of possible influences exerted by occupants. Out of a series of investigations, such as the effect of various window positions on air change in each space, or the effect of "ventilating" adjoining spaces on air change, or the variation of air change in toilets and kitchens as a function of the operation of exhaust fans, or again the measurement of air change in residential units when door and window opening cycles are repeated over prolonged periods, we will now consider the results from the first group. In a large residential unit (test unit D), under the most uniform temperature and wind conditions possible, the air change rate was determined as a function of various window positions (see Figure 1). Even a small opening in the window (curve 2) increased the air change rate by one order of magnitude in terms of the closed window, which underlines the poor adjustability of ordinary swinging-casement windows. The so-called draft system of ventilation increased the air change rate by thirty times. Such results show that short, intensive ventilation produces a very rapid and complete air change.

Under the direction of EMPA, P. Egolf (Lucerne Engineering School) observed occupant behaviour in test units A/B/C for 24 hours during two selected days. For these periods, the effective ventilation heat losses were also calculated, and compared with the heat transmission losses. The process involved was based on the principles outlined in section 2, and included the following steps:

- measuring the air change rate in a reference dwelling under various climatic conditions (windows closed and opened to differing degrees);

- developing a computation technique for ventilation losses as a function of all possible parameters;

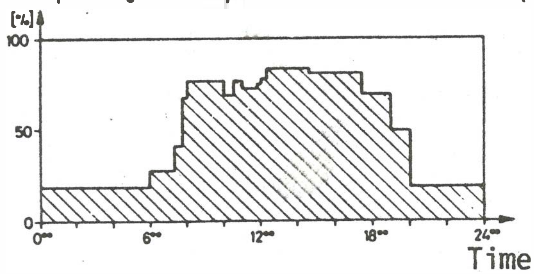
- observing the occupant during selected periods (slides taken at intervals of 15 or 30 minutes), while simultaneously measuring climatic conditions and energy consumption;

- evaluating the photos statistically (see Figure 2);

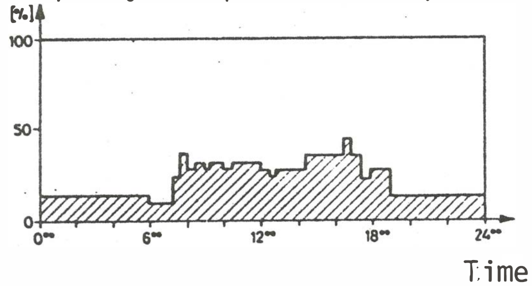
- calculating the ventilation and transmission heat losses during the course of a day, and comparing them with the measured energy consumption (see Figure 3).

Figure 2

Frequency of open roller blinds (bedroom)



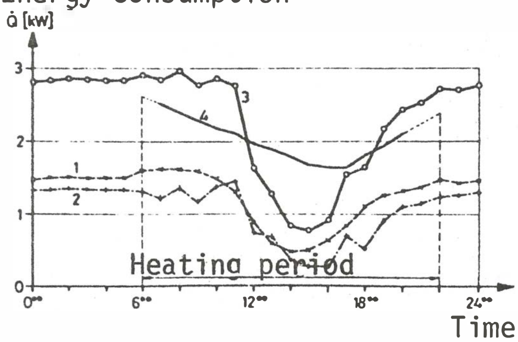
Frequency of open windows (bedroom)



Statistical evaluation of about 30 bedroom window and roller blind positions on a sunny day in February (night temperature 5°C, peak afternoon temperature 17°C).

Figure 3

Energy consumption



Comparison of ventilation and transmission losses in selected 4-room dwellings in buildings (A, B, C) on a sunny day in February (same as in Figure 2, Q̇ for each dwelling).

1) Transmission losses (steady state calculation)

2) Ventilation losses (steady state calculation at half-hour intervals)

3) Total losses

4) Measured heating energy needs (may be compared with curve 3)

The results illustrate the frequent wrong use of ventilation. In fact, about 30% of all bedroom windows were open constantly between 8:00 a.m. and 6:00 p.m. It is worth noting that the effective ventilation losses were of the same order of magnitude as the transmission losses. The fact that the measured energy consumption was substantially smaller than the calculated consumption is due to heat gains from solar and electrical energies.

5. CONCLUSIONS AND PROSPECTS

Current international research work is aimed primarily at dealing with actual situations in buildings, in the hope of introducing improved calculation technique for the design of heating installations, dynamic calculations for heating and cooling loads, as well as comparisons of effective air change rates while maintaining optimal comfort. The resulting data should make it possible to influence building construction and occupant habits in such a way that fresh air of a suitable quality is available in the right place and in the proper amounts. This fresh air is to be provided with the least possible energy consumption, with due consideration for the life cycle cost. EMPA is carrying out long-term investigation of the effect of climate on a simple building and of the behaviour of occupants in multi-family dwellings. Internationally, the following work is under way: member countries of the International Energy Agency have undertaken a large-scale project (establishment of a research-documentation centre, seminar on measuring techniques, research projects); within the framework of the CIB, there is an intensive exchange of research results.

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