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Introduction of Air Infiltration and Ventilation in a Simple Modelling for Energy Consumption Estimation in Air Conditionned Buildings

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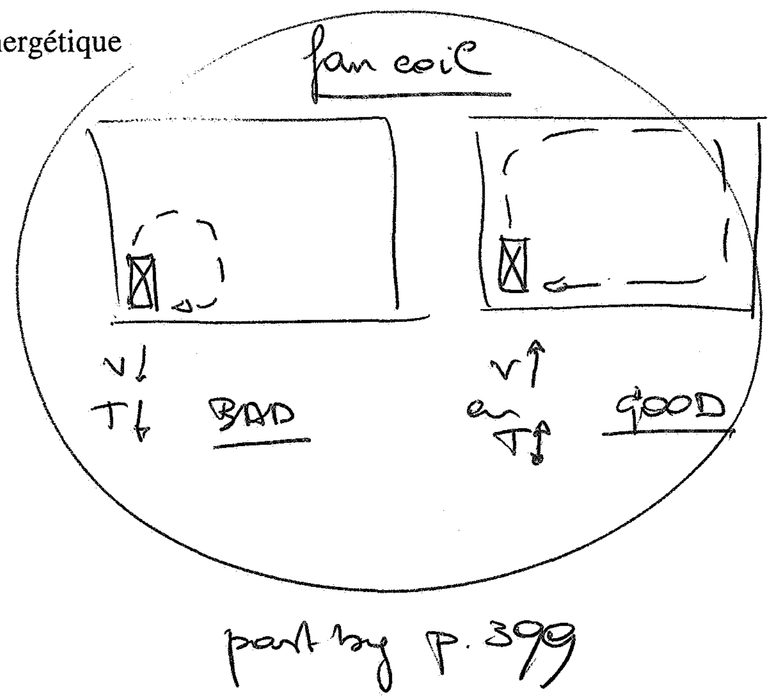

INTRODUCTION OF AIR INFILTRATION AND VENTILATION IN A SIMPLE MODELLING FOR ENERGY CONSUMPTION ESTIMATION IN AIR CONDITIONNED BUILDINGS

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Synopsis- This study reports on the introduction of air infiltration and mechanical ventilation in a model for energy consumption estimation. The model applies to air conditionned non residential building and is developped to need few inputs. Existing air infiltration models are compared and three equivalent leakage area (ELA) databases are tested on the same case study. Calculations of air input throught opened-doors are made to compare flows due to air infiltration and due to natural ventilation. Simulations are made considering mean air infiltration value and hourly values. It appears that impact of air infiltration variation is no negligible in winter (+11% compared with mean air infiltration value).

Then concerning mechanical ventilation, this study reports on taking into consideration « fresh air flow » in the model. The first solution is to introduce mechanical outdoor air flow rate in building loads. The second solution is to calculate building loads without outdoor air flow rate and to introduce it in mixing box calculation. Both solutions are not equivalent concerning energy consumption (difference +16% for particular system used).

Keywords- air infiltration, mechanical ventilation, energy consumption, modelling

LIST OF SYMBOLS

A	area	m^2	n	flow exponent	
B	permeability coefficient	$\frac{m^3}{s.m^2.Pa^n}$	N_p	number of openings per hour	h^{-1}
C	flow coefficient	$\frac{m^3}{s.Pa^n}$	P	pressure	Pa
c_D	head loss coefficient		Q	air flow	m^3/s
c_p	wind pressure coefficient		$\dot{Q}$	energy rate	W
e	exposure coefficient to wind and stack effect	Pa^{-n}	T	temperature	K
ELA	equivalent leakage area	m^2	W	wind speed	m/s
K_i	empirical coefficient		z_0	opening door mean time	s
n	air change rate due to infiltration	vol/h	ρ	density	kg/m^3

subscripts: a : ambient o : outside area : unit per m^2

1. INTRODUCTION

Fresh air introduced in building is partly controlled (mechanical and natural ventilation) and partly uncontrolled (air infiltration). Natural ventilation comes through opened windows, doors and other intentional apertures. Mechanical ventilation uses fan and intake and/or exhaust vents specifically designed and installed for ventilation. Infiltration is uncontrolled air flow through cracks, interstices, etc [ASHRAE, 1993].

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Knowing and mastering air fresh flows rates are important for two main reasons:

- fresh air is used to improve indoor air quality and to dilute indoor air contaminants,
- energy used to handle fresh air is a significant load.

The magnitude of these air flow rates should be known at maximum load to properly size the plant. Minimum air exchange rates should be known to assure proper control of indoor contaminant levels. How to simply evaluate energy consumption due to air exchanges ? A simple model for estimating air inflitration in a building has been introduced into a model for estimating energy consumption of air conditionned buildings. Main aspect of this model is to need few inputs in such a way that it could be used very soon in the design process, when materials and building caracteristics are not fixed in details.

Existing models of air infiltration are compared and tested on the same simplified case study, a simple model is chosen. Then, two mechanical ventilation model are compared, first with mechanical air flow rate introduced in building load, second in system calculation level.

2. EXISTING MODELS IN AIR INFILTRATION

Infiltration is driven by wind, temperature difference creating stack effect and/or appliance-induced pressures across the building. Several methods detailed or simplified models are found in the literature.

2.1 AICVF's Guideline

AICVF[1] Guideline for heating [AICVF, 1989] considers contribution of wind and stack effect for winter. The pressure differences due to driving forces are considered in combination by adding them together and determining the airflow rate through each opening due to this total pressure difference. The flow equation is simplified choosing a sizing approach in: $Q = A.B.0,63.\Delta P^{2/3}$ considering $e = 0,63.\Delta P^{2/3}$, exposure coefficient to wind and stack effect. On the one hand, those formulas give data calculated with e_m (maximal value of exposure coefficient in winter) considering different types of buildings. On the other, the guideline gives permeability coefficient values established from CSTB[2] in situ experiments for different types of windows, doors, walls, etc.

2.2 AIVC Methods

AIVC guideline [AIVC, 1996] and technical note [AIVC, 1994] notice that it is very difficult to identify and quantify all airflows, driving forces , size and location of each opening. Simplifications lead to different models.

2.2.1 empirical model:

Few models establish correlation to determine air change rate due to infiltration. The simplest correlation is a linear formula [Etheridge and Sandberg, 1996]: $n = K_1 + K_2|T_O - T_A| + K_3 W$

Type 19 of TRNSYS 14.2 gives values of coefficients depending on quality of building envelope construction. [TRNSYS, 1996]

2.2.2 estimation from building air-tightness

From sets of measurements, Kronvall suggests an approximate estimate of air infiltration which could be inferred from building air-tightness data. [AIVC, 1996]. This method concerns energy analysis and air infiltration impact estimation. This method is based on building air-

[1] Association des Ingénieurs Chauffage Ventilation Froid: Refrigerating Ventilation Heating Engineers Ass.
[2] Centre Scientifique et Technique du Bâtiment: Technical and Scientific Center for Building

tightness mesure determined for a reference pressure of 50 Pa. This value is divided by an empirical coefficient representing forces influence. Simplified tables [AIVC, 1994] propose for six characteristical types of construction a basical value of ACH(50Pa).

2.2.3 simplified theorical model

This model incorporates the effects of air-tighness and natural and mechanical driving forces. The model has been developed at the Lawrence and Berkeley Laboratory [Sherman, 1980]. Equation are based on Equivalent Leakeage Area under 4 Pa (ELA_4). Flows due to the wind and stack effect are calculated independently. Equivalent leakeage area under 4 Pa can be extracted from tables building components as proposed in [ASHRAE, 1993].

2.2.4 zonal method

AIVC Guideline suggest a method in 5 steps [AIVC, 1996]:

1- calculation of flow throught the opening using detailed tables [AIVC, 1994] for several components;

2- development of a flow network identifying each source of air in building envelope (monozone model) or between each zone. Infiltration and natural ventilation are separated before combining the two networks.

3- pressure forces evaluation. [AIVC, 1994] suggests values for an evaluation of C_p (wind pressure coefficient depending on the building shape and wind direction)

4- mechanical ventilation determination (fixed at a constant rate)

5- air mass flow balance (volumic balance). Equation of the balance between inflow and outflow of air is solved.

2.3 Choice for the method of energy consumption

Main models evaluation criterias are summed up in the following chart:

	AICVF	empirical model	air-tightness estimation	theorical model	zonal method
splitting airflows into zones	yes				yes
no pressure calculations		yes	yes		
few parameters		yes	yes	yes	
parameterization		existing tables	easy		
introduction in the method	medium	easy	medium	medium	hard
precision	sizing	medium	low	good	very good

The field of energy consumption model development is non-residential buildings, in which air exchange depends more on mechanical ventilation than it does on envelope performance. So a medium precision to evaluate air infiltration is enough. Considering our aim, it is excluded to incorporate a detailed calculation of airflows. Consequently empirical model, easier to introduce in the existing method, is chosen.

The method must split airflows into different zones for a multizone building, and the chosen empirical model can not do that. Three configurations exist:

- Outlet-flow is fixed by mechanical ventilation: it is suggested to characterize each zone by a pseudo-ELA (sum of artificial and unvolontary openings). Inlet flows are shared proportionnaly to ELAs.

- Inlet flow is fixed by mechanical ventilation: outlet flows are shared proportionnaly to ELAs.

- Inlet flow and outlet flow are fixed zone by zone by mechanical ventilation. The sum of the flows for the building enable how to calculate air infiltration flow throught air-tightness default and specific openings. This global flow is divided proportionnaly according to the ELAs. If flows are balanced, there is no infiltration.

2.4 Test of ELA database on a same simplified case study

In order to determine repartition of air flow rates between different zones, each zone is characterized by an equivalent opening area (pseudo-ELA: adding of air openings and tightness fault). Three permeability or ELA databases (AICVF, ASHRAE and AIVC) are tested on the same case study. It is a monozone department store described on fig 1.

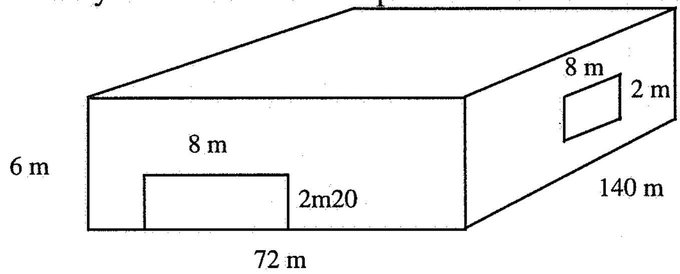

fig 1- Department store

The components chosen to describe building air-tightness are: ceiling, floor, wall, ceiling to wall joint, wall to floor joint, closed door, windows. In the 3 databases, the most important components concerning leakage are ceiling and floor (85% of total area, source of 90% of total leakeage).

2.4.1 air infiltration

	AICVF	ASHRAE	AIVC
database reference	[AICVF, 1989]	[ASHRAE,1993]	[AIVC, 1994]
flow formula	$Q = B.A_e.\Delta P^n$	$Q = ELA.c_D.\sqrt{\frac{2\Delta P}{\rho}}$	$Q = C.\Delta P^n$
main hypothesis[3]	$\Delta P = 1Pa$ applied uniformly	$\Delta P = 4Pa$ $c_D = 1$	ΔP applied uniformly $n = 0{,}66$
air flow rate splitting key	$BA_e = 11{,}8 \frac{m^3}{s.Pa^n}$	$ELA = 4{,}5\ m^2$	$C = 3 \frac{m^3}{s.Pa^n}$

2.4.2 natural ventilation

In building, natural ventilation is limited to opening doors. It is considered that windows are closed for an air conditionned building. AICVF's guideline suggest a formula that has been adapted to both other methods.

AICVF	AICVF adapted to ASHRAE	AICVF adapted to AIVC
$Q = 0{,}59\ A\ \Delta P^{0,5}\ [m^3/s]$	identification with $\Delta P = 4$ Pa	identification with $n = 0{,}5$
$B_{area} = 0{,}59 \frac{m^3}{s.m^2Pa^{0,5}}$ $BA_e = 0{,}59.z_0.A_e \frac{N_p}{3600}$	$ELA_{area} = 0{,}45 \frac{m^2}{m^2}$ $ELA = ELA_{area}.A_e.z_0.\frac{N_p}{3600}$	$C_{area} = 0{,}59 \frac{m^3}{s.m^2Pa^{0,5}}$ $C = C_{area}.A_e.z_0.\frac{N_p}{3600}$

[3] The hypothesis of uniform pressure difference is correct when mechanical ventilation is preponderant.

For the department store, two scenarios are considered:
- 750 customers per hour by group of 6 persons, N_p = 125 openings per hour.
- 1500 customers per hour by group of 6 persons. N_p : 250 openings per hour.
Opening door mean time is fixed z_0 = 8 s.

	scenario low	scenario high
AIVCF BA_e [$\frac{m^3}{s.Pa^{0,5}}$]	2,83	5,70
ASHRAE ELA [m^2]	2,2	4,4
AIVC C [$\frac{m^3}{s.Pa^{0,5}}$]	2,88	5,77

2.4.3 Comparaison of results

Airflow due to a 4 Pa pressure difference have been calculated with the 3 methods in order to homogenize results. So the three methods could be compared.

m^3/h		AICVF	ASHRAE	AIVC
$Q_{infiltration}$		105730 m^3/h 1,7 vol/h	41 830 m^3/h 0,7 vol/h	26510 m^3/h 0,44 vol/h
$Q_{natural\ vent}$[4]	min	20 400 m^3/h 0,34 vol/h	20 450 m^3/h 0,34 vol/h	20740 m^3/h 0,34 vol/h
	max	41 060 m^3/h 0.67 vol/h	40 900 m^3/h 0,68 vol/h	41540 m^3/h 0,68 vol/h

For infiltrations, AICVF method gives value 4 times more important than AIVC method, but AICVF database is used to size installation. It is probably not adapted to a energy consumption model. Considering the simplicity of case of study, ASHRAE and AIVC results have the same range of values. The two databases are equivalent. We choose to extract from one of those two databases a simplified components database.

2.5 Estimation of air infiltration on HVAC energy consumption

2.5.1 Building, system and models

The store HVAC system is composed of 12 roof-top units described in the following table:

	cooling			heating			fans	
	nominal values			nominal values			cooling	heating
	$\dot{Q}_{cooling}$	$\dot{Q}_{compressor}$	COP	$\dot{Q}_{heating}$	$\dot{Q}_{heating\ coil}$	COP	$\dot{Q}$	$\dot{Q}$
12 units	1224 kW	452 kW	2,71	1056 kW	348 kW	3,03	109 kW	61 kW
1 units	102 kW	38 kW		88 kW	29 kW		9 kW	5 kW

set point temperatures		
occupation cooling	occup. heating	non occ. heating
23°C	17°C	12°C

Air flow rate in HVAC system are the same in cooling and heating modes: 216 000 m^3/h. Rooftop units operate with constant air flow. Schedule of occupancy is the following:

	Mon-Tue-Thu	Wednesday	Friday	Sathurday	Sunday
occupation 9-19h	1309 per/hour	1527 per/hour	1636 per/hour	1909 per/hour	0

[4] The natural ventilation flow rates are same for the 3 methods because the 3 methods use the same expression.

Mechanical ventilation is calculated from mean number of customers with 30 m^3/h per person in the store and fixed to 0,75 vol/h. Meteorological datas are extracted from SRY file (2 caracteristic weeks per season) [Lund, 1985]. The simulations are made for first week of winter and first week of summer. The chosen location is Carpentras in the South of France.

Supply-air-conditions are a result of supply-air-flow-rate and thermal and hydric loads of the building, which are calculated using COMFIE as a building simulation model [Peuportier, 1992]. As roof-top air conditionners are running with a constant air flow, the cooling energy rate and the compressor electrical power are calculated, taking into consideration the fresh air flow rate, the return air flow rate, the supplied conditions at each calculation step. Air handling cycles in psychrometric chart, and finally energy consumption of roof-tops including auxiliaries (fans) are calculated, as described in [Morisot et al, 1997].

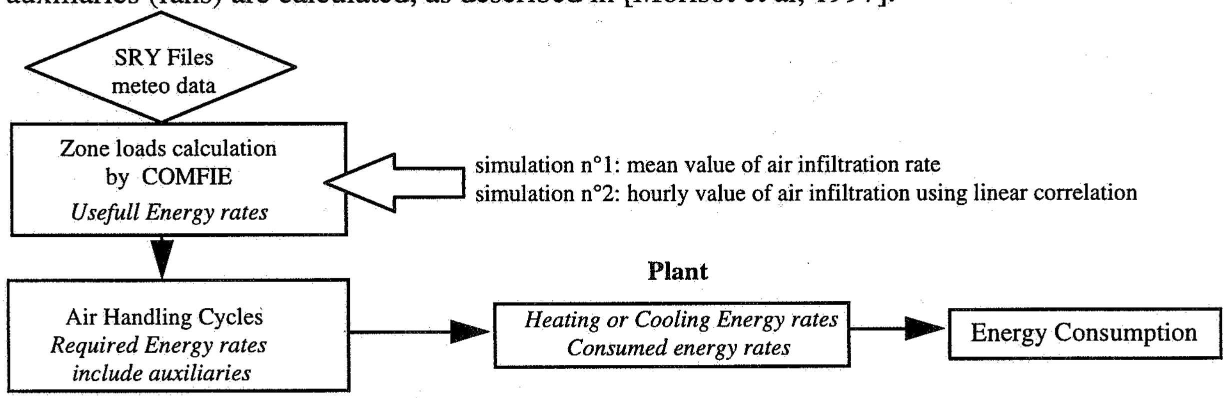

fig 2-flow chart of calculation

2.5.2 *Simulations*

Fresh air is introduced in the roof-top units. In simulation n°1, average value of air infiltration is used and in simulation n°2 hourly values are used (calculated using TRNSYS linear expression depending on temperature difference and wind). Air infiltrations are added to the loads of the building. Figure 3 shows evolution of air infiltration for the first week of summer and winter. Air infiltration rate is expressed in volume of the store per hour. Average value of air infiltration is calculated considering the 2 weeks of datas and its value is 0,44 vol/h.

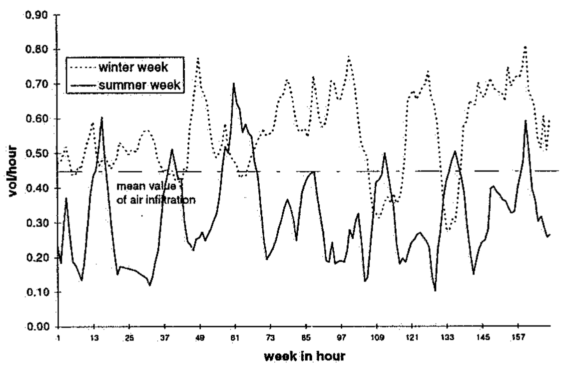

fig 3- Air Infiltration Rate for two week of SRY files

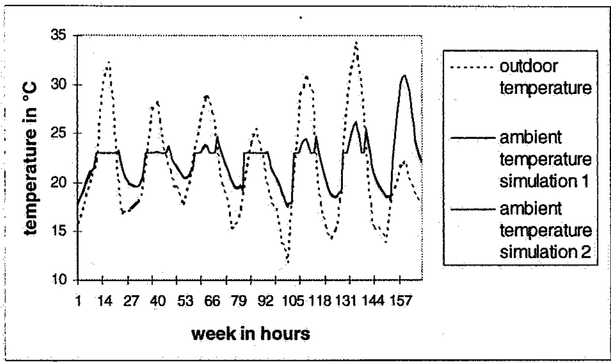

fig 4- Outdoor and ambient temperature for the summer week in simulation 1 and 2

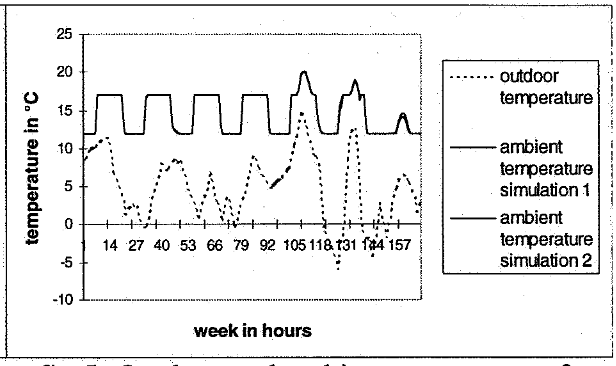

fig 5- Outdoor and ambient temperature for the winter week in simulation 1 and 2

The ambient temperatures are nearly the same in winter and in summer for simulations 1 and 2. The building thermal response is not affected by using average or hourly values. Consumption is summed up in the following chart. 168 hours are simulated, 66 hours of occupancy and 102 hours of non occupancy. The chart gives the number of hours when the system is in the dead band. During cooling season, HVAC System is off in non occupancy periods.

	$\dot{Q}$ cooling	$\dot{Q}$ heating	
	hours in temp dead band in occup	hours in temp dead band in occup	hours in temp dead band in non occup
simulation 1 mean air infiltration	32 650 kWh 1 hour/66 hours	42 000 kWh 14 hours/66 hours	19 hours/102 hours
simulation 2 variable air infiltration	32 700 kWh 1 hour/66 hours	47 170 kWh 12 hours/66 hours	17 hours/102 hours

Difference between the two simulations is unsignificant concerning cooling season. On the contrary, the difference for the heating season is 11%. Two reasons explain that. Firstly, infiltration directly depends on absolute temperature difference between ambient and outdoor. This difference is 3,6°C in summer and 9,7°C in winter: so it is 3 time bigger in winter than in summer and it induces the same impact on air infiltration flow. In addition to that, consumption introduced by air infiltration is more important in winter considering absolute temperature difference between ambient and outdoor.
It appears to be necessary to take into account air infiltration variation for a consumption simulation during heating season. Conversely, using a constant air infiltration rate seems to be valid in cooling season considering its moderate impact on energy consumption but only on one condition: determine a correct mean value of air infiltration.

3. Mechanical ventilation

The aim is to answer this question: what is the most accurate way to take into consideration « fresh air flow » in the model? The first solution is to introduce mechanical outdoor air flow rate in building loads. This solution is adequate to take into account building behaviour inside temperature dead band but drives the control of fresh air quantity difficult. The second solution is to calculate building loads without outdoor air flow rate and to introduce it in mixing box calculation. This allows fresh air control easier but drives errors for evolution of the building in temperature dead band.

Simulations are made on the store already described for the two weeks of SRY files.

3.1 Simulation

Introducing mechanical ventilation in the mixing box is compared to introduce it in building loads.

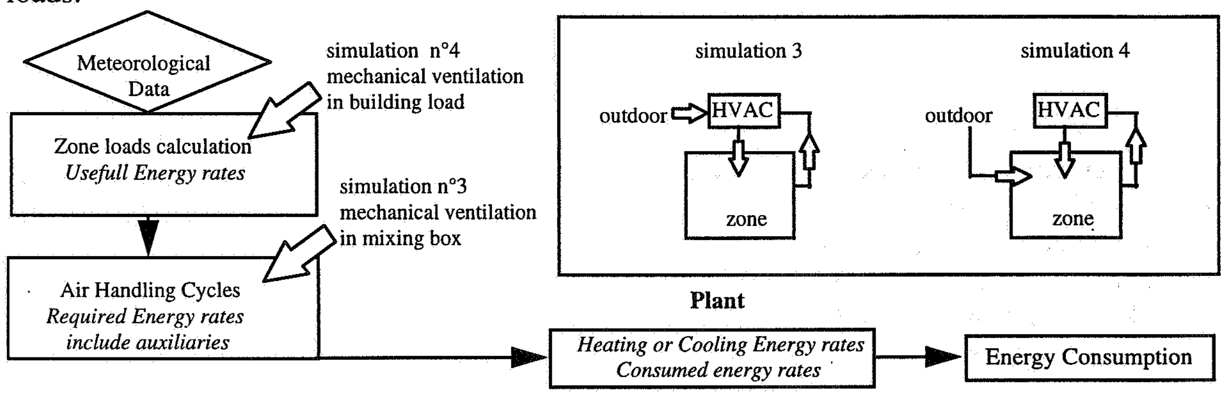

fig 6- Two possible models for mechanical ventilation

3.2 Results

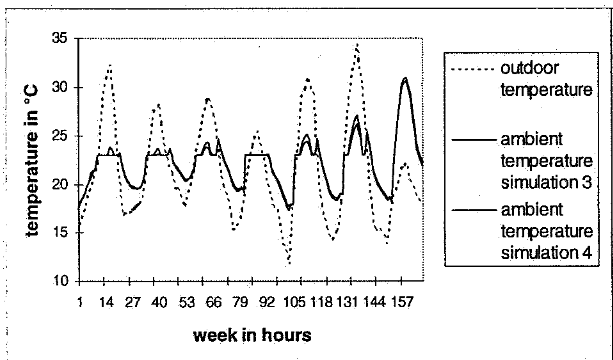

fig 7- Outdoor and ambiant temperature for the summer week in simulation 3 and 4

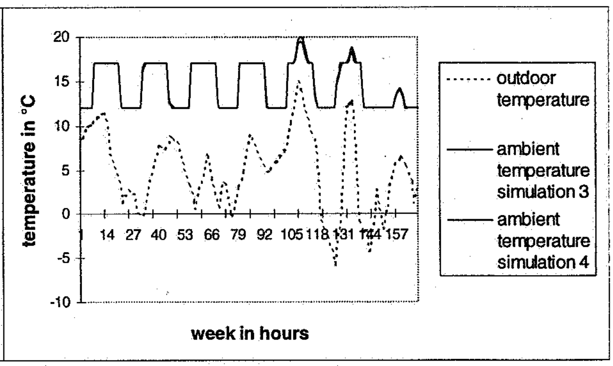

fig 8- Outdoor and ambiant temperature for the winter week in simulation 3 and 4.

	$\dot{Q}$ cooling	$\dot{Q}$ heating	
	hours in temp dead band in occup	hours in temp dead band in occup	hours in temp dead band in non occup
simulation 3 ventilation in system	32 700 kWh 1 hour/66 hours	47 170 kWh 12 hours/66 hours	17 hours/102 hours
simulation 4 ventilation in load	31 870 kWh 0 hour/66 hours	39 650 kWh 10 hours/66 hours	17 hours/102 hours

The building thermal response are nearly the same for the two models. On the other hand, consumption between simulation n°3 and 4 decreases significantly in winter (-16%) and decreases less in summer (-3%). The difference appears during the period when building temperature is in the temperature dead band. When ventilation is introduced in roof-top units, fresh air is supplied at ambient conditions as a « neutral air ». Indeed, constant air flow roof-top units chosen do not include a fresh air control. In our particular case, system never uses outdoor air as a cooling or heating source. That explains the artificial consumption increase when fresh air is introduced in the mixing box. Differences are clearly evident on figure 8. They correspond to three sequences of overheating (2 in occupancy and 1 in unoccupancy).

One can check that fresh air needs around 300 kW to become neutral (near 10000 kWh during the period).
However, considering fresh air as a building load prevents from simulating a fresh air control. In the particular case (no fresh air control and overheating in summer), model of simulation 4 must be used.

4. CONCLUSIONS

This study relates to the introduction of air infiltration and mechanical ventilation in a model for energy consumption estimation. A simplified tool of air infiltration evaluation is chosen because of its facilty to use and its medium precision. Two ELA or equivalent databases can be used to determine an air flow rate splitting key. Simulations have shown it is necessary to use hourly value of infiltration instead of mean value.
Models of mechanical ventilation have been compared. A simulation with particular system shows that both solutions are not equivalent for energy consumption (16% difference).

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