11529

THEORETICAL AND FIELD STUDY OF AIR CHANGE IN INDUSTRIAL BULDINGS

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ABSTRACT

The air leakages can have a large impact on heating needs and thermal comfort in industrial buildings. This is sometimes poorly taken into account, both due to the lake of theoretical approach and knowledge of the air tightness. We present the application of the calculation code SIREN95 in this field and its validation against field measurements.

The field study concerns five average industrial buildings, in which different tasks have been carried out : air tightness measurements, using pressurisation method, two series of measurements of air change with a tracer gas method (decay), field measurements during a whole heating season.

Weekly energy balances were calculated using the results of field measurements - and the air changes calculated by SIREN95. They showed a good agreement between heat gains (internal and solar) and heat losses (through the envelope, air change).

KEYWORDS

Air leakage
Air change losses
Stack effect
Pressurisation method
Tracer gas method

INTRODUCTION

The air leakages can have a large impact on heating needs and thermal comfort in industrial buildings.

A study has been undertaken to propose a method of determination of air leakage in this field. It is based on the aeraulic model SIREN95 developed in CSTB. SIREN95, firstly used for residential buildings, has been adapted for industrial buildings in order to calculate:

- the specific ventilation air flow rate,
- the air flow rate due to stack effect and wind effect through air leakages and air inlets,
- the air flow rate through doors when they are open,
- the heat losses corresponding to this air flow rates,

taking into account :

- the characteristics of the specific ventilation system,
- the geometric characteristics of the building,
- the air leakages,
- the doors opening.

This paper presents the application of the calculation code SIREN95 in this field and its validation against field measurements.

METHODS

The validation of SIREN95 concerns five average industrial buildings and is based on weekly energy balances constituted as follows :

- internal and solar gain and energy losses through the envelope of the buildings, as a result of field measurements and thermal modelling of the building,
- the air change rates calculated by SIREN95, which entering datas as a result of field measurements too.

Consequently, different tasks have been carried out in the studied buildings :

- field measurements during a whole heating season providing internal gains, solar gains, heat losses through the envelope, internal temperature at several levels,
- air tightness measurements, using pressurisation method, to assess the air leakages used as an entry in SIREN95. The air leakage is expressed as an equivalent hole in [m²],
- two series of measurements of air change rate with a tracer gas method (decay), to know how the leakage are distributed on the envelope ;
  - the first one without wind and with high difference between indoor and outdoor temperatures,
  - the second one with wind and low temperature difference

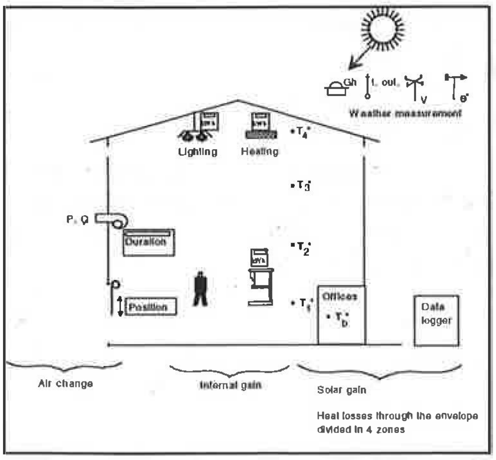

Figure 1 : field measurements

The repartition is made comparing the measured air change rate to the air change rate obtained with SIREN95

The aim of field measurements is to obtain the elements of energy balances, which are as follow (see figure 1) :

internal gain + solar gain = air change losses + heat losses through the envelope

- internal gains : energy of lighting, heating and process are measured,
- occupancy : averaged,
- solar gain : solar irradiation in a horizontal surface is measured and used to calculate energy through the envelope,
- heat losses through the envelope : calculated from the characteristics of envelope with the difference between outdoor an indoor temperatures,
- air change losses. Specific air change rate is calculated knowing the working time of fan, air flow rates being measured once.

The air change rate due to doors is calculated with the position of doors (open, half open, closed), known with a specific device.

Air leakages are measured.

Air change rate is calculated with SIREN95 from specific air change rate, position of doors and air leakage.

The following tables and figures show the main characteristics of the buildings and examples of field results.

Table 1 : main characteristics of buildings

	1	2	3	4	5
Construction	1992	1990	1981	1988	1990
Area * m^2	695	811	671	1347	558
Volume m^3	2967	4234	3086	6957	2500
H $W/m^3.K$	0,42	0,40	0,55	0,23	0,36
$H_{réf}$ $W/m^3.K$	0,28	0,34	0,41	0,23	0,32

The constructions have the same metallic structure with incorporated insulation (mineral wool) for walls and insulated roof.

Their shape is simple (parallelepiped) to make easier the field measurements and their comparison with the results of modelling.

The equipment of air tightness measurement limits their volume at 8000 m^3.

Table 2 : results of air tightness measurements

I : measurements made during an increasing pressure cycle

D : measurements made during a decreasing pressure cycle

		10 Pa		50 Pa		n	
		I	D	I	D	I	D
1	m^3/h	12393	11287	30227	32378	0.55	0.65
	Ach	4,18	3.80	10,19	10.91		
3	m^3/h	9162	8984	27637	26860	0.68	0.68
	Ach	2.97	2.91	8.96	8.70		
4	m^3/h	6558	6656	23705	23837	0.79	0.79
	Ach	0,94	0,96	3,41	3,43		
5	m^3/h	12075	12435	44930	46723	0.81	0.82
	Ach	4,83	4,97	17.97	18.69		

These results are presented for two pressure differences :

- 10 Pa : the air flow rate in m^3/h under 10 Pa is quite expressed by the same number as the hole area in cm²,
- 50pa is the reference in Europe.

It is to notice that the measurement has not been carried out in the building number two because of a too large air leakage, the pressure difference generated was too small to be significant.

The exponent for building number one in not the same during increasing and decreasing cycle : it is supposed the building could have been bent under pressure.

Table 3 : results of measurement of air change rate with tracer gas without wind and with high difference between indoor and outdoor temperatures

		Measurement location		
		Point 1	Point 2	Point 3
1	Ach	0,32	0,30	0,32
	CC*	0,996	0,996	0,997
2	Ach	without heating 0,61 heating 1,65	without heating 0,74 heating 1,51	without heating 0,58
	CC*	without heating 0,994 heating 0,997	without heating 0,987 heating 0,978	without heating 0,994
3	Ach	0,63	0,58	0,68
	CC*	0,998	0,998	0,998
4	Ach)	0,22	0,20	-
	CC*	0,998	0,997	-
5	Ach	0,67	0,68 air extraction 1,20	-
	CC*	0,995	0,995 air extraction 0,994	-

*CC : correlation coefficient

In each building the measurements have been carried out in several locations (point 1 to 3) at different highs, doors and windows closed.

The results show that :

- the air change rate doesn't vary with the high of measurement, then table 3 presents only the average of air change rate at different points.
- the differences noticed between the different points are not significant. Inside and outside conditions (temperature and speed) being constant, the measurements have not been disturbed. The air change

rate due to stack effect has an effect in the whole of the building.

During dispressurisation cycles, investigations with an IR camera have been carried out to show the air tightness faults.

RESULTS

Energy balances, made during a heating season for every building, are shown in figure 2 : internal gain and solar gain are compared to heat losses through the envelope and to air change losses. Energy is expressed in kWh/m².week.

As we can see, gains and losses are quite the same especially in buildings 1, 2 and 4.

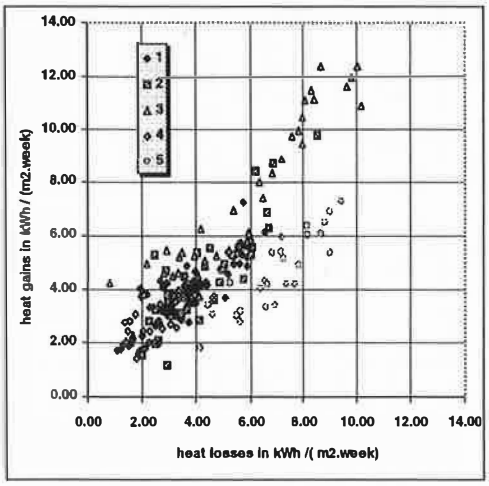

Figure 2 : weekly energy balances

Figure 3 shows weekly mean energy balances during the whole heating season and during a cold period.

During the heating season :
- solar gains are an important part in term of heating, however its calculation remains rough.
- air change losses are different, depending on the building (0.8 to 2.7 kWh/m².week), but are ever a significant part of global losses (30 to 50 %). Air leakages flow rates are larger than specific air change rate and door opening air change rate.

During a cold period :
- solar gains are obviously smaller and become negligible in relative term,
- air change losses vary from 0.8 to 3.7 kWh/m².week. Air leakage losses are important but specific air change rate is well controlled.

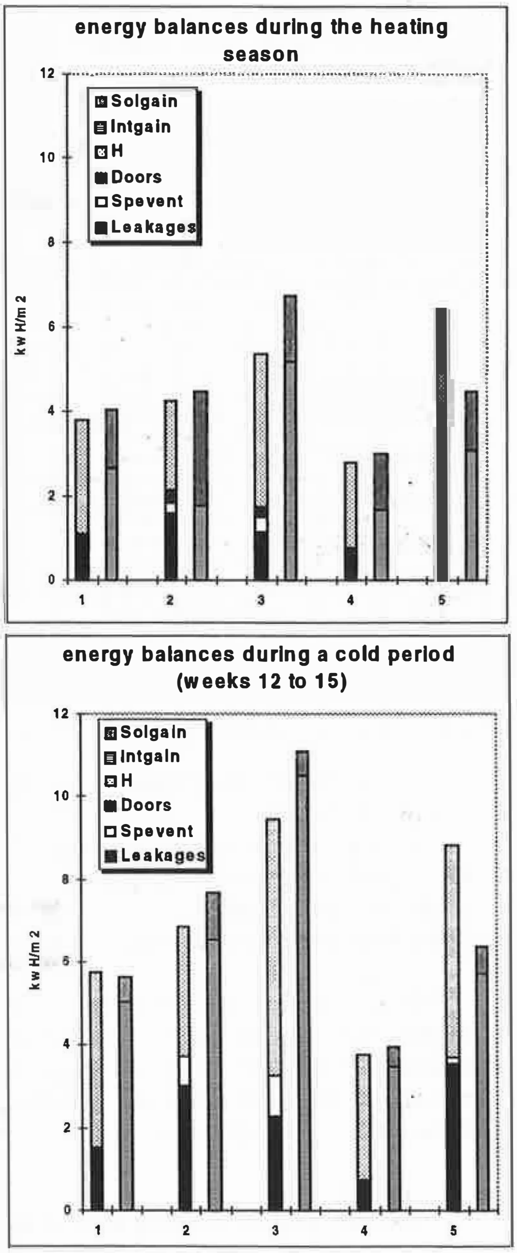

Figure 3

SIREN95 has been used to calculate the daily mean air change rate according outdoor temperatures and wind speed, without specific air change rate. See figure 4 for an example of results in building 1.

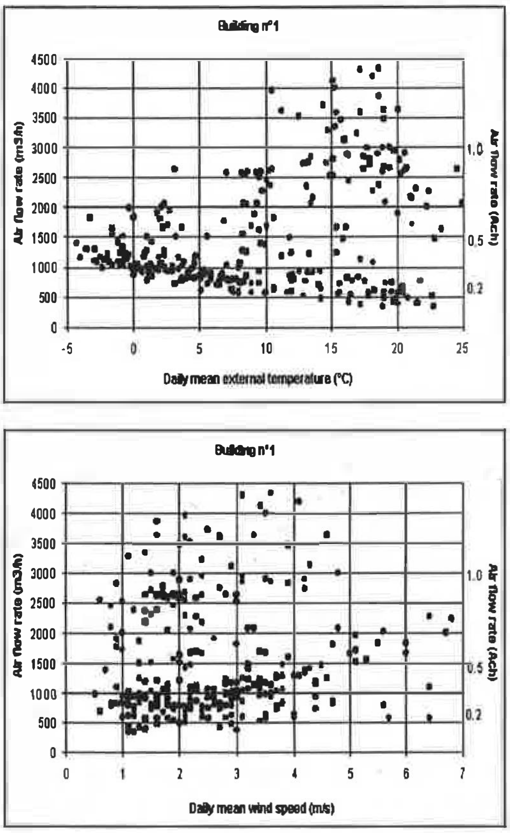

Figure 4 : daily mean air change rate according to outdoor temperature and wind speed

- according outdoor temperatures, results are divided in two parts :
  - in the first one, air change rate decrease when outdoor temperature increase. It represents the stack effect air change rate through air leakages.
  - in the second one, air change rate increase with outdoor temperature. It represents the behaviour, mainly the door opening.
  - intermediate values can be considered due to the wind.
- according the wind speed, results are divided in two parts too :
  - in the first one, air change rate increase with wind speed.
  - in the second one, air change rate, due to door opening, is not related to wind speed.

It can be noticed the air change rate due to behaviour is more important than air change rate due to air leakage, and it is independent of air tightness and represents an extra air change rate of 1 to 1.5 ach.

Air change rate due to air leakage (cold weather or high wind speed) is shown table 4;

Table 4 : air change rate due to air leakage

Building	(ach)
1	0.5
2	2
3	1.5
4	0.2
5	0.5

SENSISTIVITY ANALYSIS

In order to check the impact of the different parameter, we performed a sensitivity analysis. We choose a simple building (height : 5 m , dimensions 40 m x 20 m) with an airtightness of 0.5 a.c./h under 1 Pa.

We applied 4 weather conditions : 2 outdoor temperature (0°C and 15 °C), 2 wind speeds: 0 m/s and 5 m/s.

2 indoor conditions were defined :. 20 °C without stratification , 20 °C on ground and 25°C near the ceiling.

The air leakages were split in the lower and upper parts of the building with different ratios :
1/2 down ; 1/2 up
1/3 down ; 2/3 up
2/3 down ; 1/3 up

Results are shown in figure 5 and 6

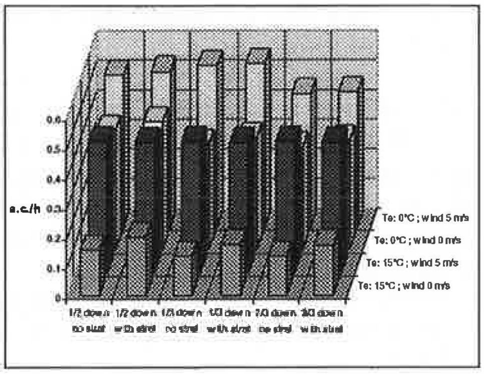

figure 5 : air change for a typical building according to outdoor conditions, position of air leakages and indoor stratification

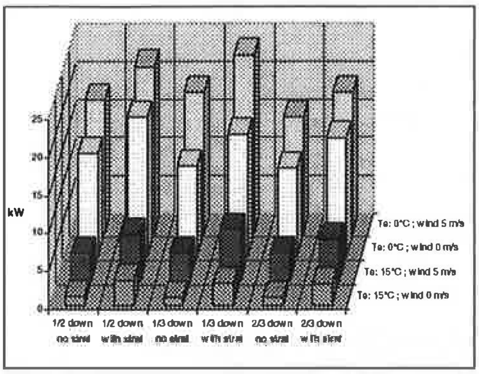

figure 5 : heat losses due to exfiltration for a typical building according to outdoor conditions, position of air leakages and indoor stratification

When stack effect is dominant, the higher flow rates are obtained with equally split leakages. When wind effect is dominant, there is no difference due to the present assumptions that the air leakages remain equally split between the windward and leeward facades. When both effects are at the same level, a calculation has to be made, as it is not easy to predict in a simple way the flow direction for each leakage.

DISCUSSION

Further developments will be undertaken in order to obtain more applied tools.

- a design and dimensioning tool, based on a simplified predicting tool of air change rate during the heating season using a simplified set of input data and based on a data base on building techniques in term of air leakage.
- a procedure of control of air change rate due to the air leakage with a tracer gas method.

ACKNOWLEDGEMENTS

This study was sponsored by EDF

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