Energy Impact of Ventilation and Air Infiltration
14th AIVC Conference, Copenhagen, Denmark
21-23 September 1993

Measurements of Air Change and Energy Loss with Large Open Outer Doors

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Synopsis

The paper describes measurements made on large doors – 10 to 20 m^2 in 2 buildings in Narvik. The air change was measured with the tracer gas (SF_6). The method of constant concentration or decaying concentration of the tracer gas was used. The dosing, measuring and calculation of the air change was made with a Brüel & Kjær gas analyser type 1302 and computer. Use of the decaying method was best with short opening times. The opening of the door in 5 to 7 minutes gives an air exchange of 500 m^3 to 1300 m^3 or an air change from 0.2 to 1.0. The energy loss is from 2 to 8.5 kWh for each opening. After opening of a door it takes from 0.5 to 1 hour before we have stable temperature and air change again.

The results are compared with the theoretical formulas for gravity driven flow air change from open doors. The number of openings and opening time of large doors is gives an energy loss that is much larger than the transmission and infiltration loss.

1. Introduction

In calculations of energy consumption for building is the air change important. The air change can be divided in two parts – ventilation and infiltration/exfiltration. The ventilation is controlled by the ventilation equipment. The infiltration (air streaming from the outside to the inside) can only be estimated, if it not measured, as it will depend on the air pressure difference and the leakage area. None of these is known very accurate. The infiltration can only be measured for a building. This measurement is normally done by measuring the air flow with a certain over– or under pressure in the building. That is done with doors and windows closed. In a real case will opening of windows and doors give an extra infiltration heat loss. Our research [3] and [4] had the purpose of finding the heat loss and air change when a large door is opened. This is compared with theoretical calculations from Kiel and Wilson 1986 [1].

2. Measuring objects

The measurements were made on two buildings in Narvik [4]. The first building is a laboratory hall for NORUT Technology. The width was 15 m and the length was 27 m and an area of 405 m^2. There was a large door on the short side with a height of 3.6 m and a width of 3.95 m. The laboratory hall contained test rigs, that could influence on the air flow. This building was used for the first series of measurements.

The second building is a wholesale distributor for grocers. The firm has a storage building of 6000 m^2. All products are transported by lorries, so they have many large doors. To reduce the heat loss from the storage is the doors placed in a front room of 440 m^2. This room can be sealed from the central storage by a large door outside working hours. That door was closed during the measurements. Our measurement is for the front room with 2100 m^3 and 4 large doors. Three had a width of 2.5 m and a height of 3 m (7.5 m^2) with manual opening. The last door had a width of 3.8 m and a height of 4.5 m (17.1 m^2) with automatic opening. Measurements were made of single door opened for a fixed time period of 5 or 7 minutes.

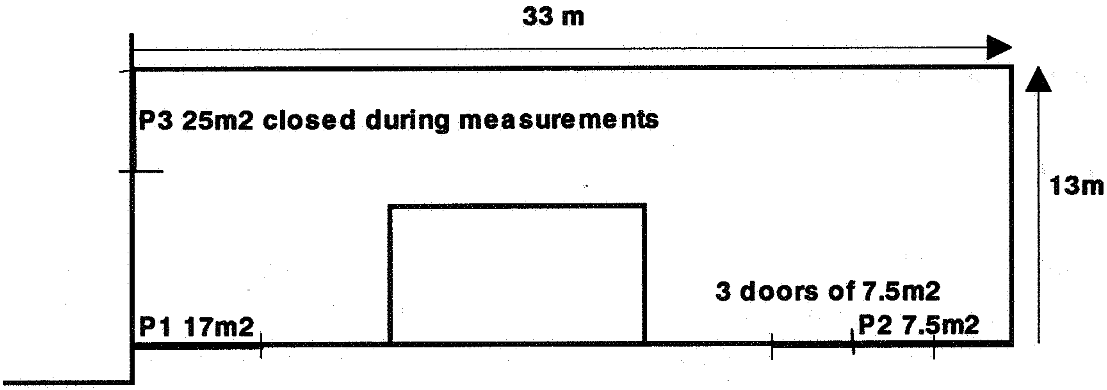

Figure 1 Plan of storage building with large outer doors.

3. Measuring method

The air change was measured with tracer gas. The tracer gas used is sulphur hexafluoride SF_6, a widely used gas for tracer gas measurements. The tracer gas is distributed in the room and is mixed by several fans. The fans are necessary to get a uniform distribution of tracer gas in the enclosure. This gives more stable tracer gas concentration, but on the other hand disturb the natural air movement in the room. This is seen in the results. The measuring equipment consists of the following three elements (all from Brüel & Kjaer): Multi–gas Monitor Type 1302, Multipoint Sampler and Doser Type 1303 and Application Software Type 7620.

The 1302–monitor uses a photo acoustic measuring technique for monitoring of the tracer gas. The 1303 sampler and doser provides for multipoint, multigas monitoring by drawing gas samples trough tubing from 3 locations and delivering the samples to the 1302. The software gives a full remote control over all the functions of the 1302–monitor and the 1303 sampler and doser to perform dosing, sampling, monitoring and data collection automatically.

The constant concentration method was used in the first measurements on the laboratory hall. The concentration of tracer gas is maintained at a constant level. The air–change rate becomes then directly proportional to the tracer gas injection rate required to maintain the concentration on the chosen level. The 7620 Application Software uses a dosing algorithm for keeping the concentration of tracer gas at a constant level. It was found that when the door was opened and the tracer gas concentration dropped the dosing could not keep a constant level. This was probably caused by the dosing algorithm, that was not good enough.

All later measurements were done with the decay method. An amount of tracer gas was totally mixed with the air. Then the gas injection was closed and the gas concentration was measured. The change in gas concentration by time is a straight line in a diagram where the y–axis is a logarithmic concentration scale. From this can we calculate the air change with the door closed. When the door is opened will the tracer gas concentration drop. This drop is proportional to the net air exchange at the opening.

4. Detailed results

In this section we will look at some of the details in the measurements. Figure 2 shows the measured air change from an opening of the large door in the storage building in 5 minutes. Before the opening is the air change approximately 0.2 h^{-1}. The air change increase to 6 h^{-1}, when the door is opened. After the closing will the air change decrease, and we have a short period when the air change is negative. This is because we don't use fans to mix the air, so the concentration will fluctuate in a period of 1 hour. This shows that a short opening of an outer door will have long time influence on the indoor air flow pattern.

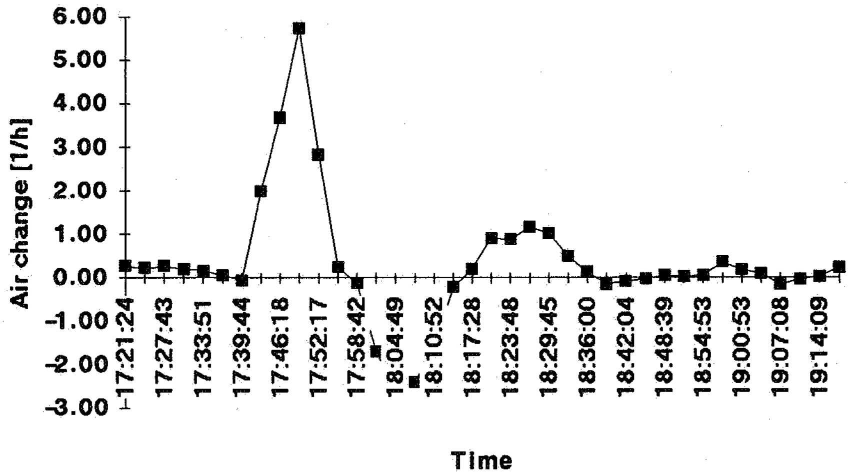

Figure 2 Air change for a 5 minute (start 17.40) opening of the large door in the storage building. The air change is first staple again after approximately 1 hour.

If we don't have equipment to make tracer gas measurements it is also possible to calculate the air change from the drop in temperature, when the door is opened. In figure 3 is the air temperature for the same case as in figure 2. The temperature drops 5 C in this case, and it takes approximately 0.5 hours before it is stable again. Calculation of air change based on the air temperature gives lower values, than with tracer gas concentration. The best method is the tracer gas method.

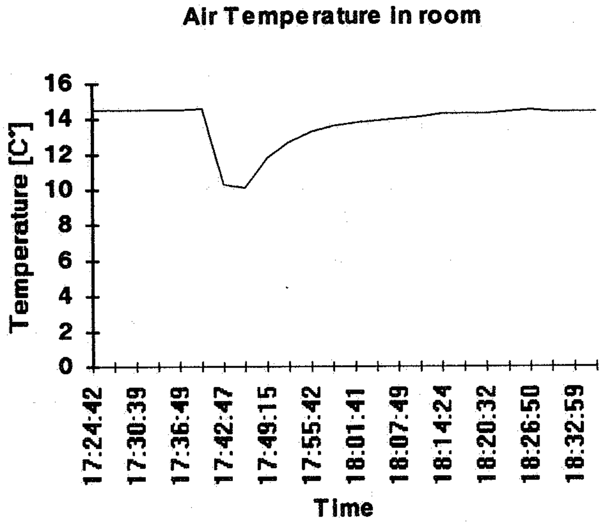

Figure 2 Temperature in the room for a door opening in the same case as figure 1.

5. Summary of measurements

			L1	L2	L3	L4	L5	L6
Case no			L1	L2	L3	L4	L5	L6
Door opening		HxW	4x3.6	4x3.6	4x3.6	4x3.6	4x3.6	4x3.6
Wind speed		m/s	3.3	3	5	4	9	10
Wind direction			SE	SE	NE	NE	NE	ENE
Opening time		sec	420	300	420	420	300	420
Temp.diff.		C°	21.2	20.5	18.9	20.9	17.4	19.0
Air change		1/h	0.30	0.52	0.35	0.45	0.40	0.58
Time to normal		h	0.45	0.90	0.82	0.87	1.00	0.54
Nett change	Measured	m^3	678	1180	798	1106	915	1320
	Calculated		1312	1082	1270	1296	1001	1258
Air flow	Measured	m^3/m^2 *s	0.12	0.28	0.13	0.17	0.22	0.22
	Calculated		0.22	0.25	0.21	0.22	0.23	0.21
Energy loss	Measured	KWh	4.9	8.2	5.1	7.1	5.4	8.5
	Calculated		9.5	7.5	8.2	9.2	5.9	8.1

Table 1 Measured and calculated air flow and energy loss from door openings in the laboratory hall based on measured air change in the room.

Table 1 is a summary of the measurements done in the laboratory hall. For each case is given the wind speed and wind direction measured at Narvik airport. The local wind speed is lower at the building site. The temperature difference between indoor and outdoor is given. The AC–method (air change method) is used to calculate air flow (m^3/m^2s) through the door opening , net air flow m^3 and energy loss kWh based on the measured air change in the room. This values are called measured. The values called calculated is based on the theory in chapter 6. The time from the door opening until we have steady state air change is found to be from 0.5 to 1 hour. The opening of the door gives an air exchange of 700 m^3 to 1300 m^3 or an air change from 0.45 to 1.0. The energy loss is from 5 to 8.5 kWh.

Case no			S1	S2	S3	S4	S5	S6	S7
Door opening		BXH	2.5x3	2.5x3	2.5x3	2.5x3	2.5x3	3.8x4.5	3.8x4.5
Wind speed		m/s	0.15	0.15	0.1	0.1	0.07	0.8	0.7
Wind direc.			SW	?	?	SE	SE	SE	NE
Opening time		sec	420	420	420	300	300	300	420
Temp.diff.		C°	12.6	13.5	13.5	15.2	15.1	14.6	15.2
Air change		1/h	0.10	0.23	0.21	0.19	0.17	0.53	0.73
Time to normal		h	0.73	0.94	0.90	0.78	0.56	0.94	1.14
Air flow	Measured	m^3/m^2 *s	0.07	0.15	0.14	0.18	0.16	0.22	0.21
	Calculated		0.18	0.18	0.18	0.20	0.20	0.22	0.19
Nett change	Measured	m^3	210	475	435	395	355	1113	1537
	Calculated		552	574	574	445	443	1132	1375
Energy loss	Measured	KWh	0.9	2.2	2.0	2.0	1.8	5.5	7.9
	Calculated		2.4	2.6	2.6	2.3	2.3	5.6	7.1

Table 2 Measured and calculated air flow and energy loss from door openings in the storage building based on measured air change in the room.

In table 2 and 3 is 7 cases of measurements on the storage building of air flow (m^3/m^2s) through the door opening , net air flow m^3 and energy loss kWh. For each case is given the wind speed measured at the site near the door and wind direction measured at Narvik airport. The opening of the door gives an air exchange of 200 m^3 to 1500 m^3 or an air change from 0.1 to 0.7. The energy loss is from 1 to 8 kWh. If the door is opened for longer time and more times during the day will the loss be much higher. The first 5 cases (S1–S5) are with a 7.5 m^2 door and the last two (S6–S7) with a 17 m^2 door.

The calculations also can be based on the tracer gas concentration as we find in table 3. We call this method the decay methods, as decay of tracer gas was used. In this case we have the gas concentration before and after in the table. We find that the measured vales from air change with the 2 methods used in table 2 and 3 gives approximately the same values. This is found in table 4.

				S2	S3	S4	S5	S6	S7
Case no				S2	S3	S4	S5	S6	S7
Door opening		HxW		2.5x3	2.5x3	2.5x3	2.5x3	3.8x4.5	3.8x4.5
Wind speed		m/s		0.15	0.1	0.1	0.07	0.8	0.7
Wind direction				?	?	SE	SE	SE	NE
Opening time		sec		420	420	300	300	420	420
Temp.diff.		C°		13.5	13.5	15.2	15.1	14.6	14.2
Gas konc.	Before	PPM		18.4	10.3	23.9	16.6	36.5	28.3
	After	PPM		14.0	8.0	20.0	13.9	17.5	8.1
Air change		1/h		0.27	0.25	0.18	0.18	0.74	1.25
Nett volume		m³		2100	2100	2100	2100	2100	2100
Nett change	Measured	m³		502	469	343	342	1093	1499
	Calculated			574	574	445	443	1132	1375
Air flow	Measured	m³/m² *s		0.16	0.15	0.15	0.15	0.21	0.21
	Calculated			0.18	0.18	0.20	0.20	0.22	0.19
Energy loss	Measured	KWh		2.3	2.2	1.8	1.8	7.6	7.2
	Calculated			2.6	2.6	2.3	2.3	5.6	6.6

Table 3 Measured and calculated air flow and energy loss based of decay in tracer gas concentration for door openings in the storage building

6. Theory and comparison

The air change and net flow through a door opening can found theoretical from methods in IEA 1992 [2] and in publications from AIVC (Air Infiltration and Ventilation Centre). The method we have decided to compare with is the method from Kiel and Wilson 1986 [1]. For a case must the following parameters be known:

- T_i Indoor temperature, K
- T_o Outdoor temperature, K
- W Opening width, m
- H Opening height, m
- t_o Opening time (from start to full opening), sec
- t_h Full Opening time, sec
- V_H Room volume below a level H, m^3

We assume, that the full opening time is much longer than the partial opening time t_o. We can therefore take t_o=0., and then calculate:

Fractional density difference	$\Delta = 2 * (T_i - T_o) / (T_i + T_o)$
Indoor outdoor temperature difference	$\Delta T = 295 \times \Delta / (1 + \Delta/2)$
Door orifice coefficient	$K = 0.4 + 0.0045 * \Delta T$
Net flow rate (m^3/s) (g is gravity m^2/s)	$Q_n = K * (g * W^2 * H^3 / 9)^{0.5} * \Delta^{0.5}$

Time (s) $t = t_h$

The gravity driven exchange is found using:

If $Q_n * t / V_H > 0.5$ then $V = V_H * (1 - e^{-A * (t - B)})$

where $A = 2 * Q_n / V_H$

and $B = (0.5 * V_H / Q_n) - 0.69 / A$

If $Q_n * t / V_H < 0.5$ then $V = Q_n * t$

This method has been used for the theoretical calculations of air flow and air change in table 1 to 3.

Case	Net air flow through opening Theory m3	Measured AC m3	Measured DECAY m3	AC %	DECAY %
L1	1312	678		52%	
L2	1082	1180		109%	
L3	1270	798		63%	
L4	1296	1106		85%	
L5	1001	915		91%	
L6	1258	1320		105%	
S1	552	210		38%	
S2	574	475	502	83%	88%
S3	574	435	469	76%	82%
S4	445	395	343	89%	77%
S5	443	355	342	80%	77%
S6	1132	1113	1093	98%	97%
S7	1375	1537	1499	112%	109%

Table 4. Comparison between the theory from Kiel and Wilson and measurement. Case numbers with L is from the laboratory hall (table 1). Case numbers with S is from the storage building with air change (table 2) or decay method (table 3).

Table 4 is a comparison between the theory and measurements. The measurement in the laboratory hall gives large variations, that is not depending on the wind speed. It is possible the test equipment in the room could reduce the air flow. We find the largest difference for case S1 where the constant concentration was used. In all other cases is the difference below 25%. Generally give the S–cases lower measured values than theory with low wind speed (0 –0.2 m/s) and higher values with higher wind speed (0.5 – 1 m/s).

7. ENERGY LOSS FROM DOOR OPENINGS

It is well known that open outer doors and windows will increase the air change and energy loss. The flow through the doors will be a function of the temperature difference between indoor and outdoor, the wind speed, the wind direction and the size of the room behind the door and the air tightness of the room. The results of these measurements are that the air flow normally is less than predicted by the theory gravity driven flow, and it is not possible to find a clear influence of the wind speed. Opening af a door in 5 to 7 minutes gives an energy loss of 2 to 8 kWh. That does not look very important, but on a yearly basis is the energy loss from openings 80–90% of the total loss , see Nielsen [5].

8. CONCLUSION

Measurements of air change and heat loss can be done with tracer gas equipment. The best method is the decay method. Comparison with the theoretical formula from Kiel and Wilson [1] shows that the formula gives results comparable with measurements. The results have also been compared with theoretical formulas from the Norwegian Building Research Institute, but the difference was larger than the other formula. We would recommend more measurements with tracer gas especially with higher wind speeds and other building types.

It is possible to get energy savings from using an air lock between the building and a lorry. This is especially interesting in a cold climate, but it is difficult to predict the real energy savings. This must be possible with tracer gas equipment.

9. REFERENCES

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