

Air pressure conditions in Finnish residences

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SUMMARY

Air pressure conditions in typical Finnish residences are analyzed using data from field measurements and computer simulations. Field measurements were conducted in a two-storey detached house and in a five-storey apartment building. The effects of airtightness, ventilation rate, air leakage distributions, and outdoor environmental conditions on air pressure conditions in a detached house were simulated on a multi-zone simulation model using the IDA ICE simulation program. There is almost always a positive and negative air pressure difference across the building envelope in detached houses and in apartment buildings. During winter, in detached houses there is continuous positive air pressure at ceiling level on the top floor and negative pressure at floor level on the bottom floor. For detached houses, the design value of air pressure difference across the building envelope for the moisture convection analysis is close to ± 10 Pa. The control of air pressure difference in normal and leaky houses is difficult: ± 15 differences in ventilation airflows have only a minor influence on the air pressure difference. To control air pressure differences, the balancing of ventilation systems in airtight houses is very important.

INTRODUCTION

The uncontrolled air movement through a building envelope leads to problems related to hygrothermal performance, health, energy consumption, performance of the ventilation systems, thermal comfort, noise, and fire resistance. Air leakage through a building envelope depends on the result of air pressure differences across the envelope and on the airtightness of the building envelope.

Air and moisture convection through the building envelope may cause severe moisture loads to be imposed on the structure. Indoor air exfiltration in cold climates may cause moisture accumulation or condensation, leading to microbial growth on materials, change of the properties of the material or even to structural deterioration. The relative humidity (RH) at the connection of floors and external walls in multi-storey platform timber-frame houses can be rather high, causing the risk of mould growth and rot fungi when there is positive air pressure inside the building [1]. The simulation results of Janssens and Hens [2] have shown that, even when a roof design complies with condensation control standards, a lightweight system remains sensitive to condensation problems because of air leakage through the discontinuities, joints and perforations, common to most existing construction methods.

Air leakage through a building envelope could introduce outdoor or crawl-space airborne pollutants to the indoor air. Field measurements [3, 4] have shown evidence of fungal spores being transported indoors from a crawl space. Although radon can enter buildings by several

mechanisms, the dominant radon entry mechanism is air leakage through the basement floor [5, 6, 7].

Hygrothermal design is one way to assess and predict the long-term hygrothermal performance of the building envelope to prevent moisture damages and to guarantee a healthy indoor climate and longer service life for buildings. Air pressure difference is one load component in the hygrothermal design of building envelopes. Wind, stack effects, mechanical ventilation and distribution of leakage sites in the building envelope influence air pressure difference. Each one of these effects influences the air pressure difference independently and in a specific way.

As many factors affect air pressure conditions, one of the most reliable ways to determine the relevant design values is to perform long-term field measurements in typical residences. To understand how different factors influence the air pressure conditions, the use of simulation is a valuable tool that makes it possible to show the importance of wind, stack effects, mechanical ventilation and distribution of air leakage places. In this study, air pressure conditions in typical Finnish residences are analyzed using data from field measurements and computer simulations.

METHODS

Field measurements

Field measurements were conducted in a two-storey detached house and in a five-storey apartment building, Figure 1. Residences were selected to represent typical Finnish residences. A detached house was selected as having average properties according to a previous field study of timber-frame detached houses [8]. There was mechanical supply and exhaust ventilation and an electrical floor and ceiling heating system in the studied detached house. The apartment building had a centralized supply and exhaust ventilation system that was demand controlled to keep RH and CO₂ below the target values of 50% and 600 or 1000 ppm.



Figure 1 Studied detached house (left) and apartment building (right)

Air change rate, indoor and outdoor temperature and humidity, as well the air pressure difference over the building envelope were monitored during a three-week period in winter. The ventilation airflows were measured from ventilation ducts at different ventilation fan speeds. During the measurement period, the ventilation fan speed was monitored continuously. Whole air change rates of residences were measured with active and passive (only in detached house) tracer gas air infiltration measurement techniques also. The

airtightness of the building envelope was measured using the fan pressurisation method [9]. The values of air pressure differences over the building envelope (ΔP), temperature (T), and RH from inside and outside the building were monitored at 15 min. intervals. Table 1 shows the main characteristic of the studied dwellings.

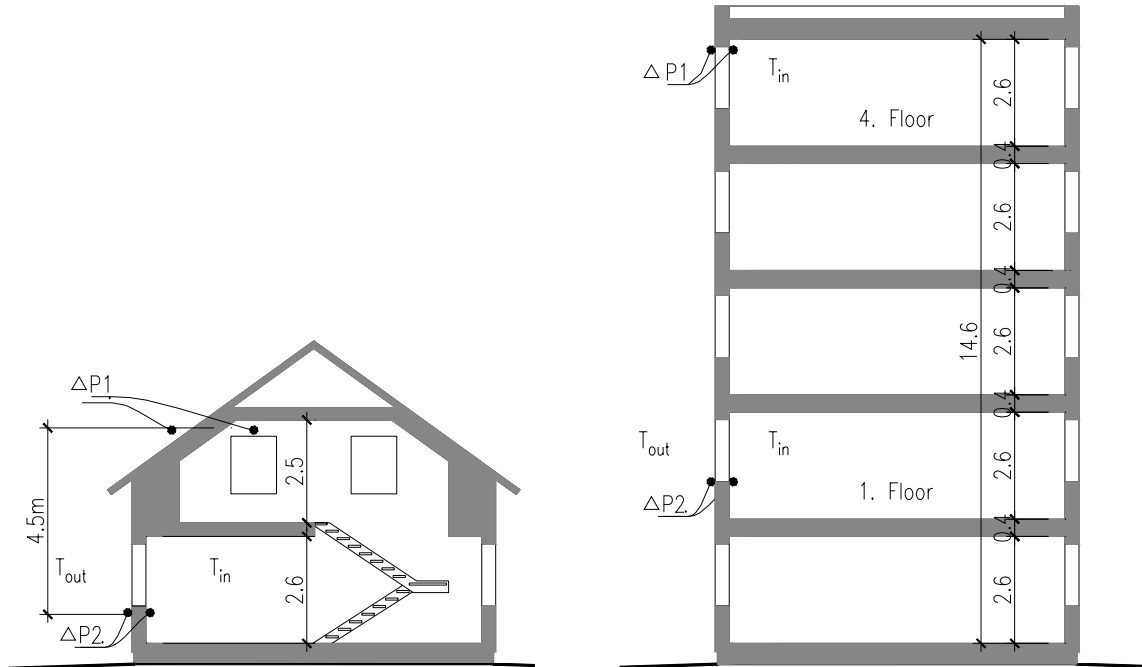


Figure 2 Measurement points in detached house (left) and in apartment building (right)

Table 1 Main characteristic data of the measured dwellings

	Detached house	Apartment on the first floor	Apartment on the fourth floor
Measurement period	4.3...24.3.2005	16.3...06.4.2005	16.3...06.4.2005
Floor area	183 m ²	70 m ²	70 m ²
Volume	452 m ³	183 m ³	183 m ³
Envelope air leakage rate at 50 Pa	3.9 1/h	1.0 1/h	1.9 1/h
Average ventilation rate	0.41 ach	0.68 ach	0.60 ach
	13 l/(s·pers.), 0.29 l/(s·m ²)	9 l/(s·pers.), 0.49 l/(s·m ²)	15 l/(s·pers.), 0.44 l/(s·m ²)

Computer simulations

To analyse the effects of airtightness, ventilation rate, air leakage distributions, and outdoor environmental conditions on air pressure conditions, the measured detached house (Figure 1, left) was simulated on a multi-zone simulation model using the IDA-ICE [10, 11] simulation program. The software is an advanced tool for simulation of thermal comfort, indoor air quality and energy consumption in buildings. The simulation model was validated on the basis of field measurements [12]. The effect of the airtightness of the building envelope, distribution of the air leakage places, performance of ventilation, and surrounding conditions (suburban, open country, no wind cases) on air pressure differences were analysed in twenty-one different simulation cases, Table 2.

An air leakage rate per hour at 50 Pa of pressure difference (n_{50}) is changed between $n_{50}=0.15...10$ ach. In the case of $n_{50} = 0.15$ ach, a building is almost completely airtight

without air leaks. The airtightness value $n_{50} = 3.9$ ach was the airtightness of the simulated detached house and can be considered typical of Finnish timber-frame detached houses [8]. The airtightness value $n_{50} = 10$ ach was selected to represent a very leaky house. The effect of the air leakage distribution is simulated with three different cases: 75 % of the leakages at the top of the house and 12.5 % of the leakages at the middle and bottom of the house; equal distribution; and 75 % of the leakages at the bottom of the house and 12.5 % of the leakages at the middle and top of the house. The effect of the performance of ventilation is simulated with three different cases: balanced system (supply airflow = exhaust airflow), 15 % decreased supply airflow, and 15 % increased supply airflow. For the reference case, the “CASE-1 n4” ($n_{50} = 3.93$ ach, suburban surrounding, normal air leakage distribution and balanced ventilation system) was selected.

Table 2 Simulation cases

Description:		Simulated cases		
		$n_{50} = 0.15$ ach	$n_{50} = 3.9$ ach	$n_{50} = 10$ ach
Surroundings	Suburban	CASE-1 n0.15	CASE-1 n4	CASE-1 n10
	Open country	CASE-2 n0.15	CASE-2 n4	CASE-2 n10
	No wind cases	CASE-3 n0.15	CASE-3 n4	CASE-3 n10
Air leakage distribution	Most leakages at the top of the house (75/12.5/12.5%)	CASE-4 n0.15	CASE-4 n4	CASE-4 n10
	Normal	CASE-1 n0.15	CASE-1 n4	CASE-1 n10
	Most leakages at the bottom of the house (12.5/12.5/75%)	CASE-5 n0.15	CASE-5 n4	CASE-5 n10
Ventilation performance	15 % decreased supply airflow	CASE-6 n0.15	CASE-6 n4	CASE-6 n10
	Balanced system	CASE-1 n0.15	CASE-1 n4	CASE-1 n10
	15 % increased supply airflow	CASE-7 n0.15	CASE-7 n4	CASE-7 n10

Air pressure differences were calculated from three rooms: from the sauna and living room on the ground floor and the bedroom on the top floor. Air pressure differences were calculated from each room at ceiling and floor levels. The simulations are carried out with hourly Helsinki weather data (1979), which is commonly used as test data for energy calculation in Finland [13].

RESULTS

Field measurements

Field measurements in the detached house showed +3 Pa air pressure at the ceiling level of the top floor and -4 Pa air pressure at the floor level of the ground floor on average, Figure 2, left. The dependency between air pressure difference and temperature difference in the detached house is shown in Figure 3, right. The trend of the measurement results shows good agreement with the theoretical air pressure (red curve) due to stack effect (Eq. 1). The deviation from the theoretical air pressure (red curve) is mainly due to wind effect. The standard deviation from the theoretical curve is 0.4 Pa.

$$\Delta_{ps} = \rho_{in} \cdot g \cdot H \cdot (T_{in} - T_{out}) / T_{out}, \quad (1)$$

where Δ_{ps} is air pressure due to stack effect, Pa; ρ_{in} is density of the indoor air, g/m^3 ; g is gravitational constant, 9.8 m/s^2 ; H is height between measurement points, m; T_{in} is indoor temperature, C; T_{out} is outdoor temperature, C.

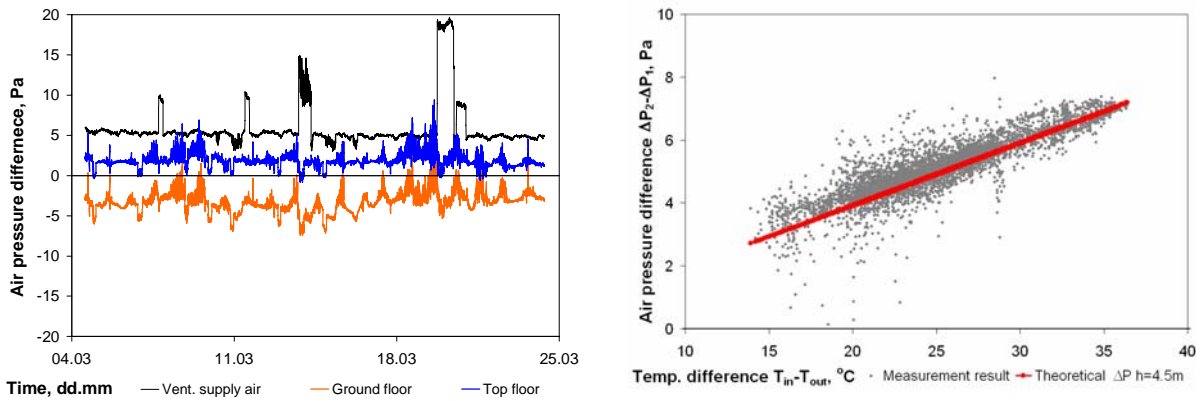


Figure 3 Air pressure difference over the building envelope during the measurement period (left) and dependency between air pressure difference and temperature difference (right) in the detached house

In the apartment building, on the first floor, the daily average air pressure difference over the building envelope was -11 Pa on average, while, on the fourth floor, it was -2 Pa, Figure 4, left. In Figure 4, left, the performance of ventilation on the apartment's second floor is also shown. The black curve is the air pressure measurement from the supply air duct. Ventilation airflows were 20% of the design value when the CO₂ level inside the flat was less than 600 ppm; the design values were switched when the CO₂ level inside the flat was higher than 1000 ppm or when the relative humidity in the bathroom exceeded 50%. This ventilation performance made a 3-Pa air pressure difference across the building envelope (Figure 4, right).

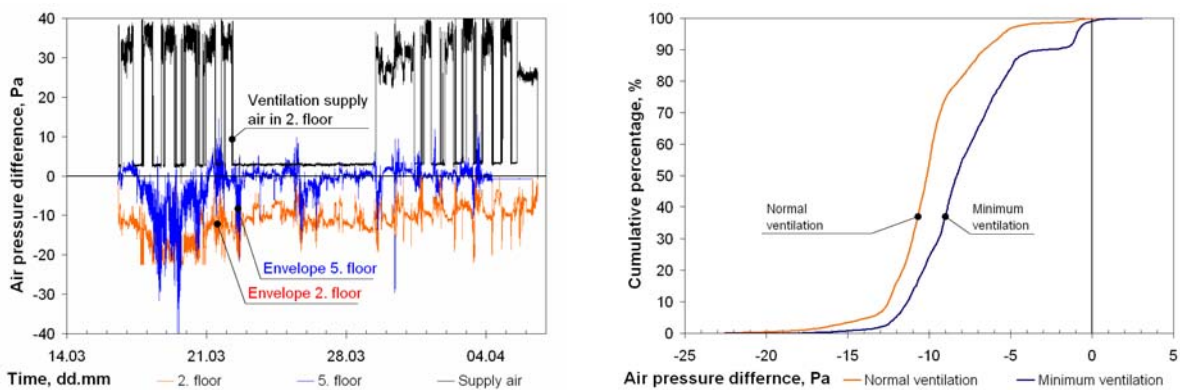


Figure 4 Air pressure difference over the building envelope during the measurement period (left) and dependency of ventilation performance on the air pressure difference (right) in the apartment building

Computer simulations

The annual air pressure difference across the envelope at ceiling level on the top floor and at floor level on the ground floor of the reference case, CASE-1 n4, is shown in Figure 5, left. Distribution of the air pressure difference during the winter season on all six simulation points is shown in Figure 5, right. Figure 6 compares the distribution of the air pressure difference in the average case with 10 % and 90 % percentile cases. There is almost always positive pressure at ceiling level on the top floor and negative pressure at floor level on the ground floor during winter. The intermediate floor can be under either positive or negative pressure.

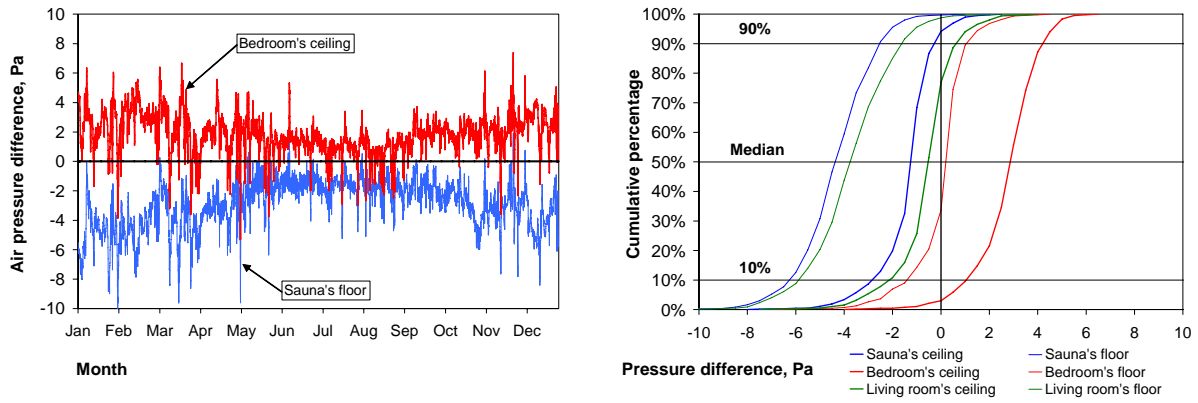


Figure 5 Air pressure difference during whole year (left) and during winter months (right)

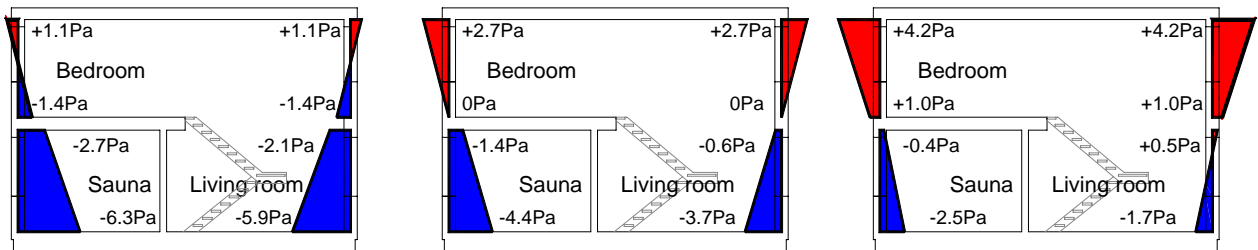


Figure 6 Average (middle), the lowest and highest 10 % percentile (left and right) air pressure difference during winter period

Table 3 shows the simulation results from two points: 10 % percentile value from the sauna at floor level and 90 % percentile value from the bedroom at ceiling level. These two points represent minimum and maximum air pressure differences at the 10 % critical level. The overall consensus [14] is that 10 % is the appropriate level to determine loads for hygrothermal calculations.

Table 3. Simulation results

Description:		Air pressure difference, Pa					
		$n_{50} = 0.15$ ach		$n_{50} = 3.93$ ach		$n_{50} = 10$ ach	
		10%	90%	10%	90%	10%	90%
Surroundings	Suburban	-7	+4	-6	+4	-6	+4
	Open country	-11	+8	-10	+8	-8	+7
	No wind cases	-6	+4	-5	+4	-5	
Air leakage distribution	Most leakages at the top of the house	-10	+2	-9	+2	-8	+2
	Normal	-7	+4	-6	+4	-6	+4
	Most leakages at the bottom of the house	-4	+8	-3	+8	-3	+8
Ventilation performance	15 % less supply airflow	-33	-22	-7	+4	-6	+4
	Balanced system	-7	+4	-6	+4	-6	+4
	15 % more supply airflow	+15	+26	-6	+5	-5	+4

Simulations show that in critical cases value of the air pressure difference across the building envelope at the 10 % percentile level is on the level +8 Pa and -11 Pa. In the most critical cases (airtight envelope with unbalanced supply and exhaust ventilation), the design value of air pressure difference across the building envelope could be up to +26 Pa and -33 Pa.

DISCUSSION

The air pressure difference across the building envelope at the 10 % percentile level in the typical detached house was +8 Pa and -11 Pa. Apartment buildings are much higher, and measurements show that the building envelope of such buildings is more airtight. Both these factors influence the air pressure difference across the building envelope and should be analyzed in addition to the others.

Air pressure simulations in the detached house were carried out during the energy test year in Finland [13]. The annual average temperature is +4.3°C, the average temperature of the coldest month, February, is -9.8°C, and that of the warmest month, August, +16.1 °C. For the period 1971-2000 in Helsinki, the mean annual temperature was +5.6 °C. Since 1900, the warmest annual average temperature in Helsinki has been +7.2 °C (1934) and the coldest +2.7 °C (1902). The annual average temperature in Finland changes from +6 °C in the southern coastal area to -2 °C in the north of Lapland [15]. The influence of different years and different locations, including apartment buildings, on air pressure difference should be studied in future studies.

CONCLUSIONS

There is almost always a positive and negative air pressure difference across the building envelope in detached houses and in apartment buildings. During winter, there is continuous positive air pressure in the detached house at ceiling level on the top floor and negative pressure at floor level on the bottom floor.

Wind influences, first of all, air pressure peak values. Comparing average values, the influence of wind is less.

For detached houses, the design value of air pressure difference across the building envelope for the moisture convection analysis is close to ± 10 Pa. In the most critical cases (airtight envelope with unbalanced ventilation), the design value of air pressure difference across the building envelope could be up to +26 Pa and -33 Pa.

The control of air pressure difference in normal and leaky houses is difficult: ± 15 differences in ventilation airflows have only a minor influence on the air pressure difference. To control extremely high air pressure differences, the balancing ventilation systems in airtight houses are very important.

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