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Short Term and Long Term Measurements of Ventilation in Dwellings

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Synopsis

A study of the reliability of systems by considering the ability of different systems to maintain a required air flow rate over time is included in a subtask of IEA Annex 27 "Evaluation and Demonstration of Domestic Ventilation Systems". Measurements were performed to determine the variation in ventilation rates due to variation in climate and variation in performance of the ventilation system. The monitoring was carried out in one-family houses and apartment buildings, which are representative of the Swedish housing stock. Three different ventilation systems were examined; passive stack, mechanical exhaust and mechanical exhaust-supply.

The monitoring period was started with diagnostic tests to discover if the installed ventilation system was functioning as designed and to determine certain values. The airtightness was tested. The air flows in mechanical ventilation were measured.

The actual monitoring phase included measurements in dwellings of overall and local (individual rooms) ventilation rates and boundary conditions. High cost and inconvenience prevent the use of continuous monitoring of these ventilation rates. A good compromise was found to be a combination of short-term continuous and long-term averaging tracer gas measurements. The main results were:
- passive stack ventilation varies over time and is at times too low
- exhaust ventilation is reasonably constant over time if the dwelling is not leaky, but is at times too low in individual rooms
- balanced ventilation is almost constant over time if the dwelling is airtight.

The paper presents and discusses the measurement techniques and the results from the measurements carried out during 1995.

1. INTRODUCTION

IEA Annex 27 "Evaluation and Demonstration of Domestic Ventilation Systems" was started last year. The overall scope of the work in this annex is to establish a general evaluation tool, which makes it possible to pre-evaluate the overall performance of different ventilation systems for domestic buildings in different climates. A number of performance criteria are dealt with within the annex. They include e. g. air quality, thermal comfort, energy, noise, life-cycle costs, moisture and reliability. The Swedish part of the research in the annex covers the reliability aspect of domestic ventilation i. e. the ability of different systems to maintain a required flow rate over time. This study is funded by the Swedish Council for Building Research. The work is divided into:
- numerical simulation of ventilation in typical dwellings
- measurements in representative dwellings
- numerical simulation of measured dwellings and comparison with the measurements
- development of a design tool for determining the reliabilty of a ventilation system
- application of the developed design tool on typical dwellings.

This paper presents results from phase 2, measurements in representative dwellings, which were carried out during the winter of 1995.

2. THE DWELLINGS TESTED

The dwellings which were examined in this project represent typical Swedish buildings. They are representative as to building technology, size of the building and ventilation system (see table 2.1 and 2.2).

Year of construction	Number, thousands	Natural, %	Exhaust, %	Balanced, %
0-1940	578	99	0,5	0,5
1941-1960	330	99	0,5	0,5
1961-1975	509	87	9	4
1976-1988	361	20	47	33
1989-1992	96	0	45	55
	1874			

Table 2.1. Year of construction and ventilation system for the Swedish one-family housing stock (Tolstoy 1993).

Year of construction	Number, thousands	Natural, %	Exhaust, %	Balanced, %
0-1940	365	64	34	2
1941-1960	770	62	34	4
1961-1975	686	19	66	15
1976-1988	192	3	36	61
1989-1992	137	0		
	2150			

Table 2.2. Year of construction and ventilation system for the Swedish multi-family housing stock (Tolstoy 1993).

The dwellings with passive stack ventilation have exhaust air terminal devices in rooms such as bathrooms, kitchens and laundryrooms and sometimes outdoor air supply to the other rooms through outdoor air vents near windows. The exhaust air terminal devices are attached to a vertical shaft to the outside. Space heating in most of the houses is provided for by radiators located below windows.

The dwellings with exhaust fan ventilation have exhaust air terminal devices in rooms such as bathrooms, kitchens and laundry-rooms and outdoor air supply to the other rooms through outdoor air vents near windows. Space heating in most of the houses is provided for by radiators located below windows.

All of the dwellings with balanced ventilation have exhaust and supply ventilation. Air is exhausted from rooms such as bathrooms, kitchens and laundryrooms and air is mainly blown into bedrooms and living-rooms. Most of the houses are equipped with radiators for space heating and with some kind of heat recovery.

The dwellings were chosen randomly. Important criteria were, however, type of ventilation, year of construction, and number of storeys (see table 2.3).

Ventilation system	Year of construction	No of storeys	Floor area, m²	Remark
Apartment building				
Balanced	1988	3	120, 120	Unoccupied
Exhaust	1990	3	58, 50	
Passive stack	1955	3	56, 55	Cross ventilation, unoccupied
One-family house				
Balanced	1991	1½	128	Crawl-space
Exhaust	1976	1½	160	Slab on grade
Passive stack	1958	1	114	Basement

Table 2.3 The tested buildings.

3. METHODS

3.1 Introduction

The measurements were started with diagnostic tests to discover if the installed systems were functioning as designed and to determine certain values:
- pressurization in order to determine airtightness of building envelope and ducts
- measurements in order to determine air flows in ducts of mechnical ventilation systems

The actual monitoring phase was began with short-term monitoring (during a winter, spring/fall and summer period):
- constant concentration tracer gas during 1 - 7 days to determine hourly variations in ventilation rates.

After each short-term monitoring long-term monitoring were carried out:
- passive tracer gas in order to determine monthly averages of ventilation rates.

During the long-term monitoring the boundary conditions were determined as follows:
- the outdoor temperature at the site was measured
- the indoor temperature was measured in at least two rooms
- the wind speed and direction was measured at a nearby weather station
- the occupants made a daily diary regarding airing and kitchen fan use.

3.2 Airtightness

The standard method for finding the leakage function of a building is fan pressurization. According to the Swedish standard for fan pressurization (SS 02 15 51) all openings in the exterior envelope intended for ventilation purposes must be sealed before the test is performed. Other openings are kept closed. For the purpose of modelling air infiltration and exfiltration, a second test was also made, with open supply vents in the dwellings with exhaust ventilation and with open vertical shafts in the dwellings with passive stack ventilation. Rooms with separate ventilation such as boiler rooms and garages are disregarded.

3.3 Ventilation

The most straightforward method of measuring the total ventilation rate i.e. the combined effect of mechanical ventilation and natural ventilation or natural ventilation only is to measure it directly. There are many ways of measuring total ventilation, and almost all of them involve a tracer gas, which permits the indoor air to be labelled so that the outdoor air ventilation can be traced (Charlesworth 1988). If the ventilation is mechanical with ducts, then in most cases the air flow in the ducts should first be measured using techniques for volume and mass flow rate measurements, without a tracer gas (ASHRAE Fundamentals 1993, NVG 1995).

The short-term measurements in the houses tested were carried out using the constant concentration technique in order to evaluate hourly variations in the total and individual room ventilation rates. The outdoor air ventilation is obtained directly. The supply of outdoor air to several individual rooms simultaneously is monitored continuously, i.e. outdoor air which enters an individual room directly instead of first passing through an adjacent room. The estimated inaccuracy in the measured outdoor air ventilation rate is ± 10 %.

A passive tracer gas technique was used to perform the long-term averaging of ventilation rates. The technique can be described as a constant flow technique with pen-sized tracer gas sources and samplers. Two different tracer gases were employed in order to be able to determine the ventilation rates for the entire dwelling and at least one bedroom. A homogeneous emission technique was used (Stymne 1994). Tracer gas was continuously injected into each room apart from bathrooms and kitchens. The tracer gas sources are adjusted to predetermined injection rates, which are proportional to the volumes of the rooms. The estimated inaccuracy in the measured outdoor air ventilation rate is ± 15 %.

3.4 Temperature

The indoor and outdoor temperatures were recorded using thermistors connected to one-channel dataloggers. Each logger stores 1800 values. The duration of the measurements can be varied from 15 minutes to 360 days. The estimated inaccuarracy is ± 0.5 °C.

4. RESULTS

4.1 Airtightness

The average airtightness of the tested apartments is 2.3 ach, compared with 6.0 for the tested one-family houses. In a previous study the airtightness as a function of year (-1940, 1941-60, 1961-75, 1976-88) of construction was presented (Kronvall 1993). Most of the tested buildings are fairly representative for their year of construction, with the exception for the apartments with passive stack and exhaust ventilation. The tested apartments with passive stack ventilation are much tighter and the ones with exhaust ventilation leakier.

Building	Number of storeys	Tested storey	Ventilation system	Volume, m³	Airtightness at 50 Pa, ach	"Typical" value, ach
Apartment	3	1	Passive stack		2.2	6.0
Apartment	3	3	Passive stack		1.8	6.0
Apartment	3	1	Exhaust		2.7	1.4
Apartment	3	3	Exhaust		5.1	1.4
Apartment	3	1	Balanced		1.3	1.4
Apartment	3	3	Balanced		0.9	1.4
Detached one-family house	1 1/2	-	Balanced		3.1	4.4
Detached one-family house	1 1/2	-	Exhaust		6.7	5.7
Detached one family house	1	-	Passive stack		8.3	6.0

Table 4.1 Measured airtightness of tested buildings compared with estimates for the Swedish housing stock ("Typical").

4.2 Ventilation rates

4.2.1 Passive stack ventilation

The hourly averages show that the overall ventilation rate varies over time. This is especially true for the apartment on the first floor, where the total outdoor air ventilation varies between 90 m³/h (0.6 ach) and 190 m³ (1.4 ach) (see figure 4.1 and 4.2). The measuring period was too short in the one-family house to see any variation. The average ventilation rate in this house was 80 m³/h (0.3 ach) during a period of 6 hours.

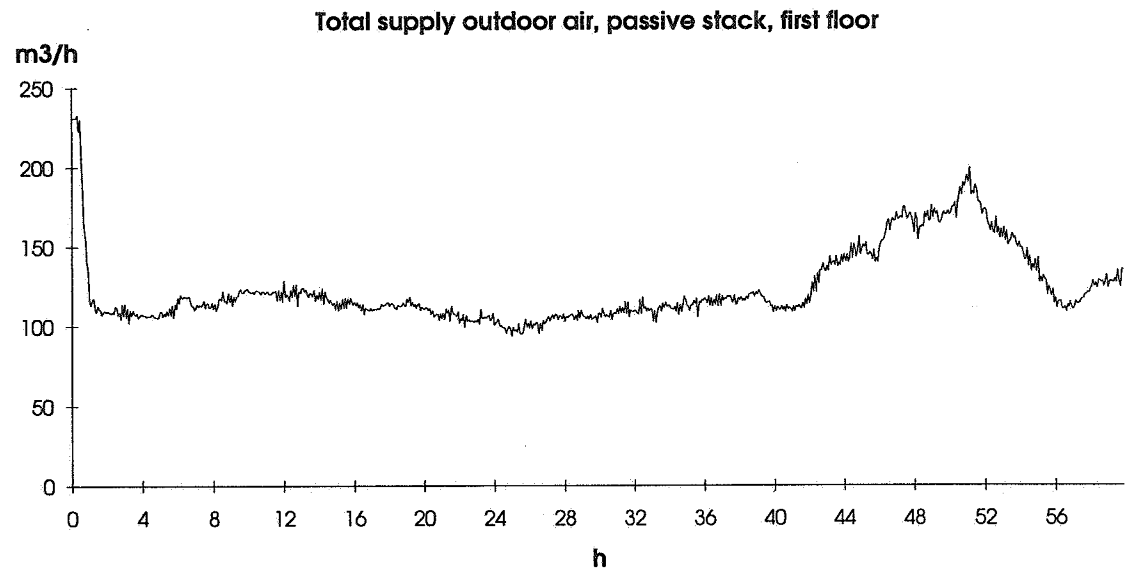

Fig 4.1 Total supply of outdoor air for the apartment on the first floor with passive stack ventilation, during a period of 60 hours. Average outdoor temperature -0.9°C (min - 8 °C, max 5 °C), average wind speed 2.9 m/s.

The outdoor air ventilation rates are very different for different rooms (see table 4.1 and 4.2) and is e g too low in the bedrooms of the one-family house.

Apartment 1st floor	**Living-room**	**Bedroom**	**Kitchen**	**Hall**	**Total**
Outdoor air, m^3/h	48	22	14	40	122
Temperature °C	19	19	19	19	
Apartment 3rd floor					
Outdoor air, m^3/h	35	17	27	6	85
Temperature °C	20	19	19	-	

Table 4.1 Average outdoor air ventilation rates for individual rooms in the passive stack apartments. For boundary conditions see figure 4.1. Apartment 3rd floor: average outdoor temperature 3 °C (min 1 °, max 5 °C), measuring period 45 hours.

	First floor				**Basement**				
	Living room	Bed-room	Bed-room	Kit-chen	Game room	Garage	Hall	Base-ment	Total
Outdoor air, m^3/h	16	4	4	5	17	17	8	9	79
Temperature °C	20	-	18	-	16	-	-	-	

Table 4.2 Average outdoor air ventilation rates for individual rooms in the passive stack one-family house. Average outdoor temperature 0 °C (min - 0.5, max 1.5 °C), measuring period 6 hours.

The long-term (monthly averages) measurements in the apartments give values similar to the short-term (hourly averages) measurements (see table 4.1 and 4.3). In the one-family house the long-term average (34 days) is much higher than the short-term average (6 hours) (see table 4.2 and 4.4). This is probably due to differences in airing, use of range hood fan and weather. During the short-term measurements the house was unoccupied.

	Living room	**Bedroom**	**Kitchen**	**Hall**	**Total**
Outdoor air, m^3/h	49	27	20	15	111
Temperature °C	-	-	-	21	

Table 4.3 Average outdoor air ventilation rates for individual rooms in the passive stack apartment on the first floor. Measuring period 25 days. Average outdoor temperature 1.2 °C (min -8 °C, max 8 °C), average wind speed 2.3 m/s.

	First floor				**Basement**				
	Living room	Bed-room	Bed-room	Kitchen	Game room	Gar age	Hall	Base-ment	Total
Outdoor air, m^3/h	19	9	13	9	13	33	8	17	141
Temperature °C	-	-	20	-	-	-	-	-	

Table 4.4 Average outdoor air ventilation rates for individual rooms in the passive stack one-family house. Average outdoor temperature 0.8 °C (-8.0, 11.5 °C), average wind speed 2.3 m/s, measuring period 34 days.

4.2.2 Balanced ventilation

Both apartments have an almost constant outdoor air ventilation due to a high level of airtightness (see figure 4.2). The measuring period was too short in the one-family house to see any variation. The average ventilation rate in this house was 155 m³/h (0.5 ach) during 6 hours. The ventilation rates of individual rooms, in the dwellings with balanced ventilation, agreed well with the measurements of the air flows through the supply air terminal devices.

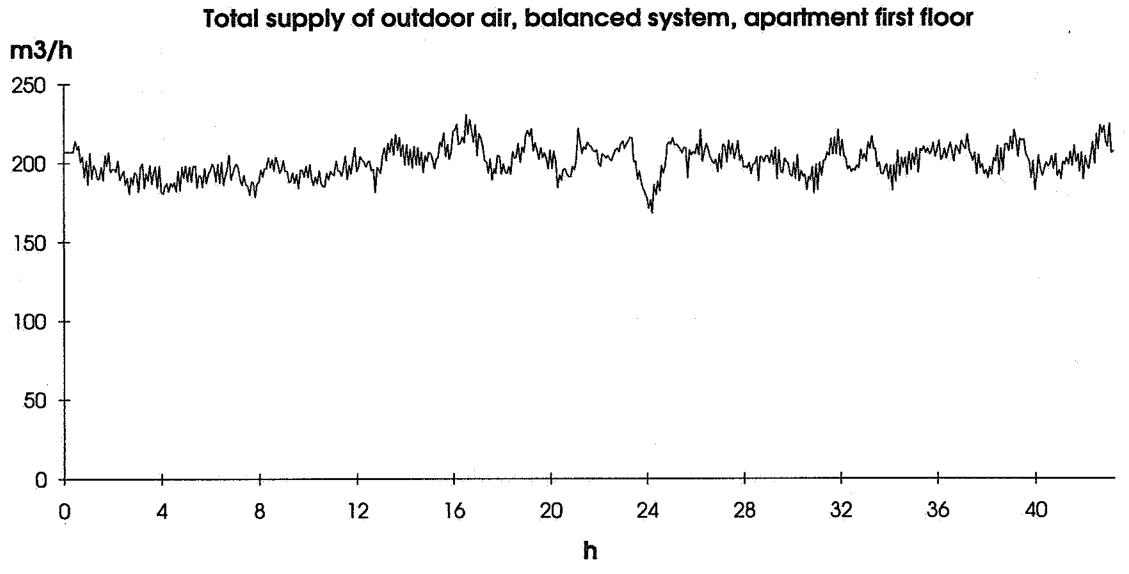

Figure 4.2 Total supply of outdoor air for the apartment (1st floor) with balanced ventilation, during 44 hours. Average outdoor temperature 3 °C (min 0.5 °, max 16 °C), wind 2.8 m/s.

4.2.3 Exhaust ventilation

The continuous measurements of the overall outdoor air ventilation in two apartments show some variation over time in the ventilation rate (see figure 4.3). For the apartment shown this is due to fairly leaky exterior walls. The average ventilation rate was 97 m³/h (0.75 ach).

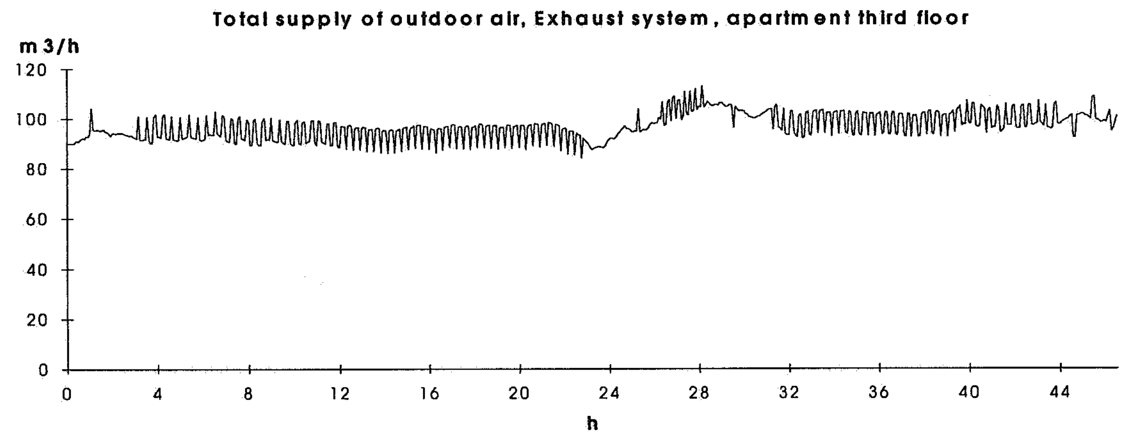

Figure 4.3 Total supply outdoor air to the on third floor with exhaust ventilation during 46 hours. Average outdoor temperature 3°C (min - 0.5 °C, max 6.5 °C), wind speed 2.3 m/s.

The outdoor air ventilation rates of individual rooms show some rooms to have too low a ventilation rate e. g. bedroom 15 and 16 in the one-family house and some rooms to have too high a ventilation rate e.g the kitchen in the apartment on the third floor (see table 4.5 - 4.6).

Apartment 1st floor	Bedroom	Living room	Kitchen	Total	Measuring period
Outdoor air, m^3/h	23	35	32	91	6 hours
Apartment 3rd floor					
Outdoor air, m^3/h	74	23	-	97	46 hours

Table 4.5 Average outdoor air ventilation rates for individual rooms in the exhaust ventilated apartments. Indoor temperature 21 °C. 1st floor: outdoor temperature 6 °C (min 5.5 °C, 9 °C). 3rd floor: see figure 4.3.

	Upstairs			Downstairs						
	Living room 14	Bed-room 15	Bed-room 16	Hall	Bed-room 9	Kit-chen	Laun-dry	Living room 6	Bed-room 7	Total
Outdoor air, m^3/h	36	8	6	33	9	6	37	3	24	163
Temp., °C	20	20	-	-	-	19	19	18	-	

Table 4.6 Average outdoor air ventilation rates for individual rooms in the exhaust ventilated one-family house. Average outdoor temperature 1 °C (min 0 °C, max 2.5 °C), measuring period 6 hours.

The long-term measurements show results similar to the short-term measurements (see table 4.7 - 4.8). There are some exceptions, the long-term average ventilation is higher for the living room in the apartment on the first floor, the same is true for one of the living rooms in the one-family house.

Apartment 1st floor	Bedroom	Living room	Kitchen	Total	Measuring period
Outdoor air, m^3/h	31	65	24	111	29 days
Temperature °C	-	21	-		
Apartment 3rd floor					
Outdoor air, m^3/h	73	27	-	119	29 days
Temperature °C	-	23	-		

Table 4.7 Average outdoor air ventilation rates for individual rooms in the exhaust ventilated apartments. Average outdoor temperature 1.3 °C (min - 8 °C, max 8 °C), average wind speed 2.3 m/s.

	Upstairs			Downstairs						
	Living room 14	Bed-room 15	Bed-room 16	Hall	Bed-room 9	Kit-chen	Laun-dry	Living room 6	Bed-room 7	Total
Outdoor air, m^3/h	41	10	10	16	14	15	-	25	12	167
Temperature, °C	20	-	-	-	-	-	-	-	-	

Table 4.8 Average outdoor air ventilation rates for individual rooms in the exhaust ventilated one-family house. Average outdoor temperature 0.7 °C, (min -8 °C, max 8 °C), average wind speed 2.3 m/s, measuring period 32 days.

5. CONCLUSIONS

5.1 Measuring techniques

Ideally the total ventilation should be monitored continuously during an entire year. There are several techniques for this purpose, but high cost and inconvenience prevent their use. A compromise is then to use short-term (1 - 7 days) continuous measurements, long-term averaging measurements and an estimation technique. The best approach is to adjust a ventilation model to fit measured ventilation values. This will improve the accuracy of the determination of ventilation. Numerical simulations of tested dwellings and comparisons with the measurements will be performed in this project. The measurements will be repeated for a summer month and a fall month.

The most straightforward approach to measurement of the total ventilation rate is to measure it directly using a tracer gas. If the ventilation system is mechanical, then the air flows in the ducts should first be measured using techniques for volume and mass flow rate measurements. There are three different tracer gas techniques: decay, constant concentration, and constant flow of a tracer gas. The constant concentration and the constant flow technique were employed as being the most accurate methods of determining the overall and the local (individual rooms) outdoor air ventilation rate. The following comments can be made:

Method	**Comments**
Constant concentration:	insensitive to effective volume problems
	unstable constant concentration can occur
	used in multichamber mode to determine supply of outdoor air
	complicated and expensive equipment
	not very practical in an occupied building
	useful for continuous long-term automated measurements
	inaccuracy in total flow rates ± 5 - 10 %
Constant flow:	relatively insensitive to effective volume problems
(passive technique)	less complicated equipment than for constant concentration
	useful for long-term averaging
	inaccuracy in total flow rates ± 15 %;
	the purging air flow can be determined
	can easily be used in an occupied building

5.2 Ventilation rates

The outdoor air ventilation rates in the dwellings with passive stack ventilation varied over time, as could be expected. Some of the individual rooms had an outdoor air ventilation rate, which at times were too low.

The exhaust ventilated dwellings had a reasonably constant outdoor air ventilation rate over time. The ventilation rate would have more constant, if the dwellings had fullfilled e g the airtightness requirements of the Swedish Building Code. Individual rooms sometimes had too low an outdoor air ventilation rate. This was especially true for the leaky one-family house, which had no outdoor air vents. If the house had fullfilled e g the airtightness requirements of the Swedish Building Code and had had outdoor air vents, then the distribution of outdoor air to individual rooms would have been better.

The dwellings with balanced ventilation had an over time almost constant outdoor air ventilation rate. This was due to the fact that the air leakage of the dwellings was very low. The dwellings fullfilled the requirements on airtightness as given in the Swedish Building Code. The ventilation systems in these dwellings were well adjusted, which meant that the individual rooms were supplied with a reasonable amount of outdoor air.

The ventilation rates will be further evaluated using a multi-zone network modell.

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