MEASUREMENT OF VENTILATION, AIR DISTRIBUTION AND INTER-ZONAL AIR FLOWS IN A 4-STOREY HISTORIC BUILDING, USING A PASSIVE TRACER GAS TECHNIQUE

J.G. Holmberg[1], H. Stymne[2], C.A. Boman[3], G. Åström[4]

[1]Royal Institute of Technology, Stockholm, Sweden, Department of Building Services
[2]Royal Institute of Technology, Gävle, Sweden, Department of Built Environment
[3]Pentiaq AB, Gävle, Sweden
[4]the National Property Board, Gothenburg, Sweden

ABSTRACT

Air temperature, air humidity and ventilation has been measured in a Swedish baroque castle. Results are presented for a measurement campaign comprising four periods under varying climatic conditions. A passive tracer gas method, known as the homogeneous emission technique has been used to measure the ventilation rates and air distribution in the building. As the palace is essentially unheated, wind pressure is the main driving force for ventilation. The air change rate is highly varying and differs considerably in different parts of the building (0.5 -1.5 ACH). The result of window renovation in certain rooms indicates that adding inner windows seems to be a possibly means to reduce infiltration rate and stabilise the indoor climate. Other means of retrofitting are also discussed.

INTRODUCTION

Läckö Palace was constructed in baroque style in the beginning of the 17th century. The National Gallery in Stockholm has decided to furnish the palace again and to decorate the walls with paintings and tapestry. However, the present indoor climate is neither suitable for such an action, nor comfortable for visitors and personnel. The indoor air is very cold and humid during winter time and spring time also creates climatic problems. The building is exposed to ruff winds blowing across the very large lake Vänern.

The overall goal of the project is to improve the indoor climate, especially with respect to the air humidity, which should be stabilised and kept at an acceptable level under 65% RH.

The following possible measures for improving the indoor climate is considered:

- improving the building envelope, especially the windows
- installing a heating system
- installing a dehumidification system

In order to get a good foundation for the measures and evaluate their effect, it was decided to perform extensive examination of the ventilation and indoor climate under varying climatic conditions before and after remedial actions were taken. The present paper describes the ventilation measurement technique and the results of a series of measurement campaigns. Besides temperature and humidity logging, extensive air infiltration studies using a passive tracer gas technique were performed. The passive tracer gas technique, used before in historic buildings by Holmberg [1], yields information of how the infiltration air is distributed in the building. Information of internal air flows between the storeys can also obtained. As the measurements were repeated several times, the effect of weather conditions can be evaluated.

DESCRIPTION OF THE BUILDING

An overview of the building is shown in figure 1. The castle is a 4 storey building surrounding a central square court. Three of the corners form tower structures, extending from the main facades. Each floor level has a space volume of approximately 4000 m^3.

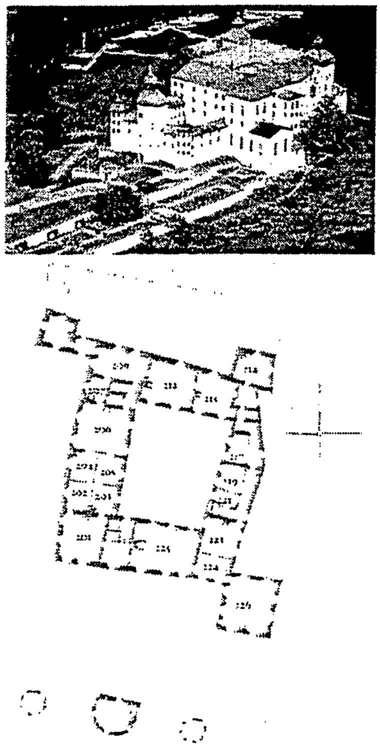

Figure 1. *Schematic layout of the castle (third floor) and a photographic view.*

The building is not heated, except for a staff room on the first floor and a restaurant on the ground floor. The windows are single glazed and rather leaky. There is no means for mechanical ventilation and the driving force for infiltration is essentially only wind pressure. The infiltration rate is therefore expected to be highly varying, depending on the wind velocity and wind direction. As the castle is situated on a tongue of land in the large lake Vänern, the wind is often strong and highly varying.

Measurement program

It was decided to measure indoor climate characteristics before and after remedial actions were taken on the building envelope and climatisation system. Due to the fact that the indoor climate is nearly completely determined by the outdoor climate, it was essential to repeat the measurement during different climatic conditions. The measurement campaign therefore included two measurement occasions during early summer time (May and June resp.) and three measurement occasion during winter time (October, November and December resp.). The last two measurements were performed after installation of inner windows in some rooms on the second and third floor level.

The measurement periods lasted 13-25 days. The following parameters were measured:

- Continuous recording of air temperature in selected rooms
- Continuous recording of air humidity in selected rooms
- Average air humidity in most rooms during the measurement periods
- Average air infiltration rates in most rooms during the measurement periods
- Air exchange between two adjacent storeys

In addition, outside air temperature and humidity as well as wind velocity and direction data were available from a nearby meteorological station.

Ventilation measurement techniques

The air infiltration rate in naturally ventilated buildings can only be measured using tracer gas methods. The "classical" tracer gas technique is the decay technique [2]. It relies on the spreading of a suitable tracer gas (e. g. sulfurhexafluoride or dinitrogenoxide) to an even concentration in the whole building and then recording the decay of the concentration as a function of time in the rooms of interest.

The *local mean age of air* (τ) at the measurement point is thereafter computed from the integrated area under the tracer concentration curve, divided by the initial concentration.

$$\tau = \frac{\int_0^\infty C dt}{C_0} \qquad (1)$$

The local mean age of air is normally converted to *local air change rate* (local ACH) by taking the inverse of the τ-value.

$$\text{local ACH} = \frac{1}{\tau} \qquad (2)$$

However, the decay technique is not suitable for field measurements in large buildings for several reasons. Apart from being a very labour and instrumentation intensive technique, the main reason is that it is not possible to attain a uniform initial concentration in a large building. Another reason is that the ventilation probably is different at different spaces, which makes it necessary to record the tracer gas concentration at many positions - a difficult matter in large buildings. A third reason is that the ventilation usually varies not only in space but also with time, a fact which makes it difficult to draw conclusions on average circumstances.

A useful alternative to the tracer decay technique is to utilise a *passive tracer gas technique*. Using such a technique, tracer gas is continuously emitted from miniature tracer gas sources, distributed in the building space. The average tracer gas concentration during an extended period is usually measured using passive diffusive samplers also distributed in the building space. The samplers are analysed in a laboratory after the experiment.

If passive tracer gas sources are distributed in the building in such a way that the emission rate (S) is proportional to the zone volume in each part of a zone divided building, the *local mean age of air* (τ_p) can be obtained from the measured local tracer concentration (C_p), divided by the emission rate per volume unit.

$$\tau_p = \frac{C_p}{\left(\frac{S}{V}\right)} \qquad (3)$$

This special passive tracer gas technique, called the *homogeneous emission technique*, has been developed by Stymne and Boman [3] and has been accepted as a Nordtest method [4].

We have used the homogeneous emission technique in the present project. Using two different types of tracer gas, it is not only possible to calculate the local mean ages of air, but also to calculate the air exchange between two storeys.

It should however be noted here that conversion of local mean ages of air into local air change rates according to equation (2) gives a biased result if the ventilation rate varies during the measurement period. If such variation occurs the air change rate is underestimated [5]. In spite of this fact, we have chosen to present the result in terms of local air change rates, which in this case should not be regarded as true averages of the room specific flow rates but rather as "effective" values according to Sherman´s terminology [5].

RESULTS

Figure 2a shows that the indoor temperature, on the average only slightly exceeds the outdoor temperature during winter time. The stack effect on infiltration rate can therefore be assumed to be small, the wind effect being the main driving force for ventilation. Figure 2b displays the corresponding indoor and outdoor air humidity, showing that the indoor humidity is high, but still 10-20% lower than outside.

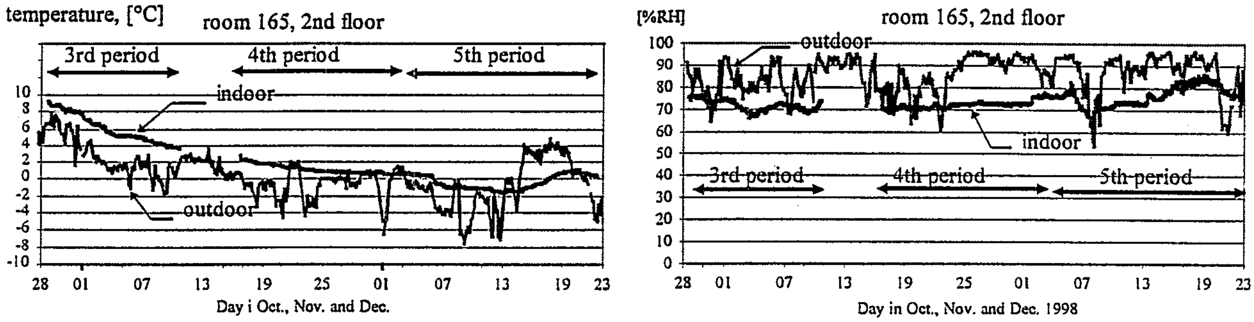

Figure 2. a) *Display of indoor and outdoor temperature during the winter measurement campaign* b) *Display of indoor and outdoor air humidity during the periods*

The driving force for wind induced infiltration is approximately proportional to the square of the wind velocity. In figure 3 the wind velocities during measurement periods 3 and 5 are displayed. It is evident that the wind is much stronger during period 5, compared to period 3. The mean of velocities squared during period 5 is 54 [m^2/s^2] compared to 31 [m^2/s^2] for period 3. The predominant wind direction is SW during both periods.

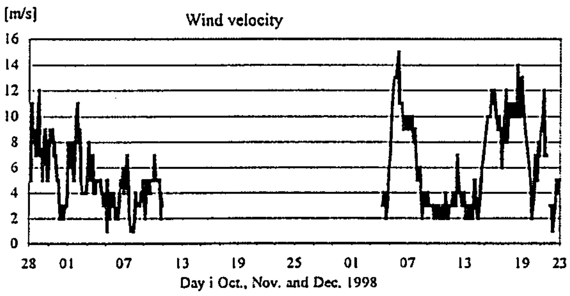

Figure 3. *Wind velocities [m/s] (3 hour averages of 10 min. intervals) during period 3 and 5.*

In figure 4 the room specific flow rates (local ACH) as determined using the homogeneous emission technique are displayed in rooms at the second and third floor level, during the third and fifth measurement periods. It can be observed that the ventilation rates differ very much from room to room and that the ventilation rate during the fifth period on the average is higher than during the third period as expected due to the higher wind pressure.

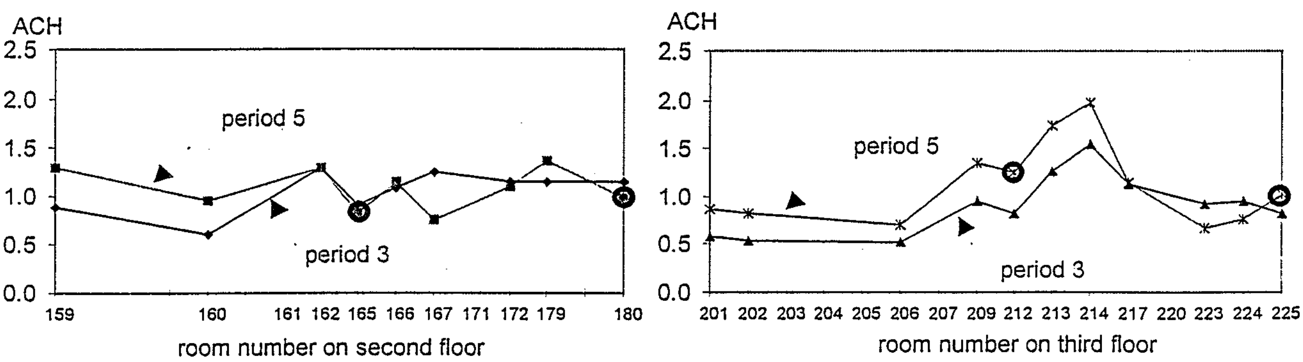

Figure 4. *Room specific flow rates (local ACH) on the second and third floors during period 3 and 5. The rooms indicated with the* o-*symbol are equipped with inner windows after period 3.*

The result displayed in figure 4 also indicates that the ventilation rates in the two rooms at the second floor, which were equipped with inner windows, show a decrease in infiltration rate (compared to the average ACH) from period 3 to period 5. The same effect is not easily observed for the rooms on the third floor, subjected to same type of renovation (especially room 212). However, the strong wind during the fifth period, together with the fact that there probably are other important paths for the infiltration air than through window leaks, makes any conclusions on the effect of the extra inner windows uncertain until more measurements are made.

Figure 5 shows that the patterns of infiltration rates during the early summer months are similar to the ones obtained during the winter.

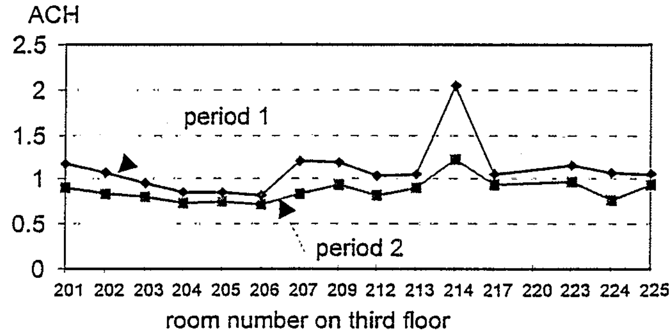

Figure 5. *Measured room specific air flow rates in rooms on the 3rd floor during period 1 (May) and period 2 (June).*

Air exchange rate between floor levels.

During the measurements two different perfluorocarbon tracer gases were utilised. During measurement periods 1 and 2, tracer gas A was used on the second floor and tracer gas B on the third floor. During the third period, tracer gas A was utilised in the ground, first and second floor, while B was used on the third floor. During the fifth period, tracer gas A was used on the ground and first floor, while B was used on the two uppermost floors. This arrangement allows estimation of exchange of air between those storeys equipped with different types of tracer gas using a two-zone approach.

Proper computation of air flow rates between zones using a two zone approach requires that the air mixing is complete within each zone. This is evidently not the case in the present building. However such calculations give valuable crude indication on the order of such air exchange. Table 1 gives estimated total airflows into the different floor levels as well as the estimated air exchange between the floor levels equipped with different types of tracer gas. Results from the fourth period is not given because of an unfortunate contamination of samplers.

Table 1. *Estimated total inflow of air [m³/h] (bold figures) into the different storeys, the air flow rate between storeys [m³/h] and the average ACH (figures within paranteses)*

	period 1	period 2	period 3	period 5
3rd floor	**6600** (1.0)	**6200** (0.8)	**6100** (0.7)	(1.2)
between 3rd and 2nd floor	1700 ↓ 3200 ↑	760 ↓ 2200 ↑	900 ↓ 3400 ↑	
2nd floor	**7800**	**3400**	**3900** (0.8)	**6500** (1.2)
between 2nd and 1st floor				1300 ↓ 1900 ↑
1st floor			(0.9)	**3600** (1.0)
ground floor			(0.7)	(0.7)

DISCUSSION

It is believed that an air humidity of 65 %RH is a suitable goal in historic buildings, in order to get an indoor climate suitable for preservation of the historic heritage and keeping an acceptable climate for people. The recommendation to the National Property Board concerning Läckö Palace, was firstly to improve the building envelope by installing a second inner window, not permanently fixed to the existing window frames, but weather proofed. Secondly it was recommended to dehumidify the indoor air using rotary solid desiccant dehumidifiers placed in fire safe comparments which are isolated with fire dampers. The equipment is placed in the attic space. Dry air is distributed to the storeys using textile ducts, suspended in the chimney channels, and recirculated via ducts suspended in chimney channels at the opposite end of the storeys (see figure 6). The dehumidification is designed to yield a moisture reduction of 2 g/kg air on a 24 hour basis.

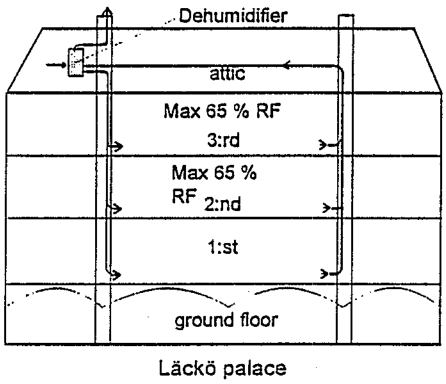

Figure 6. *Dehumidification system*

CONCLUSIONS

To be able to improve indoor climate in historic buildings, it is needed to keep the air infiltration rate under control. In order to take advantage of the experience from different building renovation measures in this context, it is of great value to be able to measure the air infiltration before and after such measures. The present work shows that the passive tracer gas method is suitable and reliable. The homogeneous emission technique allows a detailed mapping of the air distribution, which is of special importance in large buildings, like many historic buildings, in which the air infiltration may be very uneven.

ACKNOWLEDGEMENTS

The National Property Board, Gothenburg, Sweden is gratefully acknowledged for financing this study. The staff at Läckö Castle are also gratefully acknowledged for their kind assistance during the work. We also want to thank Mrs Anita Eliasson for the skilful laboratory work. We appreciate very much the interest in this project by Mr John Rothlind from the National Museum of Fine Arts and other people engaged in the preservation of this historic monument.

REFERENCES

[1] Holmberg J G (1986). "Ventilation measurements in Schloss Schönbrunn, Vienna, with passive tracer gas technique". EUREKA EU 1383 PREVENT, report no 5, Univ. of Technology, Vienna.

[2] Etheridge D, Sandberg M (1996)."Building Ventilation - Theory and Measurement", John Wiley & Sons Ltd, Chicester, UK

[3] Stymne H, Boman CA. 1996. "Determination of air distribution patterns in large premises - application examples of the homogeneous emission technique". Proceedings of ROOMVENT'96, Yokohama, Japan, 1996 Vol **1**, pp 485-492

[4]NORDTEST (1997). "Ventilation: Local Mean Age of Air - Homogeneous Emission Technique". NT VVS 118, ISSN 0283-7226.

[5] Sherman M H, Wilson D J (1986). "Relating actual and effective ventilation in determining indoor air quality". Building and Environment, **21**, 135-144 [1986].