Work Package 2: Performance of naturally ventilated buildings

Detailed Monitoring Report
The Renson office building (BE3)
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1. Introduction

This report describes the monitoring report of the office building of the Renson Company during the summer of 1997. The monitoring was executed in the framework of the NatVent project. The objective of the monitoring is to evaluate the performances of a natural ventilated office building under summer conditions.

2. Description of the building

2.1 The Renson office building

The Renson Company produces components for natural ventilation such as (self-regulating) window ventilators for hygienic ventilation, large grilles for intensive ventilation, etc… (for more information see: www.renson.be). The company employs about 125 people and has a turnover of 800 million BEF. The main office is located in the industrial zone ‘Flanders Field’ at Waregem, Belgium. Air pollution is not a problem in this area but noise is an important environmental constraint as the office building is situated along an access road of the industrial zone.

Figure 1: Front façade of the Renson office building (before renovation)

The office building is a two-storey building constructed of prefabricated concrete elements. These elements have an internal insulation layer of 3cm PUR. The building has a flat roof, which is insulated with a layer of 5cm PUR.

The reception, a showroom and a landscape office are situated on the ground floor. The first floor contains several offices and two meeting rooms. A central open staircase connects the ground floor and the first floor.

The rear side of the building is connected to the production hall (see Figure 2). This partition wall is not insulated. The front façade of the building is south-west oriented and contains a considerable net surface of glazing (25%) (see Figure 1).
2.2 The renovation project

In the beginning of 1997, for several reasons it was considered to replace the existing double-glazing of the building. In the framework of this replacement of the double-glazing rose the idea of a more wider renovation of the building.

2.2.1 A package of renovation measures for thermal summer comfort

The experiences of the previous summers (1995 and 1996) showed that overheating is a main comfort problem in the existing office building. Therefore a small cooling unit was already installed in the drawing room. The internal temperatures in this office were especially high due to the considerable internal gains from computers. As active cooling was not desired for the other offices, a detailed study was carried out to analyse the influence of several renovation ‘passive’ renovation measures on the thermal summer comfort. The following measures were considered in the study:

- Reduction of the direct solar gains through the glazed surfaces by:
  - movable horizontal overhangs (see Figure 3)
  - selective glazing (g-value = 0.34)
  - external vertical screens (solar transmissivity = 0.10)
- The application of intensive night ventilation.

<table>
<thead>
<tr>
<th></th>
<th>g-value</th>
<th>U-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>double-glazing (before renovation)</td>
<td>0.77</td>
<td>3.0 W/m²K</td>
</tr>
<tr>
<td>selective glazing (after renovation)</td>
<td>0.34</td>
<td>1.3 W/m²K</td>
</tr>
</tbody>
</table>

Table 1: Characteristics of the glazing
Other renovation measures like increasing the insulation of the roof (to reduce the indirect solar gains) were not evaluated, as they were not considered as feasible.

Figure 3 gives the results of the simulations with the ESP-r program of several models with different shading devices for a warm week of the Test Reference Year of Ukkel (Belgium). The figure illustrates clearly the important influence of the reduction of the direct solar gains on the indoor climate. The best results are obtained by placing an overhang.

The orientation of the façade is an important element in the functioning of an overhang. The front façade is south-west oriented. This means that the sun is located rather high when it is shining on the front façade. Therefore the overhang provides a lot of shading and its impact on the internal temperatures is substantial. The effect of an overhang on a west or east oriented would be much smaller.

The internal summer comfort can also be improved by the application of intensive night ventilation. The objective of night ventilation is to cool down the internal mass of the building by high ventilation rates of cold external air. There are two indispensable elements in this concept: the internal mass & the high ventilation rates:
Night ventilation: In a first phase the possibilities of a completely natural night ventilation design were evaluated. This first concept is based on the thermal stack effect. The building is divided in two zones (see Figure 7). The first zone (continuous line) contains the ground floor and the two meeting rooms on the first floor. The second zone (dotted line) contains the separated offices on the first floor. On all floors the fresh air is supplied through large supply grilles, which are integrated in the window frames (see Figure 6). The air is extracted through two chimneys on the roof:

- A first chimney above the stairwell, on the flat roof (Figure 7 – section BB). This chimney is placed above an existing roof light. The chimney is controlled in function of rain, time and internal and external temperature. An external screen is integrated in the chimney to reduce the solar gains if necessary.

- A second chimney on the roof of the production hall (Figure 7 – section AA). This chimney is placed on the roof of the production hall to create a certain height difference with the supply grilles (stack effect!). The chimney is connected to the offices by a large duct (1,5 x 0,7 m²).

The installation of this last chimney involved a lot of practical problems. Therefore in the final solution it was chosen to apply mechanical extraction for zone 2 (see Figure 8). The fan has a maximal airflow of 4,900 m³/h (or ±7 air changes per hour). An internal temperature sensor and a clock will control the fan.

The final ventilation system is a hybrid system: zone 1 is ventilated completely natural, zone 2 has free (or natural) supply and mechanical extraction.)
Table 2: size and characteristics of grilles

<table>
<thead>
<tr>
<th>Net Size</th>
<th>Flow Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>± 2 x 0.81 m x 1.22 m (surface)</td>
<td>976-1660 m³/h.m² @ 1 Pa</td>
</tr>
<tr>
<td>± 4 x 0.9 m (length)</td>
<td>16-81 m³/h.m @ 1 Pa</td>
</tr>
</tbody>
</table>

Figure 7: Intensive night ventilation – first design: completely natural ventilation

Figure 8: Intensive night ventilation – final design: hybrid ventilation

- **Internal mass**: The second indispensable element in the concept of intensive night ventilation is the presence and the accessibility of the internal mass. The building has concrete floors and ceilings. A lot of this internal mass is however not accessible as the
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building has a false ceiling and carpet (see Figure 9). Therefore the impact of the intensive night ventilation on the peak temperatures during the office hours is rather limited (see Figure 10).

Figure 9: Landscape office on ground floor

Figure 10: Impact of intensive night ventilation on the internal temperature during a warm week in June – simulation results

Based on the results of the simulations it was decided to carry out the following actions to improve the summer comfort:

- Replacement of existing glazing by selective glazing
- Installation of movable overhangs
- Installation of chimneys, a fan and large louvres for intensive night ventilation
The combined influence of these measures is given in Figure 11.

![Figure 11: Impact of the overall package of renovation actions on the internal temperature during a warm week in June – simulation results](image)

2.2.2 A hybrid ventilation system for IAQ

The existing ventilation system for IAQ (Indoor Air Quality) consists only out of ventilation grilles above the windows (see Figure 6). These ventilation grilles are all located at one side of the building (the front façade). This implies that the ventilation grilles are at the same time supply and exhaust opening. The working of the system depends on the variation of the wind pressure on the façade. Therefore both the ventilation flows and the indoor air quality in the offices are very variable.

To achieve a more constant indoor air quality a hybrid system was installed (see Figure 12). The ventilation grilles above the windows serve as natural supply and the supplied air is mechanically extracted. Therefore a ductwork with several extraction devices was installed in the building. The devices in the offices extract 50m³/h.pers. This extraction works only during the office hours. The mechanical extraction in the meeting rooms can be manually controlled (Off + 4 levels). At last there is also an extracting system foreseen in the toilet rooms (30m³/h.toilet).
3. The measurement campaign

Two measurement campaigns have been organised. One during the summer of ‘97 and one during the winter of ‘97-’98. These measurement campaigns have different main objectives:

- Summer measurements: The main objective of the summer measurements is to evaluate the influence of the different renovation actions mentioned in §2.2.1 on the thermal summer comfort.
- Winter measurements: The main objective of the winter measurement is to evaluate the performances of the hybrid system for hygienic ventilation described in §2.2.2 (CO₂-concentration, internal wind velocity, etc.).

3.1 Summer monitoring

3.1.1 State of the renovation works

The renovation actions for a better summer comfort were not completely finished before the end of the summer of ’97. The large ventilation grilles in the front façade were installed. The chimneys on the roof and the extract fan between the first floor and the production hall however were not yet installed. Also the overhangs and the selective glazing were installed only after the summer of ’97. Table 3 gives an overview of the state of the renovation works during the monitoring period.

<table>
<thead>
<tr>
<th>Renovation action</th>
<th>Completed</th>
<th>In progress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Louvre grilles in front façade</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Extract fan &amp; chimney</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Overhangs</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Selective glazing</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

Table 3: State of the renovation works at the start of the summer monitoring campaign
Therefore the measurements are rather a presentation of the situation before the renovation. The only substantial difference is the application of intensive night ventilation.

At night the large louvre grilles in the front façade and the doors between the office building and the production hall (see Figure 13) were opened. As the extract chimney and fan were not yet installed there are no main driving forces. Therefore several patterns of ventilation flows are possible (see Figure 13). The patterns depend on the pressure differences on the front façade.

![Figure 13: Possible flow patterns – night ventilation during the monitoring period](image)

### 3.1.2 Monitoring set-up and monitoring periods

The following measurements were carried out in the office building:

- **During the whole summer (01/06/97 – 01/10/97)** the **internal temperatures** of all offices were measured every 30 minutes by means of Tinytag® dataloggers. The accuracy of these temperature measurements is about 0.4K. Unfortunately, the measurements in office 6 failed (see Figure 15).

- **Supplementary measurements** in office 6 (28/08/97 - :26/09/97):
  - internal wind velocity
  - heat flux: A heat flux sensor was placed under the carpet on the concrete floor to study the influence of the thermal mass.
  - surface temperature at the heat flux sensor

- **The ventilation flows** in the offices were measured by using active tracer gas techniques (28/08/97 – 31/08/97). The tracer gas SF₆ was used and the constant concentration technique was applied (target concentration: 5ppm SF₆). The location of dosers and samplers is given in Figure 15. The ventilation flows were analysed by a multipoint sampler and doser unit Bruel&Kjaer 1303. The constant concentration technique is described in several publications (1).
Remark on tracer gas measurements:

Office 9 is one large open zone. In theory this zone forms one zone together with office 7 because the stairwell connects them. In reality the influence of the dosers is limited. A fictitious barrier is given in Figure 15. This assumption is confirmed by the results of the tracer gas measurements (See Figure 20).

Figure 15 shows in which zones the concentration of SF₆ is kept constant (5ppm). The concentration of SF₆ in the other zones and the production hall is very low or even zero.

This means that for an office with a constant concentration both the air exchanges with the external environment and air exchanges with the other offices with a low concentration lead to an injection of SF₆ in the office. This implies that the measured ventilation rate of an office includes the air exchange with the outdoors as well as the air exchange with the other offices where the concentration of SF₆ is not kept constant.

![Figure 15: Set-up of the tracer gas measurements](image)

<table>
<thead>
<tr>
<th>Office</th>
<th>Surface</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 &amp; 2 (1 zone)</td>
<td>72m²</td>
<td>194m³</td>
</tr>
<tr>
<td>3</td>
<td>32m²</td>
<td>86m³</td>
</tr>
<tr>
<td>4</td>
<td>32m²</td>
<td>86m³</td>
</tr>
<tr>
<td>5</td>
<td>32m²</td>
<td>86m³</td>
</tr>
<tr>
<td>6</td>
<td>29m²</td>
<td>79m³</td>
</tr>
<tr>
<td>7</td>
<td>39m²</td>
<td>105m³</td>
</tr>
<tr>
<td>8</td>
<td>78m²</td>
<td>215m³</td>
</tr>
<tr>
<td>9</td>
<td>237m²</td>
<td>641m³</td>
</tr>
</tbody>
</table>

Table 4: Dimensions of the offices
3.1.3 User behaviour and internal gains

It is necessary to have some information on the internal gains and user behaviour to analyse the measurement results.

User behaviour: In principle all windows were closed during daytime. However, the measurements reveal that the windows sometimes were opened during the office hours (see §4.2). The occupants were asked to open at night the large ventilation griles, all the internal doors (first floor) and the doors to the production hall. For reasons of security the doors of **office 6** were always closed. Also during daytime the doors of this office were always closed. This means that the measurements of the air flows through this office can not be influenced by air flows coming from office 7, which has a low SF<sub>6</sub>-concentration. The measured air flows of office 6 are only air flows coming from the exterior.

The internal gains of all offices (ground floor and first floor) are quite similar. Only the internal gains in office 1 and 2 (drawing room) are especially high due to the large number of computers, printers and plotters. In this room a unit of active cooling installed.

3.2 Winter monitoring

The objective of the winter monitoring is to analyse the performances of the ventilation system for IAQ. This can be done by means of CO<sub>2</sub>-measurements.

The installation of the mechanical exhaust system was however not finished at the beginning of the winter of ‘97-‘98. Therefore no measurements were performed with the hybrid system.

4. Measurement results and analysis

The results of the monitoring campaign are analysed in several steps:

- Analysis of the temperature measurements (§4.1)
- Analysis of the tracer gas measurements (§4.2)
- Analysis of the heat flux measurements (§4.3)

4.1 Temperature measurements (Tinytag® dataloggers)

The internal temperatures of all offices (ground level and first floor) were measured during the whole summer (01/06/97 – 31/08/97) by means of dataloggers.
Figure 17 gives the internal temperature of some offices on the first floor:

- Office 4 has the lowest internal temperature. The temperature of office 4 is also very dynamic: the temperature decreases strongly at night. This could mean that the night ventilation is the most intensive in office 4. The ventilation flows and the relationship with the internal temperature are studied more in detail in §4.2. One of the main advantages of the application of intensive night ventilation seems to be that the internal temperature drops very fast after a warm period instead of staying at a high level (see Figure 17 day 5/9 & 6/9 & 7/9).

![Figure 17: Internal (first floor) and external temperature (28/8/97 – 11/9/97)](image)

- Office 1 & 2 is the drawing room. This room is equipped with a cooling unit. The temperature in this office is however higher than in the other office. This can be due to several reasons:
  - The power of the cooling unit is not sufficient
  - The temperature sensors are place outside the influence zone of the cooling unit
  - …

- There is very clear relation between the internal temperature and
  - the internal gains: The internal temperatures are lower during the weekends (30/8 & 31/8) due to the absence of internal gains. These results prove how important it is to reduce the internal gains by the use of low energy lighting and equipment (PC’s, screens, …)
  - the solar radiation (see Figure 18): The solar gains through the transparent surfaces of the front façade sharply raise the internal temperature. This rise occurs in the afternoon as the front façade is south-west oriented. It is clear that the indoor climate can be improved a lot by installing a shading device like the planned overhangs.

Figure 19 shows the internal temperature of the landscape office on the ground level and the average temperature of several offices on the first floor. The internal temperature on the first floor is higher than the temperature on the ground floor, because:
• the landscape office has no indirect gains through the roof
• the influence of the shading of the surrounding buildings is the highest for the landscape office on the ground floor.

Figure 18: Solar radiation (28/8/97 – 11/9/97)

Figure 19: Internal and external temperature – comparison first floor & ground floor (28/8/97 – 11/9/97)
4.2 Ventilation flows

The ventilation flows were measured by means of tracer gases. The set-up is described in detail in §3.1.2 (see also Figure 15). The constant concentration technique was used. Figure 20 shows the concentration in an office with a doser (office 6) and an office without a doser (office 7). The SF₆-concentration in office 6 is continuously kept at 5ppm. The concentration of SF₆ in office 7 is very low. Office 7 forms in principle one zone together with office 9 (= zone with a doser). The effective area of the dosers in office 9 is however limited, as the concentration of SF₆ in office 7 is very low. Therefore office 7 can be considered as a separated zone without a doser.

In the further discussion we will analyse the airflows of office 5 and 6. These are the only two offices were an injection of SF₆ always corresponds with an air change with the exterior, because:

- the SF₆-concentration in the office around office 5 is kept constant
- the internal doors of office 6 were always closed.

For the other monitored offices (office 4 & 9 – see Figure 15) it is possible that an injection of SF₆ corresponds with an air exchange with another zone (office 3, production hall, etc) where the SF₆-concentration is very low.

![Figure 20: SF₆-concentration](image)

The measured ventilation flows of office 5 & 6 are given in Figure 21.

- The air changes of office 5 are considerably larger than the air changes of office 6. This phenomenon can be due to several reasons:
  - The louvre grilles were only partially opened or not opened at all
  - The internal doors of office 6 are always closed. This means that only single sided ventilation is possible. Ventilation between different offices due to pressure differences on the front façade is in that case excluded.
Unfortunately it is not possible to see whether the difference in night ventilation also leads to a difference between the internal temperatures; the temperature measurement in office 6 failed.

- As the grilles have to be opened manually, the system of intensive night ventilation is very **user-dependent**. Examples:
  - The air changes are very low during some nights (4/9-5/9, 9/9-10/9, 10/9-11/9). Probably grilles were not opened. (Maybe to avoid too low temperatures in the morning)
  - The grilles were opened in the forenoon of 4/9.
These results show that it is very important to give clear instructions to the occupants.

- During the weekend of 6/9-7/9 the grilles in office 5 were opened all the time. There is a clear relation between the ventilation rates and the indoor-outdoor temperature difference (see Figure 22). The higher the indoor-outdoor temperature difference, the higher the air changes.

**Explication:** During the measurements the ventilation of the offices was mainly based on single sided ventilation through the large louvre grilles. The ventilation through a large opening depends mainly on the temperature difference at the opening (stack-effect):

\[
Q = 0.04WH^{1/2} \Delta T^{1/2}
\]  

with

- \( W \) = width of the opening
- \( H \) = height of the opening
- \( \Delta T \) = temperature difference at the opening

![Figure 21: Air changes (4/9/97 – 11/9/97)](image-url)
Remark: In the final situation office 5 will be ventilated mechanically (±5 ACH).

After the weekend the internal temperatures is quite low: 17.5°C (see Figure 22). This is one of disadvantages of the system. (This is probably also the reason why no night ventilation is applied during the following nights).

4.3 Thermal mass

In office 6 a flux sensor was placed on the top surface of the concrete slab, under the carpet (see Figure 24). The measured heat flux through the surface gives an idea of the working of the thermal mass of the concrete element.
Figure 24: placement of flux sensor

Figure 25 gives the measurement results. The black thin line shows the measured heat flux. A positive value means that there is a heat flux from the concrete to the zone and vice versa. In the context of summer comfort it is interesting to see that the concrete transfers a heat flux of $\pm 13 \text{W/m}^2$ at most.

Figure 25: Heat flux at concrete surface in office 6 and external temperature

The thick black line gives the daily moving average of the heat flux through the surface. This line shows the behaviour of the mass on day level. It is clear that the mass absorbs heat during warm periods (see the curves of the external and the surface temperature) and releases this heat during colder periods. The mass has a buffer function.
Interesting questions are…:
− How important is the influence of the carpet insulation on the accessibility of the thermal mass?
− The night ventilation air flows of office 6 are rather limited (see Figure 21). In which measure can the effect of night ventilation be improved by more intensive night ventilation?

Comparative measurements and simulations will have to give more information.

5. Conclusions

During the measurement period not all foreseen renovation measures were already carried out. Therefore the thermal comfort in the building can still be improved by several measures. The most important possible improvements are:

➢ Reduction of the direct solar gains by a shading device, as the overhang which is foreseen in the total concept.

➢ To increase the air flows at night. The air flows of the hybrid system for night ventilation, which is explained in §2.2.1 will be much higher than the measured air flows in some offices during the monitoring period.

The measurements also revealed that the working of the system depends strongly on the punctuality of the occupants. The large ventilation grilles have always to be opened at night and windows and large ventilation grilles must stay closed during the day when the outside temperature is higher than the inside temperature. Therefore the distribution of clear information to the occupants is a crucial element.

6. References

(1) AIVC, Air Exchange and Airtightness Measurements Techniques – An Application Guide, Peter S. Charleswort
(2) IEA, Annex 20 Air flow patterns within buildings – Airflow through large openings in buildings – Subtask 2 Technical Report, J. van der Maas