DOUBLE FACADES: COMFORT AND VENTILATION AT AN EXTREME COMPLEX CASE STUDY

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ABSTRACT

In a Dutch project the double façade became an integral part of the ventilation concepts aa well as the heating system by trying to optimize the heat gain within the cavity during spring and autumn. The study shows how variable facade parameters influence the energy flows coming through the facade, in order to optimize the indoor environment for the comfort of the individual occupant. How can the facade make optimal use of the free incoming energy flows to maximize the comfort level of the individual building occupant at minimal energy use? The type of façade described as a second skin façade is characterised by a single glass layer on the outside and an isolated façade layer on the inside. The application of the single glass layer as a second skin around the insulated layer results in an air cavity between these two layers of around 0.9 m. The property that distinguishes a second skin façade from other DSF is that it relies on natural ventilation of the cavity, in comparison to other facades which use mechanical systems to induce the airflow. The advantage of merely using natural ventilation in the façade cavity is the lower energy consumption. However, it also results in some unresolved issues which require further attention. The researched was focussed the behaviour of the highly complex shaped second skin facade of a Dutch office building, and its thermal comfort impact on the building user. During 3 weeks different measurements were done to determine the main characteristics of the glass and the cavity of the facade. A key difference between a second skin facade, as well as other climate facades, and more traditional opaque facades is its dynamic behaviour. DSF have several adjustable properties, such as the shading device and ventilation mode, and because various physical processes take place in the air cavity, these facades can show very dynamic behaviour. In case of a second skin facade this dynamic behaviour is especially of interest since its cavity airflow merely relies on temperature differences and wind effects to induce the ventilation in the cavity, resulting in very limited control and highly erratic behaviour. The complex form of the facade in combination with the large atrium and exhaust only ventilation of the offices in the case study led to a problematic thermal indoor environment.

KEYWORDS

Please provide a maximum of five keywords which reflect the content of the paper

1 INTRODUCTION

A building envelope is critical to the energy performance and comfort of its occupants. As more buildings are becoming better insulated, lesser energy in the nearest future would be needed to counter excessive gains/losses through the envelope(Kalmar and Kalmar 2012). However, there is a shift towards the impact of the glazed area of building envelopes on energy consumption and comfort (Tsikaloudaki et al 2012). From the energy and comfort perspective, glazed components of a building’s façade can act as both the strongest and weakest element (Clarke et al 1998). Although glazed areas of building envelopes are not the only factors that influence both physical and physiological comfort of building occupants, its influence on both energy consumption and physical comfort becomes significant when building occupants due to innate need to be in contact with nature (Boyce et al., 2003)are situated close to the glazed surface area for extended periods. The interior surface temperature of glass, the most commonly used glazing material due to its thermal properties is highly susceptible to changes in the outdoor weather and compared to other opaque elements of the building façade, is a lot more vulnerable to energy flows (Tsikaloudaki et al., 2012). Variations in outdoor weather conditions influences the interior surface temperature of glass significantly affecting the radiant heat exchange between an occupant the environment (Arens et al., 2006).

The façade of a building is one of its most distinct features, defining not only a buildings aesthetics, but also separating the indoor environment for the outdoor climate as a large part of the building shell. As a result of this, a façade strongly affects the comfort level and energy use of a building. Improving the performance of the façade is therefore aspired in order to further improve the quality of a buildings indoor environment while also reducing its energy consumption. In modern buildings the facade is often considered as part of the climate system, since its performance greatly affects the indoor climate and thus comfort and energy use. The second skin principle offers excellent possibilities to improve the comfort level and energy use of existing buildings, by applying the second skin to its current facade.

In today's modern architecture, highly glazed envelopes are a common feature of non-residential buildings and for more efficient control of energy gains through glazing components on the facade of adequately insulated building envelopes, various active façade building systems have been proposed (Altan et al., 2009). One of the common systems available in practice today is the naturally controlled double skin façade system which relies on the stack effect. The potential of this system lies in the possibility of obtaining a dynamic behaviour by creating a naturally ventilated air-gap between two glazed layers with the possibility also to locate a shading device within the gap to protect against direct solar radiation(Serra et al., 2010). In recent years a good deal of research has been done on the energy performance of the double skin façade (Pappas and Zhai 2008, Hashemi et al. 2010, Gratia and de Herde 2007, Jiru and Haghighat 2008, Saelens et al. 2008, de Siva and Gomes 2008, Chan et al. 2009, Jini et al. 2011, Lou et al. 2012),

For efficient control of heat flux through the glazing into the building interior in temperate climates, the air flow through the cavity should be high in summer but low in winter. However due to dependence on environmental wind conditions, in practice large mechanical systems have to compensate for excessive gains or occupants would have to tolerate some level of discomfort due to varying radiant temperature resulting from varying glass surface temperatures. In the design of building control strategy in temperate climates regions as that in the Netherlands, designers often only consider the effect of extreme weather changes in winter and summer but little attention is placed on the periods in-between this extremes such as autumn and spring with rapid frequent variations in outdoor weather conditions. In highly glazed building envelopes this frequent changes in the outdoor climate may affect the radiant temperature, which has a major influence on thermal comfort(Dong et al 2010).

Despite all these positive effects associated with the application of the second skin façade to buildings, sometimes realized applications are linked with comfort problems (Lyons 2000. Poirazis 2006, Hwang and Shu 2011, Joe et al 2013) The inducement for this study originates from a building in the Netherlands, displayed in Fig. 1. Occupants of this building complained about the quality of the indoor environment, especially the thermal environment. It was discovered that the behavior of the applied second skin was not in accordance with its design, and the presumption is made that this could be the cause of a part of the comfort complains. Considering all the positive and negative implications associated with a second skin facade made it a very interesting subject for further study.

Figure 1: Outside of the façade, the cavatity of the DSF and the atrium behind the DSF

In subsequent sections of this paper, preliminary results from measurement obtained from a modern naturally controlled highly glazed office building in the Netherlands is presented. The impact of frequent variations in the outdoor weather , particularly the effect of direct solar radiation and daylight on occupants working near the glass façade is discussed.

2 MEASUREMENTS

During a period of nearly two weeks, from April 5th till April 17th 2013, the temperatures within the cavity were measured as well as the indoor solar radiation in the horizontal plans as well as parallel to the window. The surface temperatures (T_s) of both sides of both panes are measured in one line and not too close to the window frame. The different sensors that are used for the measurements can be found in table 1. Since the measurements continue for one week, the data is stored with data loggers. Two different data loggers are used. One data logger is used for the parameters that are measured in the office space and one for the parameters that are measured in the cavity and outside the building. This data logger has a wireless connection with transmitters that are connected to the sensors, which makes it possible to station the data logger inside and the sensors and transmitters outside and in the cavity.

Table 1: Sensors used by measurements

Parameter	Sensor	Accuracy
Temperature	NTC thermistor Sensor data DC 95	calibrated sensitivity
Solar radiation	Pyranometer (CM5 and CM11)	1 %
Air velocity	Dantec 54R10	calibrated sensitivity

The air temperatures (T_a) in the cavity are measured at three levels: 2^{nd} floor, 3th floor and 4^{th} floor. The pyranometer and air temperature sensor to measure the outside conditions are placed on appropriate positions on the roof, where there are no obstructions. The air temperatures inside are measured at 0.5 m from the façade at a height of 1.10 m. The air velocities are measured on the same positions as the air temperature at 0.5 m from the façade at a height of 1.10 m. The horizontal radiation asymmetry (T_{ra}) is measured at 0.5 m from the façade at a height of about 1.1 m and the vertical radiation asymmetry is measured at the same distance from the façade at a height of about 1.1 m. The solar radiation inside is measured vertically at a minimum distance of the façade, see Fig. 2 and for the set-up Fig. 3. The airflow through the outlet grills at the top of the cavity were measured as well as the air flow through the open windows on the 4th floor, see Fig. 4

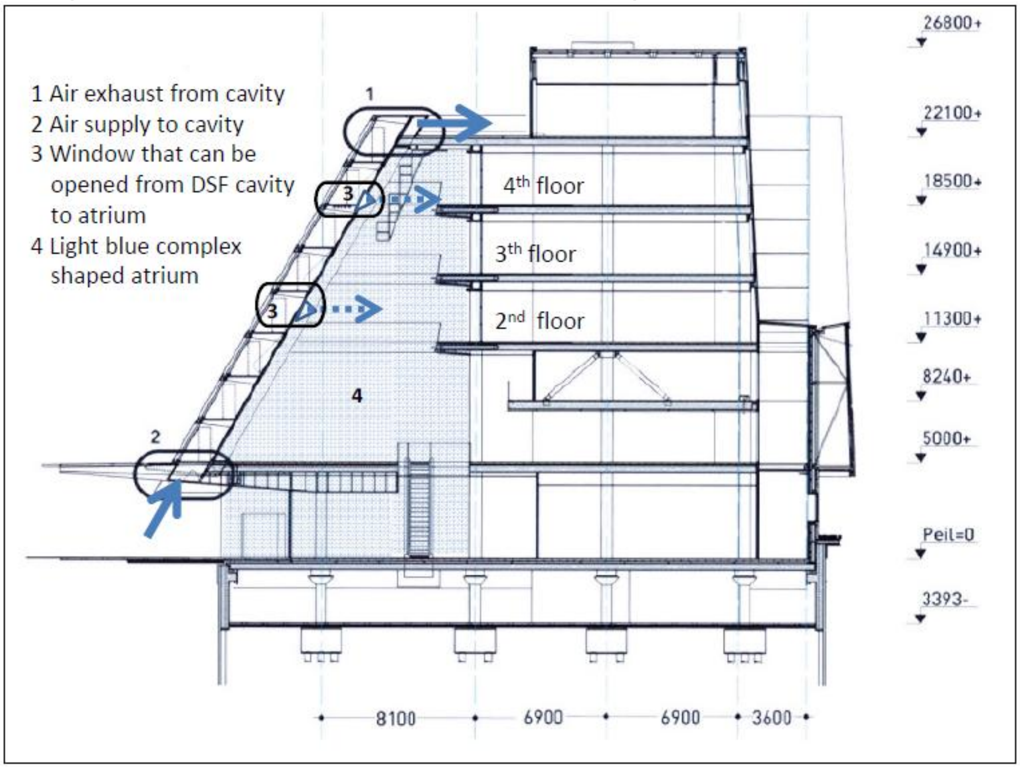

Figure 2: The schematic representation of the ventilation supply from the cavity to the atrium

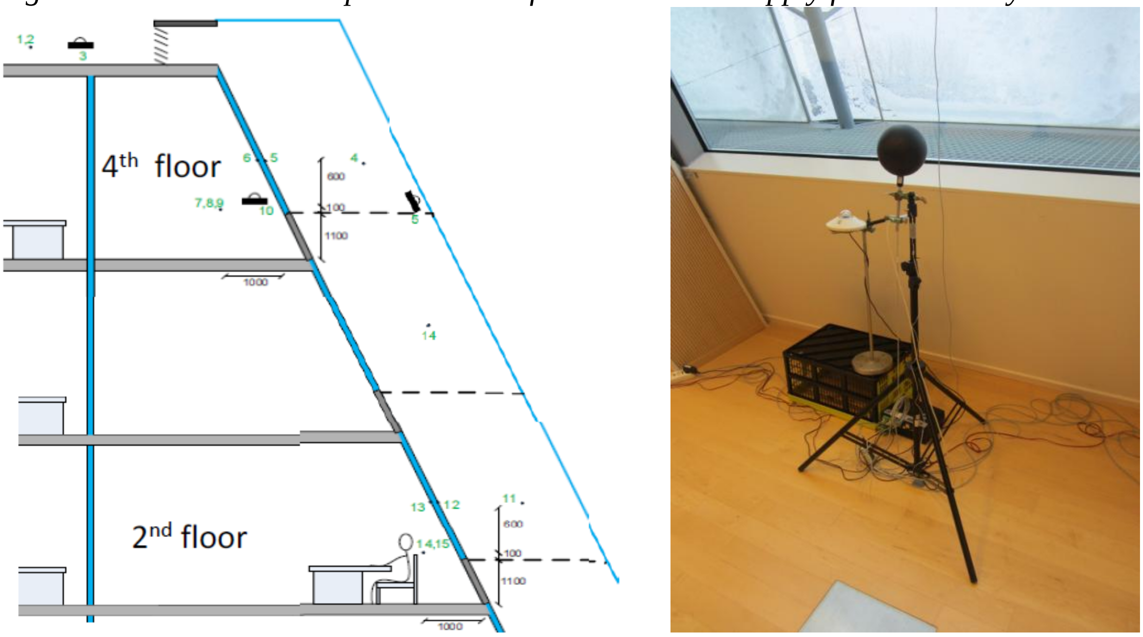

Figure 3: The schematic measurements setting on the 2nd and 4th floor

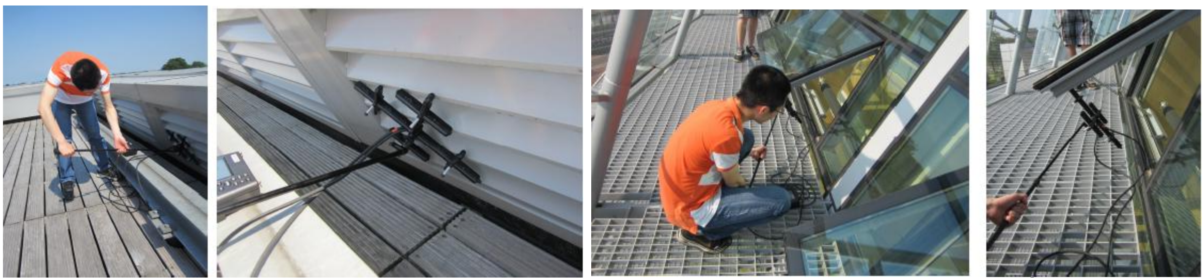
Figure 4. Measurements of air quantities at roof outlets and inlet windows on 4th floor

3 QUESTIONNAIRE

In addition to the field measurements a questionnaire was held in the case building, which was aimed at determining the actual comfort that was perceived by the building users. In this questionnaire several comfort issues were addressed, including thermal comfort. The main purpose of the questionnaire was to establish the perceived comfort by the building users, and to determine whether there were differences between different floors and locations in the building. The building occupants at the second, fourth, and fifth floor were asked to fill out the questionnaire. The second and fourth floor both adjoin the second skin facade, whereas the fifth floor does not. By distinguishing between different floors it is possible to determine if there are differences present in the comfort perception of the building users at the floor near the top of the facade. Finally, a distinction between the building users near the second skin facade and the rest of the building user was made, in order to see if there are differences present. In the questionnaire the users were asked about several comfort aspects during both winter and summer conditions. For the response to the above stated topic a 7-point scale was applied, allowing the subjects to give a rating to each of aspects. Although there was still a difference present between these scales, which require a short explanation because a distinction between ambiguous and unambiguous voting scales is present in the questionnaire. For the unambiguous aspects (thermal comfort) the highest score lies in the extremity of the voting scale, whereas for ambiguous aspects (sensation) this lies in the middle of the voting scale. The distribution of the responses of the questionnaire is provided in table 2.

	1	2	3	4	5	6	7	
Comfortabel	☐	☐	☐	☐	☐	☐	☐	Oncomfortabel
To hot	☐	☐	☐	☐	☐	☐	☐	Too cold

Figure 5. Example of two aspects on the 7-point scale.

Table 2:The distribution of the questionnaire respondents

Total participants	*78*	**<20 year**	*1*
Male	*49*	**20 – 30 year**	*9*
Female	*28*	**31 – 40 year**	*10*
2nd floor	*36*	**41 – 50 year**	*26*
4th floor	*34*	**51 – 60 year**	*28*
5th floor	*10*	**>60 year**	*6*

4. RESULTS

4.1 Measurements air flows

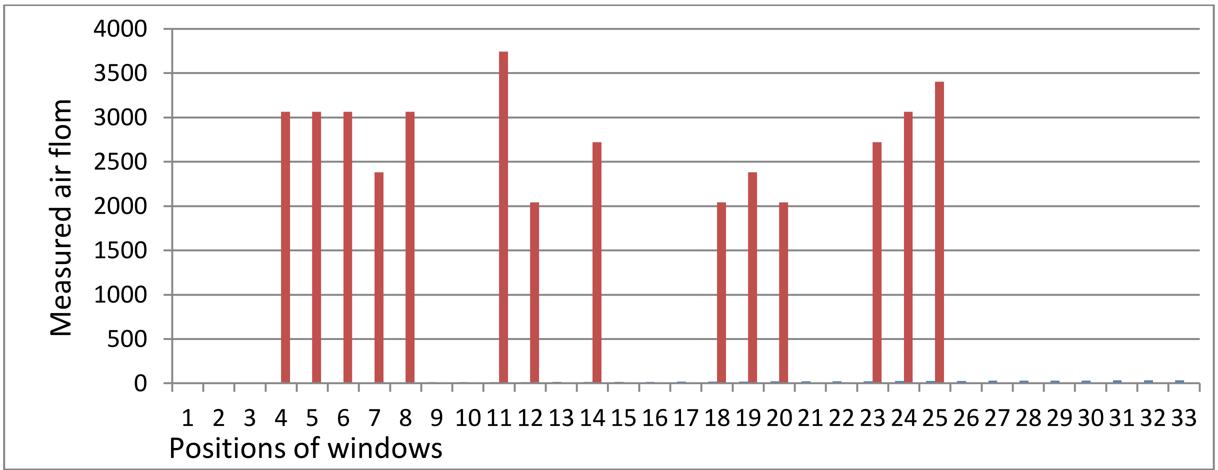

Figure 6. Measured air flow through the windows in the cavity on the 4th floor

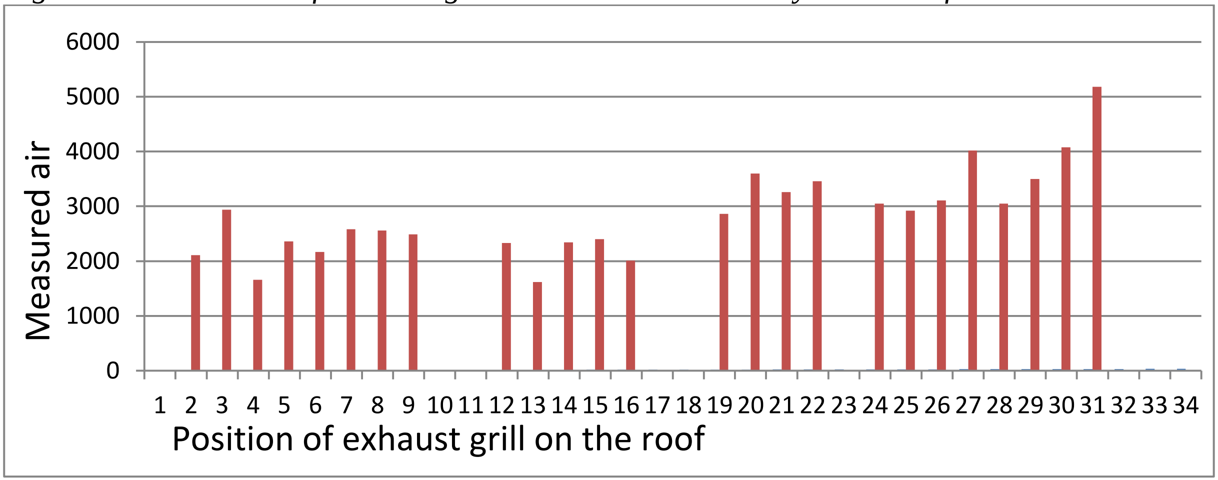

Figure 7. Measured air flow through the exhaust grilles in the cavity on the roof

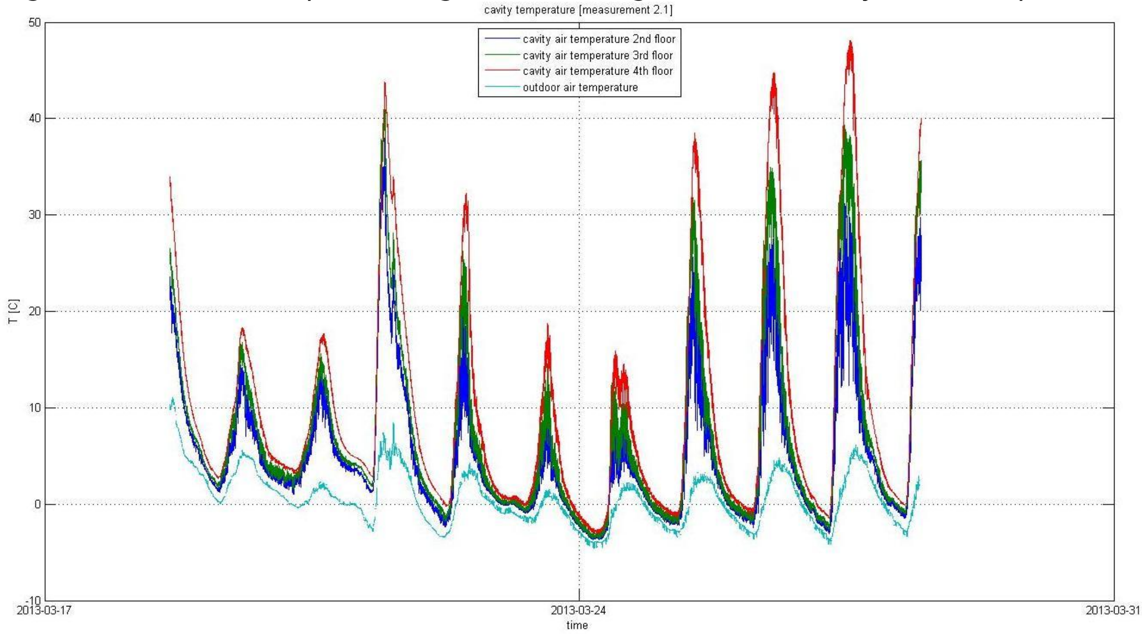

Figure 8. The increase in cavity temperature on the 2nd, 3rd, and 4th floor in comparison to the outdoor temperature of the second measurement period.

Important is the cavity temperature increase due to the solar radiation and the fast changes to the thermal indoor conditions for the occupants. The correlated dissatisfaction between radiant temperature and air temperature is presented in Fig. 9. The lines represent the range of perceived thermal comfort (Lusden and Freymark 1951).

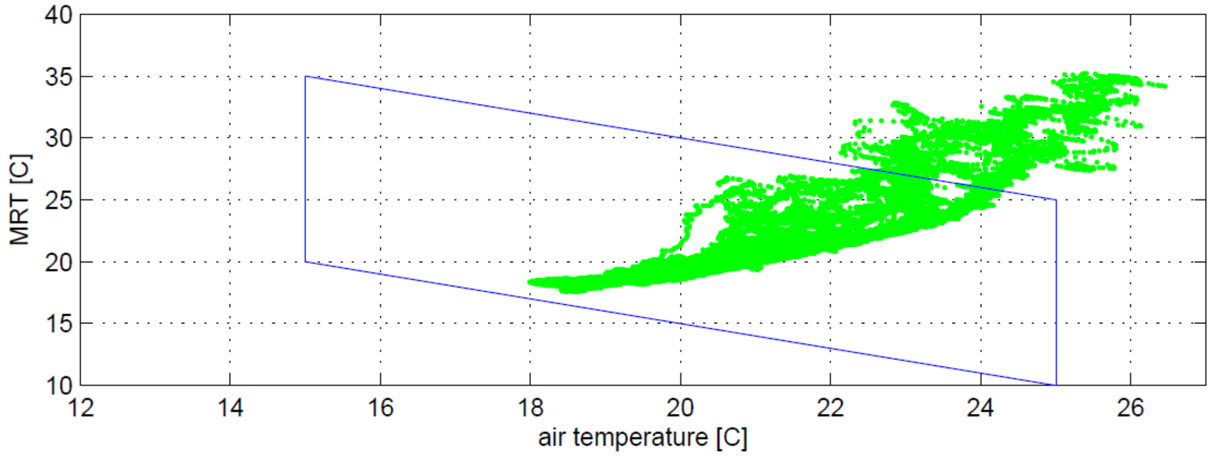

Figure 9: Ration between radiant temperature and air temperature of 4th floor

4.2 Questionnaire results

In figures 10 and 11, the results of the questionnaire are provided, where the figures displays the results for winter time and in summer time.

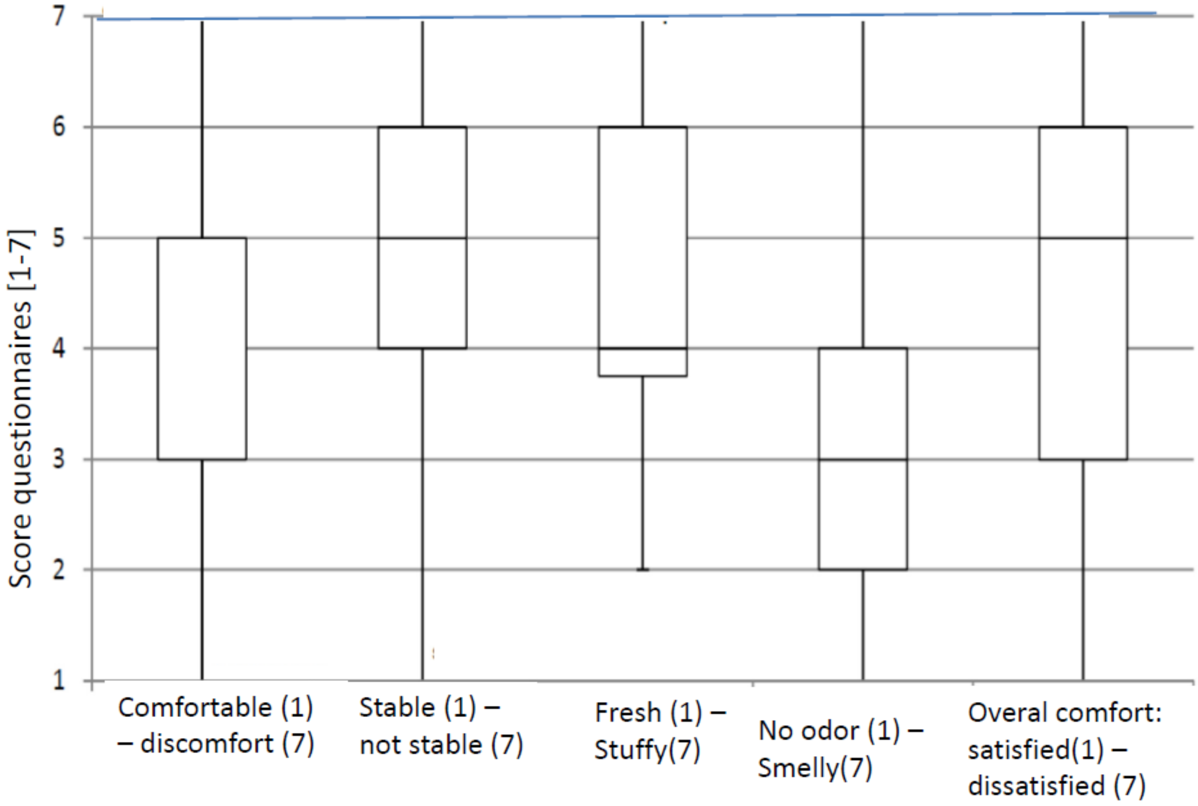

Figure 10: Results questionnaires perceived indoor air quality aspects in winter

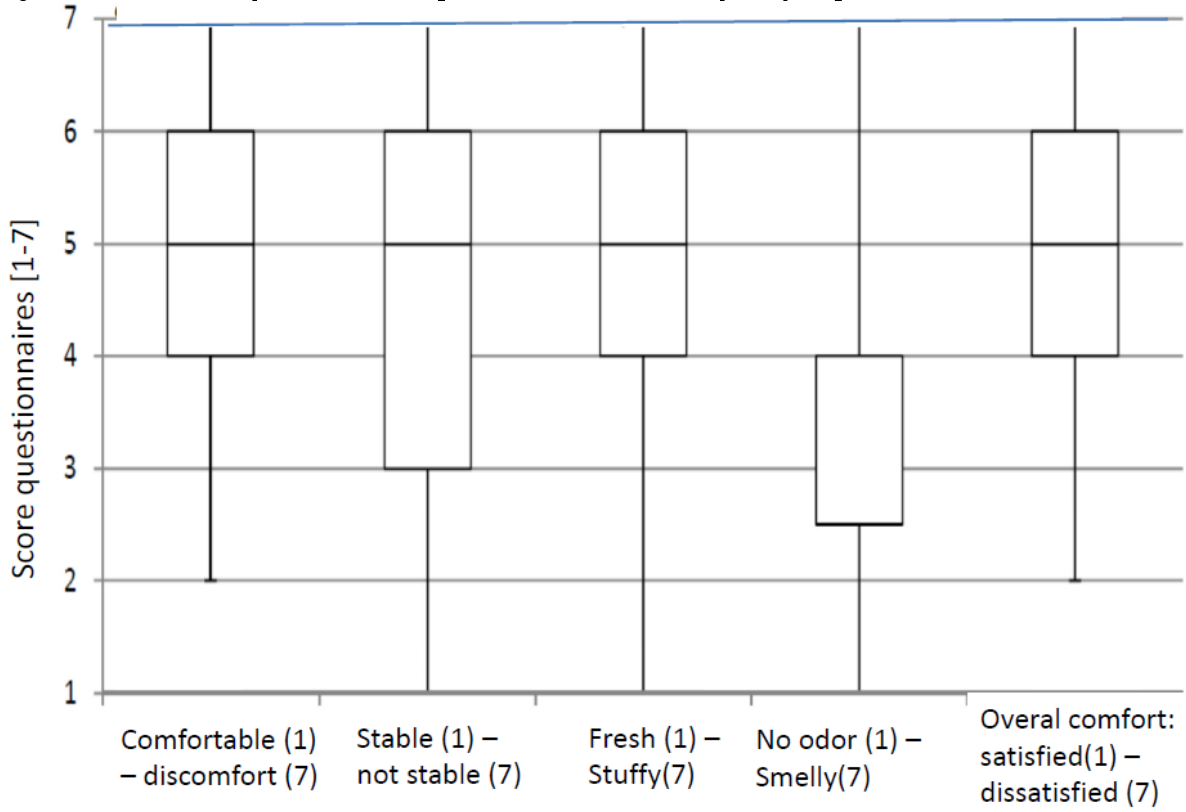

Figure 11: Results questionnaires perceived indoor air quality aspects in summer

4 CONCLUSIONS

The real behaviour of air flows within the cavity of a double façade and within the building itself due to ventilation from the cavity to the building is extremely complex. An important influencing factor is the fluctuations in wind strength and wind direction resulting in a stochastic fluctuation of the wind pressure, see the measured air volume in Fig. 6 and 7. Due to the complex shape of the building there was quite a difference in the air volume through the windows and outlet grills on different positions, see Fig. 12.

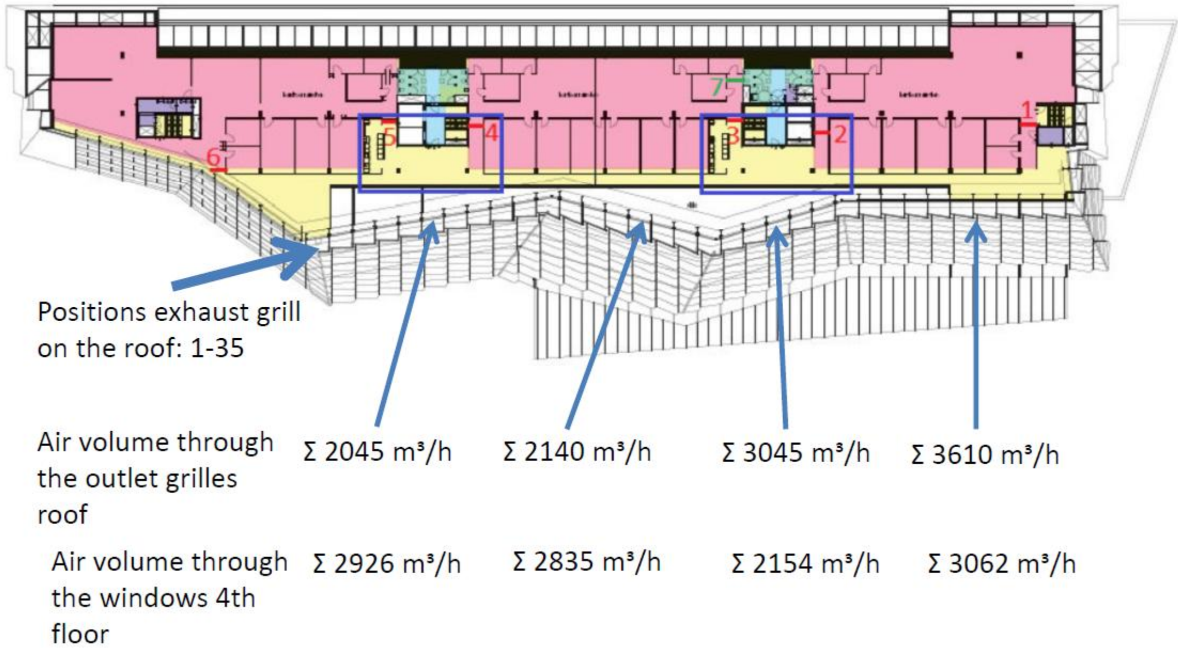

Figure 12: The different air flows through windows and outlet grilles

As a result the air flow inside the cavity of the examined building was restricted due to wind pressure on the outlet grilles on top of the roof. and as a result the temperature increase within the cavity over several floors was enormous. This increase was directly related to the solar radiation, see Fig. 13.

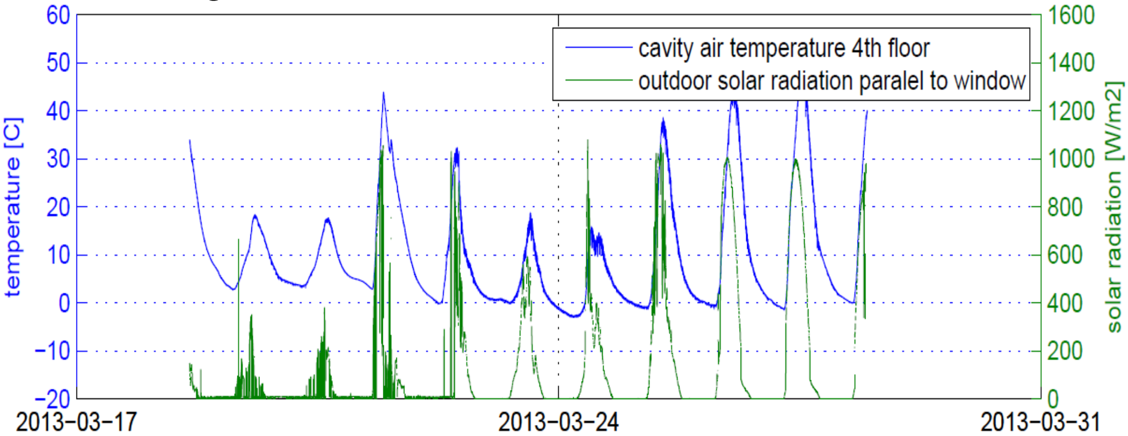

Figure 13: Cavity temperature 4th floor versus outdoor solar radiation

As a result the cooling load for the building was much higher than calculated and also the perceived thermal comfort especially in summer was rather poor. Although there are many simulation studies about the behaviour of double facades, in real live the effects of wind in combination with complex building shapes can lead to real problematic situations in practice to control and balance the ventilation is such buildings.

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