VENTILATION TECHNOLOGIES IN URBAN AREAS

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Active Envelopes – Essential in Urban Areas?

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Abstract

Today, the development of new technologies to improve building-envelopes performances are highly encouraged and provide a clear challenge for designers and researchers. In this context several typologies of active envelopes are becoming very popular amongst designers and architects. They are favorite choice in offices and many advantages are claimed in the professional literature. Especially in urban areas, designers choose for active envelopes because of the good sheltering from the high external pollution and noise load. Reading some one-sided articles a designer could get the idea that if he uses an active envelope, he automatically gets an energy-efficient and highly comfortable building.

To improve energy-efficiency, active envelopes should act as an active solar collector in summer, decreasing the cooling loads. In winter they should behave like an air-air heat exchanger, recovering heat losses and gather the solar energy to use this energy in the HVAC-system. A higher glass to wall ratio provides more daylight and the extra pane improves the sound insulation. Although active envelopes might offer high potential in improving energy efficiency and in thermal and acoustical comfort performance, the expectations are not nearly always achieved.

The performances of the airflow window of the DVV-headquarters building in Brussels where the subject of a performance based assessment. The paper presents the experimental data and the model used to quantify the thermal and acoustical properties. The attention is drawn on correctly dividing the radiation and convection balances, the impact of a bad workmanship, the unclear meaning of the equivalent U-value and the Solar Coefficient and the importance of absorbing the short wave solar radiation to realize a good solar coefficient.

Concluding, one could say that the high expectations (i.e. the performances) are not always fulfilled due to a wrong choice of typology, doubtful models and bad workmanship. Secondly, designers should be aware that even huge efforts could lead to disappointing small results and that the overall energetic, economical and ecological performance could be very discouraging. Even if, in some cases, the performances are achieved one could ask whether the extra costs count for the, sometimes small, benefits.

Active Envelopes – Essential in Urban Areas?

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Synopsis

Today, the development of new technologies to improve building envelope performances is highly encouraged and provides a clear challenge for designers and researchers. In this context several typologies of active envelopes have become very popular. The paper starts with an overview of the history and the performances of active envelopes in the context of urban design. With these considerations in mind we will analyse the performance of the active window system of the DVV-headquarters downtown Brussels.

This paper presents experimental data and a model to quantify the physical properties of active envelopes. The experiments clearly demonstrate that workmanship and design have an important impact on the results: the performances, predicted at the design stage, are not always achieved after construction. For instance the DVV Case Study reveals that airtightness and the use of frames with thermal break are extremely important. The attention is also drawn to the importance of a correct split between the convection and radiation when predicting thermal performance, the unclear meaning of the equivalent U-value and the Solar Heat Gain Coefficient and the importance of the absorption of short wave radiation in the cavity.

List of symbols

Lower and upper cases

c	specific heat capacity (J/(kg K))
d	cavity width (m)
e	emissivity (-)
h	heat transfer coefficient (W/(m²K))
z	height (m)
E	absorbed solar energy (W/m²)
E_{st}	total solar radiation (W/m²)
G	airflow rate per unit width (m³/(hm))
H	window height (m)
R	thermal resistance (m²K/W)
SHGC	Solar Heat Gain Coefficient (-)
U	thermal transmittance (W/(m²K))

Greek symbols

α	absorption coefficient (-)
θ	temperature (°C)
λ	thermal conductivity (W/(mK))
ρ	reflection coefficient (-)
τ	transmission coefficient (-)
ϕ	heat flux (W/m²)

Subscripts

a	air
c	convection
cav	cavity
di	direct
e	exterior
i	interior
in	indirect
r	radiation
s	shading device

1. An introduction to active envelopes

1.1 Definition and history of the active envelope

Active envelopes are facade systems, which are designed to act as air-air heat exchangers. They typically consist of two panes, with a cavity in between, which commonly incorporates the shading device. Through the cavity air is drawn by means of natural or forced convection.

In 1849 Jean-Batiste Jobard described the first active envelope concept: warm air in winter and cooled air in summer flowed between two glazed panes. Approximately 65 years later, Paul Scheerbaert describes a similar idea, and in 1930, Le Corbusier develops his so-called

“Le mur neutralisant”: a double skin system for La Cité de Refuge. The first studies on airflow-windows were published in the fifties in Scandinavia. The issue was to improve the energy efficiency and the comfort performance of windows in dwellings. In 1957 the first patent related to airflow-windows was filed in Sweden. In 1967 the EKONO Company built the first office building equipped with airflow-windows in Helsinki. [1]

The spirit for further development is to be found in the energy crises of 1973 and 1979 and the growing environmental awareness. Suddenly energy-efficiency and thermal comfort was no longer an exclusive issue for Scandinavian countries only.

1.2 Active envelopes in urban areas

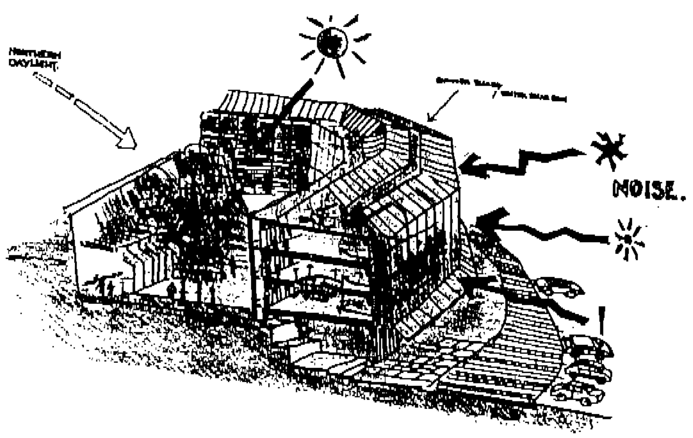


Figure 1: Briarcliff house in Farnborough

Project developers and architects prefer the major urban areas to locate the headquarters. Easy access to public services, a well-developed public transport system and the accessibility from major traffic roads justify this choice. Another, and perhaps more important, motivation is the influence on the project’s prestige and the company’s reputation. Therefore it is not surprising that glass and active envelopes are increasingly applied in prominent office buildings. The building and the company get an attractive, high-tech image and there is no need for an external shading device to ruin that appearance.

The city is a hostile environment. The high noise and pollution loads threaten the comfort in the building. Again active envelopes seem to be the ideal solution: the double skin forms an adequate protection against the aggressive surroundings. Furthermore, active envelopes claim to be energy-efficient and highly comfortable: in winter they collect the solar energy and act as air-air heat exchangers while in summer they protect against overheating by removing the heated air from the cavity. After reading some one-sided articles the designer could get the idea that active envelopes are always the perfect choice.

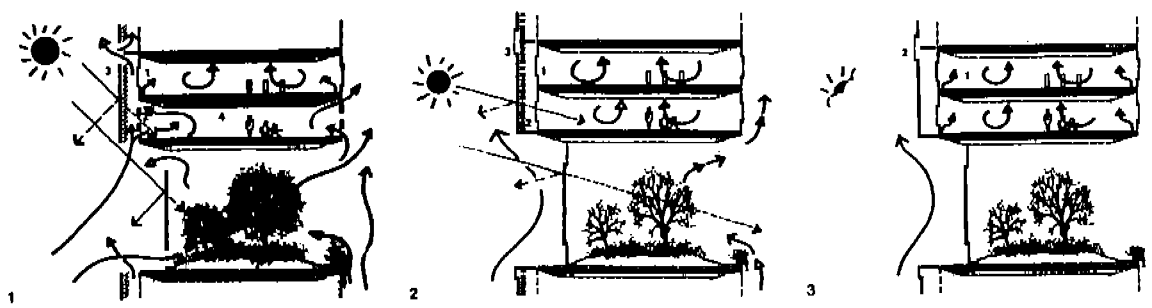


Figure 2: RWE-Tower in Essen, Germany

The first active envelope that catches the attention of the architectural literature was the Briarcliff house [2] (Figure 1). At Farnboroughs, Arup’s designers had to design an office building that could deal with a severe acoustical load: high noise levels from the nearby airport, service roads and the roundabouts the building looks over. From the experience Ove Arup had at the British Sugar Company (1975), the engineers had learned that the double skin idea shelters the building from the sun and the traffic noise. More recently, designers pay attention to the integration of natural ventilation in office buildings by means of active envelopes. Examples are the Commerzbank A.G. in Frankfurt am Main (Germany) (Figure 2) [3] [4] and the Dienstleistungszentrum Stern RWE A.G. in Essen, Germany [5]. Since the eighties, especially airflow windows and airflow facades attracted a lot of attention. The Brussimmo Building in Brussels and the DVV-headquarters in Brussels (Belgium) are two examples. [6]

2. The DVV case study

2.1 Introduction to DVV-headquarters

***Figure 3**: DVV-Headquarters*

The previous paragraph showed that there are numerous reasons for choosing active envelopes in urban areas. Now, we focus on a case study and find out to what extent the claimed advantages are met in reality. The object of this case study is the new extension of the DVV-Insurance Company office building downtown Brussels. (Figure 3) After further expansion of DVV, the existing building became too small and an extension was planned. Construction started in 1993 and the building was finished in April 1995. The new extension contains five office floors, wrapped around an atrium. The active windows form an integral part of the HVAC-system and each window acts as a return-duct for the HVAC-system. The choice for an active envelope was ruled by the wish to achieve optimal energy efficiency, excellent thermal and acoustical comfort and sheltering from the external pollution.

In the DVV-building the conditioned air is injected at floor level. Exhaust is realised through the light armatures, which are connected to the active windows. The exhaust air flows top-down through the cavity and returns to the air conditioning system, where it either is re-used or expelled.

2.2 Modeling and measuring

The model focuses on performances at the envelope level: the U-value and the Solar Heat Gain Coefficient. In the Annex 32 terminology the performances at element level are called level two performances. [7] It is clear that the level two performances are closely related to the building level performances (level one). If, for example, energy efficiency is formulated at level one, requirements on the thermal insulation values are a level two consequence.

In cavities, conduction, convection, radiation and the enthalpy transport through the cavity define the combined heat-mass transport. (Figure 4) Starting point are the heat balances for the three panes and the roller blind and the heat balances describing the enthalpy-transport in the cavities (eq. 1-6). When we calculate the U-value, the coefficients E are set zero to eliminate the solar influence. The U-value is calculated from the heat flux through the inner

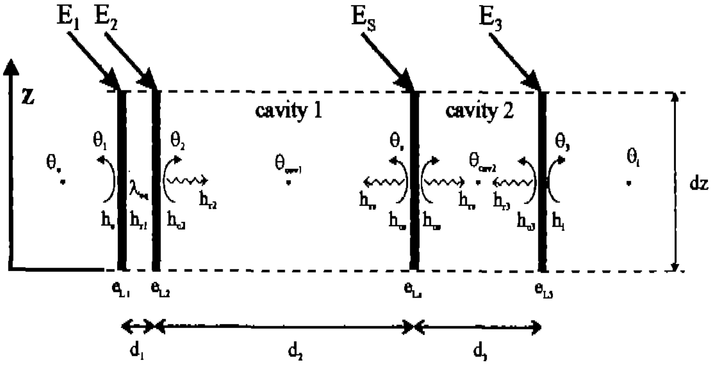


***Figure 4**: Model diagram*

surface (eq. 7 and 8). The SHGC is defined as the ratio of the total energy flux (ϕ_{di} + ϕ_{in}) into the building to the total solar radiation (E_{ST}) (eq 9,10 and 11). The direct gains are also calculated from the heat flux through the inner pane (eq. 10). When calculating the SHGC, only the effect of the solar radiation should be rated: therefore the inner and outer temperatures are set zero (θ_i = θ_e = 0). The shading device is supposed to be airtight, not allowing any air-exchange between the cavities. The airflow rates in the cavities are supposed to be proportional to the third power of the cavity width.

pane 1	$E_1 = h_e \cdot (\theta_1 - \theta_e) + \frac{\lambda_1}{d_1}(\theta_1 - \theta_2) + h_{r1} \cdot (\theta_1 - \theta_2)$		(1)
pane 2	$E_2 = h_{c2} \cdot (\theta_2 - \theta_{cav1}) + \frac{\lambda_{eq}}{d_2}(\theta_2 - \theta_1) + h_{r1} \cdot (\theta_2 - \theta_1) + h_{r2} \cdot (\theta_2 - \theta_s)$		(2)
shading device	$E_s = h_{rs} \cdot (\theta_s - \theta_2) + h_{cs} \cdot (\theta_s - \theta_{cav1}) + h_{rs} \cdot (\theta_s - \theta_3) + h_{cs} \cdot (\theta_s - \theta_{cav2})$		(3)
pane 3	$E_3 = h_i \cdot (\theta_3 - \theta_i) + h_{c3} \cdot (\theta_3 - \theta_{cav2}) + h_{r3} \cdot (\theta_3 - \theta_s)$		(4)
cavity 1	$[h_{c2} \cdot (\theta_2 - \theta_{cav1}) + h_{cs} \cdot (\theta_s - \theta_{cav1})] \cdot dz = G_{in1} \cdot c_a \cdot d\theta_{cav1}$		(5)
cavity 2	$[h_{c3} \cdot (\theta_3 - \theta_{cav2}) + h_{cs} \cdot (\theta_s - \theta_{cav2})] \cdot dz = G_{in2} \cdot c_a \cdot d\theta_{cav2}$		(6)
heat flux and U-value	$\phi_u = \frac{1}{H}\int_0^H \frac{\theta_i - \theta_3}{R_2}$	$U = \frac{\phi_u}{(\theta_i - \theta_e)}$	(7,8)
direct and indirect gains	$\phi_{di} = \tau_1 \cdot \tau_2 \cdot \tau_s \cdot \tau_3 \cdot E_{st}$	$\phi_{in} = \frac{1}{H}\int_0^H h_i \theta_3 dz$	(9,10)
solar heat gain coefficient	$SHGC = \frac{\phi_{in} + \phi_{di}}{E_{st}}$		(11)

***Table 1**: governing equations*

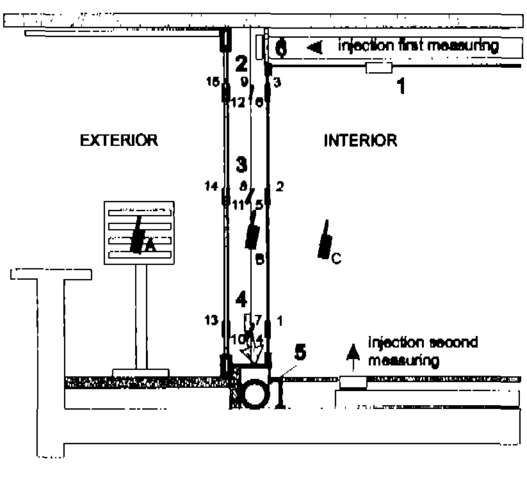


***Figure 5**: Experiments diagram*

The temperature profiles can easily be found by writing an expression for the pane and roller blind temperatures (θ_2, θ_s and θ_3). After substitution of these expressions into the cavity heat-balances (eq 5 and 6), we obtain a system of two coupled differential equations from which we can compute the temperature profiles. A detailed description of the model can be found in the references [6 and 8]. To check the performance of the active window system experimentally, the following measurements were set up on a south-west orientated window:

(1) Temperature profile analysis. Data from 15 thermocouples, shielded from direct solar radiation with aluminium foil, were logged every 15 minutes. *(2) IR- thermography.* Infrared thermography measures the surface temperatures to

reveal thermal bridging and air leakages of the building's envelope *(3) Measurement of the airtightness*. To check the airtightness of the active windows at DVV's, three experiments were set up: (1) airflow-visualisation with smoke-sticks, (2) pressure difference measurement and (3) tracergas measurement. On figure 5, the tracergas measuring points are indicated with bold numbers, the thermocouples with small numbers.

2.3 Main results

2.3.1 Interpretation of the equivalent U-value and SHGC

Table 2 shows **the importance of dividing the convection and radiation balance.** Models that use a combined surface coefficient underestimate the U-value. [7, 8 and 9]

Under normal conditions the U-value and SHGC depend on the material properties only. The U-value and SHGC of active envelopes, however, are no longer single values, depending on a set of thermal conductivities, thicknesses, solar properties, et cetera. Both quantities are strongly related with the system properties. [7, 8 and 9]

airflow rate	*U-value: use of combined surface coefficients*	*U-value: division between radiation and convection, without shading device*	*U-value: division between radiation and convection, with shading device*
$m^3/(hm)$	*$W/(m^2K)$*	*$W/(m^2K)$*	*$W/(m^2K)$*
40	0.91	1.25	0.86
90	0.54	0.94	0.60
140	0.39	0.82	0.49

***Table 2**: Effect of the model and the shading device [7]*

Correct calculation of the U-value and SHGC is one thing. When discussing performances of active envelopes, **the equivalent U-value and SHGC should be interpreted cautiously.** A low equivalent U-value, for instance, does not automatically stand for a low energy demand. If we consider for instance, the following simplified model (Figure 5) we notice that despite the decrease of the U-value with increasing airflow rate, the energy consumption of the HVAC-system will increase. This is due to the fact that the air, which is reused in the HVAC-system, cools down when passing through the airflow window.

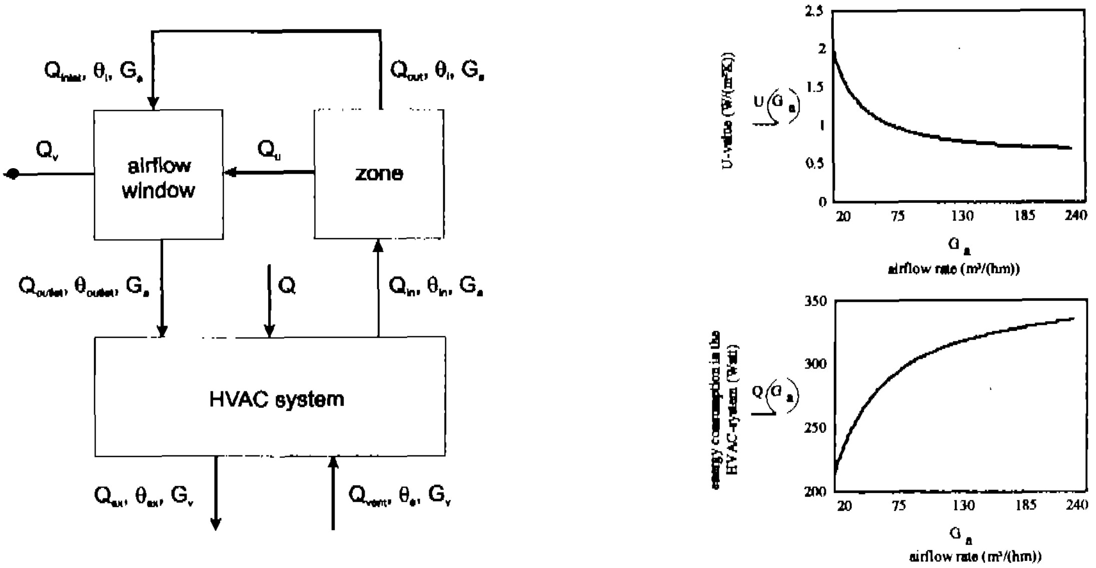


***Figure 5**: Comparison between the U-value and the energy added to the HVAC-system (Q).*

2.3.2 The influence of bad workmanship

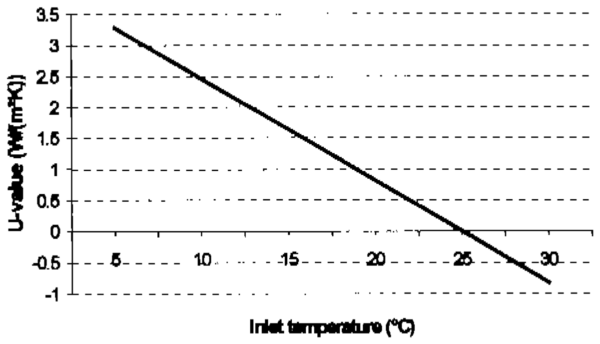


***Figure** 7: The U-value as a function of the inlet temperature*

In practice the calculated performances are not always achieved due to bad workmanship. We can illustrate the influence of bad design and bad workmanship by the influence of the inlet temperature on the U-value. Figure 7 shows that the U-value changes linearly with the initial temperature. Theoretically, even negative U-values are possible for initial temperatures higher then 25 °C. This figure shows that the infiltration of cold air has a disastrous influence on the U-value and stresses the importance of profiles with a thermal break.

At DVV's, the assumption that the inlet temperature equals the room temperature proved to be completely wrong. Passing the lights, the air warms up: so, one could expect a higher temperature at the inlet. Surprisingly, the measured inlet temperatures lay far below room temperatures (Figure 9a). Two hypotheses were made: air from the outside is sucked into the cavity, or thermal bridging may be present.

A tracergas measurement with constant emission rate could not demonstrate a lack of airtightness of the outer pane, so the thermal-bridging hypothesis was more likely. Measurement of the temperature profile in the duct revealed that the air cooled down with 3°C while passing through the duct. This cooling is probably caused by a wrong insulation concept. We suppose the thermal insulation is simultaneously used as acoustical insulation and therefore placed just on top of the acoustical ceiling, not covering the ducts at all.

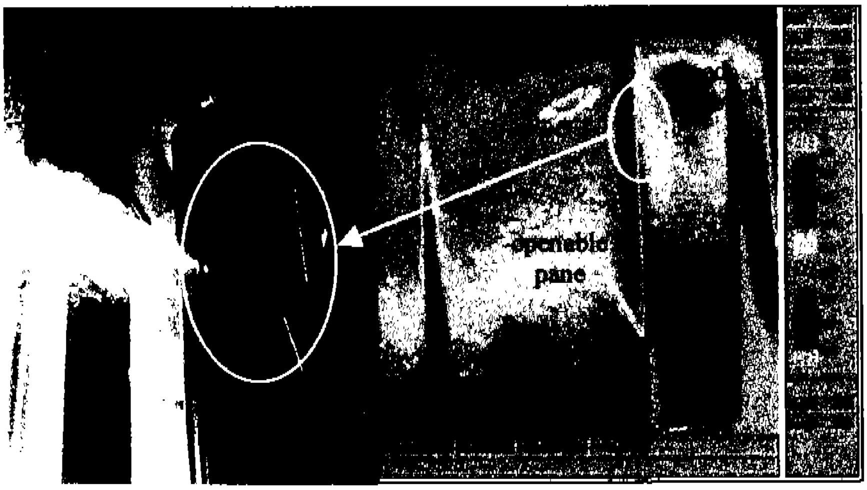


***Figure** 8: Photograph of the smoke-stick experiment and the IR-thermography*

Another design weakness is demonstrated by the bad sealing of the inner pane. Both the smoke-stick experiment and the IR-thermograph reveal this phenome-non. Figure 8 clearly shows how the smoke is sucked into the cavity (a pressure measurement indicated an under-pressure of 3 Pa in the cavity). Figure 8 shows an infrared photograph of the window and also illustrates the effect of bad sealing: the temperature along the right edge of the openable one is much lower then the temperature in the middle of the pane. The air sucked from the room into the cavity is colder and causes a local drop in temperature. Compared to the fixed pane right from the openable pane we do not detect a temperature drop along the edge. The locks were the cause of the bad sealing: they do not properly press the inner pane against the edge.

2.3.3 The active envelope as a solar collector

Solar heat storage and the excellent SHGC without exterior shading device are pointed out as an important feature of active envelopes. In winter the collected solar energy should be used to heat the building. In summer the solar energy is expelled to diminish the cooling loads and the low SHGC should prevent against overheating.

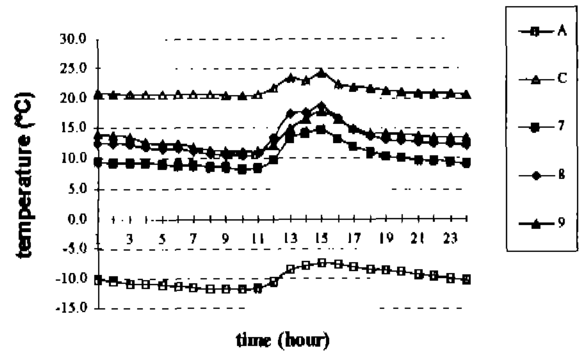
The use as a solar collector is not possible without absorption of solar energy in the cavity. SHGC without sunshading or special glazing in the active system doesn't exceed the SHGC of absorbing double glazing (SHGC = 0.45 to 0.66). Table 3 proves the importance of the airflow rate and the absorption of solar energy in the cavity. The SHGC without sunshading is largely independent of the airflow rate, as glass and air are to a large extent transparent for the short-wave solar radiation.

SHGC	airflow rate m^3/(hm) 0	140	difference
no sunshading, no absorption	0.63	0.56	10%
no sunshading, absorption at pane 2	0.45	0.29	35%
sunshading, no absorption	0.36	0.21	40%

***Table 3**: The importance of the shading device and the absorption in the cavity.*

From the above we understand that absorption of solar energy in the cavity is necessary to heat the air. With the outlet temperature we can describe the solar collector efficiency. The higher the temperature the higher the amount of energy absorbed by the air. To have an idea what the solar heat storage capacity is we will analyse the temperature profiles measured on the first of January 1997. (Figure 9a) (position of the thermocouples: Figure 5) Due to the low solar inclination in winter the sun penetrates deep into the building, not being obstructed by the overhanging roof. The shading system is not in use. To know if the active envelope is suitable to act as a solar collector, we compared the interior and the outlet temperature (point 7 and 9 on Figure 5) (Figure 9b). We discover that the interior air always is hotter then the outlet air. As the area above the base line is a measure for the energy loss in the cavity, in this case the active window always loses energy. This shows that heating the air while passing through the cavity in this case is fiction.

A second point of attention is the temperature drop when the sun does no longer heat the air. Once the air passed the sunlit part, temperature quickly decreases: the air hardly can hold the absorbed heat because of its low capacity.



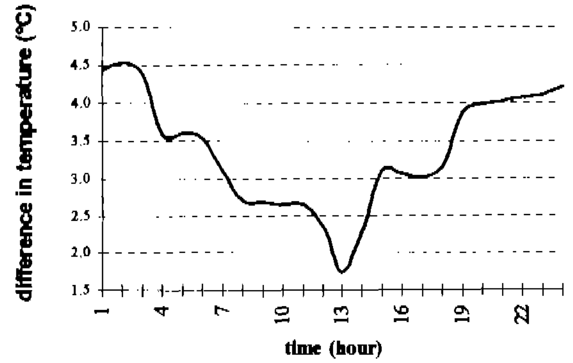


***Figure 9b:** difference between inlet and returntemperature*

3. Conclusions

In this paper we defined the goals of the DVV project in an urban context: the active window with forced convection was designed to shelter the building from the high noise and pollution load. Second reason to apply the double skin concept was energy-efficiency.

In the case study we focused on the envelope level performances. While analysing the model and comparing the results with experimental data we highlighted some misconceptions about active envelopes and stressed that good design and workmanship are essential to fulfil the claimed performances.

We proved that a model that does not divide convection and radiation strongly underestimates the U-value. With a simplified example, we indicated that the U-value and SHGC have to be interpreted cautiously! Low equivalent U-values do not automatically imply low energy demands.

Bad workmanship and poor design have a severe influence on the active envelope performance. Infiltration of cold air and thermal bridging of the window frames dramatically raises the U-value. In the DVV case study we first demonstrated the poor design and the bad workmanship of the duct between the lightarmature and the air inlet. Secondly, we illustrated the inferior design of the locks of the inner pane.

Regarding sunshading and the use of active envelopes as solar collector, we stressed the importance of absorption of the solar radiation in the cavity. Active envelopes without absorption do not collect solar energy nor have a good SHGC. The reason is that glass and air badly absorb the short wave solar radiation and that air has a very low capacity for heat.

4. Acknowledgement

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