OVERALL PERFORMANCE OF VENTILATED DOUBLE FAÇADES COMPARED TO A STATE OF THE ART SINGLE SKIN FAÇADE

J.H.A. Verdonschot, G. Boxem, and W. Zeiler †,
Technical University of Eindhoven, the Netherlands

ABSTRACT
The concept of a ventilated double façade is invented with the intention of improving the thermal qualities of a fully glazed façade. Over the years, the properties of the single glazed façade have improved. The aim of this study is to compare different ventilated double façades to a single skin façade and determine which façade has the best overall performance.
To compare the façades, fifteen functional aspects on the areas of thermal and visual comfort, energetic and acoustical performance, ventilation and maintenance have been determined, next to eight realization aspects on the areas of costs, sustainability, flexibility and architecture. Measurements were performed on four existing façades for a period of one week in winter. Together with the gathering of information, this resulted in an evaluation of the total performance. In high-rise buildings, natural ventilation and shading devices in the cavity are the main advantages of the ventilated double façade. In low-rise buildings the performances can be equal, although the costs of the single skin façade rise quickly if a higher sound insulation is needed. It is therefore important to determine which performance has to be achieved in order to choose between a ventilated double façade and a single skin façade.

KEYWORDS
Performance
Façade
Comfort
Winter
Measurements

INTRODUCTION

"I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you can not express it in numbers, your knowledge is of a meager and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the state of science, whatever the matter may be."

William Thomson, Lord Kelvin (1824-1907)

Modern facades often combine a wide diversity in functions. These functions have to be performed under strongly dynamic outdoor conditions and indoor demand. Thermal and visual comfort is determined by the presence of occupants, their location in the building, their activities and personal preferences.
Ventilated double façades open up new possibilities for principal and architects seeking creative innovative design that is intelligently adapted to environmental conditions. Preservation of energy resources, occupant comfort and environmental impact limitation are the key issues of modern and sustainable architecture. A major portion of primary energy consumption, about 40 %, is used to create thermal comfort in buildings by heating, cooling, ventilating and lighting. The façade, in combination with the HVAC installation, is responsible for most of the energy used.
In modern high performance office buildings, active and interactive façade technology is often used. Though these modern façade concepts should be an improvement, up to now efficiency is under discussion. Some disadvantages of the ventilated double façade are:
- expensive
- user unfriendly

† Corresponding Author:
E-mail address: W.zeiler@bwk.tue.nl
- much unusable space
- increased cleaning costs
- high cavity temperatures

In favour of the ventilated double façade are:

- reliable, weather independent solar control
- low g-values
- low U-values
- improved sound insulation
- weather independent, natural ventilation
- building height independent, natural ventilation

Reduction in energy consumption and capacity of the HVAC system is one of the main arguments supporting the application of ventilated double façades (Saelens 2002, Saelens et al. 2003). But with the current state of the art single skin façades the arguments in favour of ventilated double façades are becoming less convincing.

The main objective of this research (Verdonschot 2006) is to compare the overall performance of different ventilated double façades to the overall performance of a state of the art single skin façade. The overall performance of a façade is determined on the areas of thermal and visual comfort, energetic and acoustical performance, ventilation, maintenance, costs, sustainability, flexibility and architecture

**FAÇADES**

Ventilated double façades have many characteristics and therefore have to be categorized on several aspects. The classification that is used in this research is described in Loncour et al. 2004 and is based on three different aspects:

- type of ventilation
- partitioning of the façade
- mode of ventilation in the cavity

The two main categories of facades are:

**Single skin façade**

The ventilated double façades above are compared to the state of the art single skin façade of the ‘Effenaar’ in Eindhoven. The special double glazing of this façade has a very low U-value and ZTA-value and is applied without the use of supporting heating units near the façade and a shading device.

**Ventilated double façades**

The façades that are subject of this research can be classified according to these three aspects (table 1).

The ventilated double façade of the Kennedy Business Centre in Eindhoven is naturally ventilated, partitioned by storey and the mode of ventilation in the cavity is called an outdoor air curtain. This means that outdoor air enters the cavity and also leaves the cavity to return outside.

The ventilated double façade of the ABT-office in Velp is mechanically ventilated, it is a climate window and the mode of ventilation is called a reversed air exhaust, which means that indoor air is directed through the cavity to outside.

The ventilated double façade of the ‘Bouwhuis’ in Zoetermeer is a multi-storey type and has a hybrid ventilation system. In the summer the mode of ventilation is defined as an outdoor air curtain (natural ventilation) and in the winter the mode of ventilation is called an air supply (mechanical ventilation). In the air supply mode, outdoor air enters the cavity and is then led into the building.
Table 1: Overview ventilated double façades

<table>
<thead>
<tr>
<th>Building</th>
<th>Kennedy Business Centre</th>
<th>ABT-office</th>
<th>Bouwhuis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partitioning</td>
<td>Ventilated double façade</td>
<td>Ventilated double</td>
<td>Ventilated double façade</td>
</tr>
<tr>
<td></td>
<td>partitioned by storey</td>
<td>window</td>
<td>‘multi-storey’ type</td>
</tr>
<tr>
<td>Type of ventilation</td>
<td>natural</td>
<td>mechanical</td>
<td>Summer: natural</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Winter: mechanical</td>
</tr>
<tr>
<td>Mode of ventilation</td>
<td><img src="image1.png" alt="Diagram 1" /></td>
<td><img src="image2.png" alt="Diagram 2" /></td>
<td><img src="image3.png" alt="Diagram 3" /></td>
</tr>
</tbody>
</table>

METHOD

Since the comparison of the four façades takes place on many different fields, an evaluation method that is often used to make such a comparison is chosen: the evaluation method of Kesselring (van den Kroonenberg and Siers 1998) Decision support methods are intended to help designers in making decisions.

As people are limited in their capacity to process information, evaluation should be conducted in terms of each criterion separately. Subsequently, the values determined have to be aggregated into a score for the ‘overall’ value of each alternative. Kesselring developed a visualization technique, with which different variants can be compared with each other. Within the Kesselring method, the criteria for the requirements are separated into a category for realization and a category for functionality.

By doing this the strong point can be seen in the so called S-(Stärke) diagram. To visualize the scores the criteria of the program of requirements are separated in groups with relating requirements. The first group of criteria has to do with the functionality of the design and the other group of criteria with the realization, see figure 1.
Each group of criteria is evaluated and supplementary to the total score of each group of criteria. These criteria are derived from the program of requirements, the design brief. The total score of the functional and realization criteria is expressed as a percentage of the maximum score to gain. In the diagram the percentage of the criteria for functionality is set out on the y-axis and the percentage of the criteria for realization on the x-axis (figure 2). The best variants lie near the diagonal and have high scores. It is wise to set values to limit the selection area. A practical suggestion is to divide the area in two with a minimum border set by the x- and y-value of 40 and by (x+y)-value of 55% (figure 2). The Kesselring method makes singularities visible, whereas that in the normal choice tables and bar diagrams only could be retrieved with much effort. In the Kesselring diagram it is easy to see if the improvements must take place in the functionality or on the realization side.

A total of 23 evaluation criteria, fifteen functional aspects with respect to the operational period and eight aspects with respect to the realization period, are determined. A number of these criteria resulted in measurements that are performed in four office buildings in Netherlands, each with its own characteristics. The other criteria are evaluated based on information by the building owners and users.
Measurements
The measurements are performed in the month February and March of 2006. The results of these measurements are used to calculate the U-value, g-value, daylight factor, temperature gradient, radiation asymmetry and draught. The measurement set-up at the four different facades is basically the same. The surface temperatures of both sides of both panes are measured in one line and not too close to the window frame. The heat fluxes are measured in the same line as the surface temperatures. The air temperatures in the cavity are measured at three heights, as low as possible, as high as possible and in the middle. The pyranometer, cup anemometer, lux meter and air temperature and relative humidity sensor to measure the outside conditions are placed on appropriate positions on the roof. The air temperatures inside are measured at 0.5 m from the façade at a height of 0.10, 0.50, 1.10 and 1.75 m and in the middle of the room. The mean radiant temperature and relative humidity are also measured in the middle of the room. The air velocities are measured on the same positions as the air temperatures inside. The horizontal radiation asymmetry is measured at 0.5 m from the façade at a height of about 1.3 m and the vertical radiation asymmetry is measured at the same distance from the façade at a height of about 1.0 m. The solar radiation inside is measured vertically at a minimum distance of the façade.

RESULTS AND DISCUSSION
Measurement results
With the results of the measurements described in the previous section, the following values are calculated: the U-value, the solar factor, the daylight factor, the temperature gradient, the horizontal radiation asymmetry, the occurrence of draught and the sound insulation. Table 2 shows these values for all four façades.

<table>
<thead>
<tr>
<th></th>
<th>'Effenaar'</th>
<th>Kennedy BC</th>
<th>ABT-office</th>
<th>'Bouwhuis'</th>
</tr>
</thead>
<tbody>
<tr>
<td>U-value [W/m²K]</td>
<td>1.1-1.2</td>
<td>0.9-1.1</td>
<td>1.1-1.2</td>
<td>0.4-1.0</td>
</tr>
<tr>
<td>Solar factor [-]</td>
<td>0.1</td>
<td>0.2</td>
<td>0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>Daylight factor [-]</td>
<td>7-8</td>
<td>8-10</td>
<td>5-9</td>
<td>6-9</td>
</tr>
<tr>
<td>Temperature gradient [°C/m]</td>
<td>0-1</td>
<td>0-2</td>
<td>0-2</td>
<td>0-1</td>
</tr>
<tr>
<td>Horizontal radiation asymmetry [°C]</td>
<td>1-2</td>
<td>0-1</td>
<td>0-1</td>
<td>0-1</td>
</tr>
<tr>
<td>Draught [-]</td>
<td>minimal</td>
<td>minimal</td>
<td>none</td>
<td>none</td>
</tr>
<tr>
<td>Sound insulation [dB(A)]</td>
<td>29</td>
<td>36</td>
<td>32</td>
<td>40</td>
</tr>
</tbody>
</table>

Performance assessment
According to the measurement results described above and the information that is gathered about the facades, the buildings are given scores on all 23 aspects. These results are plotted in the Kesselring diagram in figure 3. The diagram shows that the façade of the Kennedy Business Centre has the highest and well balanced performance of the four researched facades. The 'Bouwhuis' has a similar score with respect to the functional aspects, but a much lower score with respect to the realization. Opposite to that, the 'Effenaar' has a much lower score than the Kennedy Business Centre with respect to the functional aspects, but only a little lower with respect to the realization. The ABT-office has the lowest score with respect to the realization and a similar score as the 'Effenaar' with respect to the functional aspects.
Discussion
The objective of this study is to compare different types of ventilated double façades to a state of the art single skin façade in order to evaluate the application of a certain type of ventilated double façade. The total performance of each façade is a result of the performance of each of its characteristics. Since only one façade of each type is researched, it is difficult to determine the advantages and disadvantages of a façade type. The results of this research should be joined with other studies of ventilated double façades to be able to draw conclusions about the application of a certain façade type. In order to draw a more general conclusion from the results of this research, certain characteristics of the researched façades that are not inherent to the façade type, are changed to improve the overall performance of the façade type.

Another aspect that should be included in further research, is the performance of the façade in the summer. Several evaluation criteria, like for example the solar factor will have different values in summer, caused by the use of a shading device in the cavity. The change of these values over the seasons should be taken into account, since this can be one of the advantages of an active façade.

The evaluation model that is used in this research is useful to determine which façade has the most advantages for a certain location and certain demands with respect to the performance. In the design process, the choice between a ventilated double façade and a single skin façade is often mainly based on the investment costs. If this is the case the evaluation model is not effective due to the fact that the costs are just a very small part of the evaluation. High rises in the investment cost only result in a small decrease of the overall performance.

CONCLUSIONS
A first result of this study is the comparison of the three existing ventilated double façades to a single skin façade. The façade of the Kennedy Business Centre and the 'Bouwhuis' have a better performance than the 'Effenaar', according to the evaluation model. The overall performance of the façade of the ABT-office is not better than that of the 'Effenaar'.

A more general conclusion with respect to the façade type can be drawn from the evaluation of the improved façades. The overall performance of the single skin façade (based on the 'Effenaar') in case of low-rise buildings, the ventilated double façade, corridor type (based on the Kennedy Business Centre) and the ventilated double façade, multi-storey type (based on the 'Bouwhuis') are close.
together. Leading to the conclusion that a single skin façade can reach the same performances as a ventilated double façade.

However, the high sound insulation and low U-value and solar factor of the single glazing cause a high rise in costs for the façade, which could mean that the advantage of the low cost for a single skin façade is no longer present. Together with the fact that the application of an outside shading device and operable windows is only possible in low-rise buildings, the advantages of the single skin façade decrease. In high-rise buildings, ventilated double façades have the advantage of the possibility to apply natural ventilation through operable windows. And also to apply a shading device in the cavity, which can be almost as effective as an outdoor shading device if the device is placed near the outside glass layer.

In short, the possibility to apply natural ventilation and a shading device in the cavity in high-rise buildings are the main advantages of the ventilated double façade over the single skin façade. In low-rise buildings the performance of a ventilated double façade can also be achieved with a single skin façade. It is therefore very important to determine which performance has to be achieved in order to choose between a ventilated double façade and a single skin façade.

Recommendations
The measurements that are performed in this study only address the performances of the façades in the winter period. The measurements should be repeated in the summer to obtain an overall picture of the performances. Especially the solar factor can have a different performance in winter than in summer, which on its turn influences other criteria and thus all the more the total performance. This difference is caused by the shading device that is used in the summer. The Effenaar does not have a shading device, thus the solar factor that is measured should be the same as in the winter. The other façades all have a shading device in the cavity, which contributes to a lower solar factor. Therefore the measurements of the solar factors have to be repeated in summer when a low solar factor is desirable.

In order to determine well-founded advantages and disadvantages of a certain façade type, it is recommended to include several façades of the same type in the evaluation model and perform measurements on these façades with the same classification. This way, the fortuitous advantages of a façade that, on its own, represents a façade type, are taken into account.

Furthermore, a more in-depth investigation of the cost aspects of the façade and their dependence on the different criteria is recommended.

ACKNOWLEDGEMENT
Thanks goes to Nelissen consultants in the persons of Elphi Nelissen and Pieter van der Palen for their support during the project and thanks to PIT for their financial support.

REFERENCES