Active façades to obtain comfortable low energy dwellings

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Abstract

Where a conventional façade is usually a passive boundary between the indoor and outdoor climate, an 'active' façade responds to (and anticipates on) changes in indoor and outdoor conditions. In cooperation with our project partner, De Vries Kozijnen, four different ‘active’ façades are built. The façades are of prefab construction, ensuring a much higher product quality than is possible with on-site assembly of components. The functions of the different components can be tuned to cooperate. Prefab construction also allows for an aesthetic and appealing look.

The four active façades are integrated in a research facility on the ECN premises, where they have been tested for over a year. The techniques used appear to function well although the sun shading in one design is prone to improvement.

Simulations show the potential of the façades to reduce energy consumption and improve indoor comfort in a regular dwelling. With fully functional ‘active’ façades, using a CO_2 sensor to guard and control indoor air quality, the heating demand of 17 kWh/m^2.a is nearly as low as that of a Passive House (15 kWh/m^2.a), while overheating is practically eliminated.

Introduction

A conventional façade forms a passive boundary between the indoor and outdoor climate. One way to reduce energy consumption for space heating is application of the ‘Passive house’ concept [Feist 1988]. Main characteristics are a thermally well insulated building shell and application of a heat recovery unit in the ventilation system. In combination with other (passive) measures, heating demand for space heating can be reduced to less than 15 kWh/m^2. There are doubts however about the indoor climate in summertime. Once heat finds itself a way into the dwelling, it is very difficult to get it out again.

An ‘active’ façade on the other hand responds to (and anticipates on) changes in indoor and outdoor conditions. For instance sun shading devices are operated automatically, using intelligent algorithms, ventilation openings are controlled using indoor air quality (IAQ) sensors and windows are opened automatically for night cooling. These techniques may offer a very good complement to the (passive) measures of a passive house, especially to improve indoor climate in summertime.

Active façades may also find applications in the renovation sector. Demolishing the old façades and equipping the building with prefab ‘active’ façades may well solve all problems that existed with respect to energy consumption and indoor comfort.

In the utility sector, active façades in some form or other have existed for some time e.g. [Haartsen, 1999]. Quite often however, the main intention to is to give the building a high tech look. Also, the budget available to realise an active façade is usually higher than that available for dwellings. The present ‘active’ façades are primarily intended for the housing market where available budgets are much lower.

To assess the potential of an 'active' façades with respect to improving indoor comfort and minimising energy consumption, four different active façades are built and tested in a research facility on the ECN premises.

The functions of the 'active' façades

The main goals of using active façades in a building are to decrease the energy consumption for space heating and to improve indoor comfort. This is achieved by providing the façades with three automated functions: ventilation, sun shading and night cooling. The reason for selecting these techniques is that they are rather common ones and implementation does not require high budgets.

VENTILATION

Ventilation of a dwelling is necessary to maintain good indoor air quality (IAQ). Unfortunately, the vented air also carries away heat, which the heating system will need to replenish. From the point of energy reduction, these so called 'ventilation losses' should be minimised.

One way to minimise 'ventilation losses' is to implement a heat recovery unit in the ventilation system, in which the exhaust air preheats the incoming fresh air. Such a unit can be a central unit (usually placed in the attic) or a local unit in the façade. The main advantages of using a local unit instead of a central one are ease of implementation (no air ducts through the dwelling are needed) and little pollution of the air ducts (because they are of short length) which some claim has a negative effect on IAQ. Also, indication of polluted filters (e.g. by a small light) is not overlooked as easily on a local unit as on a central unit stowed away in the attic.

An alternative way to limit ventilation losses is to minimise the ventilation rate in the absence of sources of air pollution. This is called 'demand controlled ventilation'. For spaces where human occupation forms the main source of pollution, the CO_2 concentration appears to be a good indicator of IAQ [NEN 1997]. When the rate of ventilation is controlled by such a sensor, IAQ can be maintained at a desired preset level (having a positive effect on indoor comfort), while preventing excess ventilation (reducing energy consumption). Minimising ventilation rates will also decrease he risk of draughts, which adds to the improvement of indoor comfort.

__Figure 1.__ The four façades built, integrated in a research facility. To the left: yellow (bottom) and red façade (top). To the right: blue (bottom) and grey façade (top). The solid arrows indicate the position of the panels in the blue façade (behind grids) that can be opened for night cooling. The dotted arrows show the location of the ventilation openings, concealed under the window threshold.

All four active façades constructed and tested use demand controlled ventilation. Additionally, in one of the façades a (local) heat recovery unit is integrated.

SUN SHADING

Dwellings with large surfaces of glass facing south risk overheating, especially in summertime. A sun shading device, especially one with an intelligent control system will shield the dwelling from too much solar radiation and thus help to prevent or minimise overheating. The advantage of an automated system for the sun shading is that it also works in the absence of the occupants, e.g. when they have gone off to work or school. Keeping the dwelling cool until they return obviously has a positive effect on indoor comfort. In addition, it can avoid the need for an air conditioning unit, which usually adds considerably to the energy demand.

An intelligent control system also distinguishes between summertime and wintertime. In wintertime, solar radiation can assist the heating system in heating the dwelling. In this case, as much solar radiation as possible should be allowed to enter the dwelling to the effect of saving (fossil) energy.

NIGHT COOLING

In spite of an automated and intelligently controlled sun-shading device, the dwelling may get overheated because of heat internally produced by inhabitants, lighting, appliances etc. or by other heat sources (e.g. open doors and windows during the heat of day). An environmentally friendly way to cool the building is night cooling (by means of natural ventilation), where one or more windows are opened at night to allow cool outside air to flush the building. This technique works best with thermally 'heavy' buildings, which can effectively store the night time cold.

The façades built

In cooperation with our project partner, De Vries Kozijnen, four different active façades are built, shown in four different colours in Figure 1.

The façades presented offer the following novelties:

1. The façades are prefab constructed which ensures a much higher product quality than is possible with on-site assembly of components. Tolerances can be made smaller, assembly is carried out by able personnel under good working conditions etc.
2. The functions of the different components can be tuned to cooperate, e.g. to ensure that opening a window does not physically conflict with the operation of a sun shading device.
3. Prefab construction also allows for an aesthetic and appealing look. As an example, the ventilation inlet and outlet openings of the heat recovery unit on the outside of the blue façade are concealed under the window threshold.

Table 1. Main characteristics of the façades built.

Façade	Sun shading	Type of window	Opening for night cooling	Other
Blue	screen	none	2 panels	Climarad ® heat recovery unit
Yellow	internal blinds	parallel	window	triple glazing (double on the outside + sash window on the inside, blinds in between)
Grey	awning	bottom hung	window	
Red	awning	parallel	window	

4. Intelligent controls allow taking into account more variables than are commonly used. See for instance Figure 4 showing the control algorithm for night cooling. Application of more advanced algorithms, anticipating on weather forecasts is possible.
5. Since the housing sector forms the primary market, cost effectiveness is a prerequisite.

The main characteristics of the four façades built are shown in Table 1.

Special Features worth mentioning are:

- Integration of a Climarad ® local heat recovery unit (shown in Figure 2) in the blue façade.
- A window, opening parallel to the façade (shown in Figure 3). It can be opened for base ventilation (also offering noise reduction) and for night cooling.

THE CONTROL SYSTEM

All sensors (for indoor and ambient temperature, IAO, irradiation, wind speed etc.), actors (motors to operate window openings, sun shading devices etc.) and a central control unit are connected to a wire loop. Each sensor and actor has its own address and communicates with the central unit using the EIB (European Interface Bus) protocol. The control unit reads signals from the sensors and sends signals to the different actors, the readings and commands being preceded by the sensor's or actor's unique address. That way, only a particular actor will make the desired response to a particular (set of) reading(s).

This system is open for addition of a large (in theory infinite) number of sensors and actors, giving great flexibility and versatility to the system. A possible addition is a microphone that detects high noise levels (e.g. a passing train or airplane) to which the façade would respond by temporarily shutting all openings. In the present project this is not realised. A movement detector shutting all windows as an anti-burglary device is another possibility.

The central unit can be programmed to take action depending on the output of any sensor in the system or combinations thereof. As an example, the control strategy for night cooling is shown in Figure 4.

The research facility

Measurements are carried out in one of the research facilities at ECN, shown in Figure 5. It is of timber frame construction with artificially preserved pine panelling on the outside. It consists of four 'identical' rooms that are vertical-

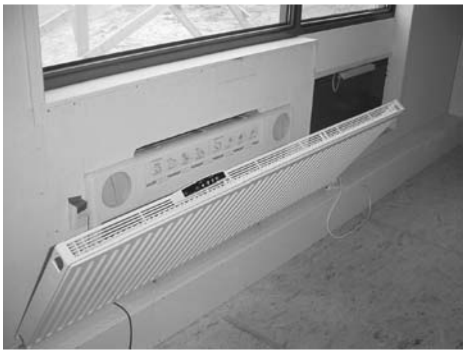

Figure 2. *The Climarad ® heat recovery unit, integrated in the blue façade in combination with a radiator that can be tilted to a side for good access.*

Figure 3*. Detail of the yellow façade with the parallel window partly opened.*

Control strategy for night cooling
Open windows **if**
$T_{indoor} > 23°C$ **and**
$T_{indoor} - T_{ambient} > 4°C$ **and**
Time between 11 p.m. and 6 a.m.
Close windows **if**
$T_{indoor} < 18°C$ **or**
$T_{indoor} - T_{ambient} < 4°C$ **or**
Time **not** between 11 p.m. and 6 a.m.

Figure 4. *Control strategy for night cooling. The condition of indoor temperature will practically prevent any night cooling occurring in wintertime.*

Figure 5. *Research facility containing four separate rooms each holding a different façade.*

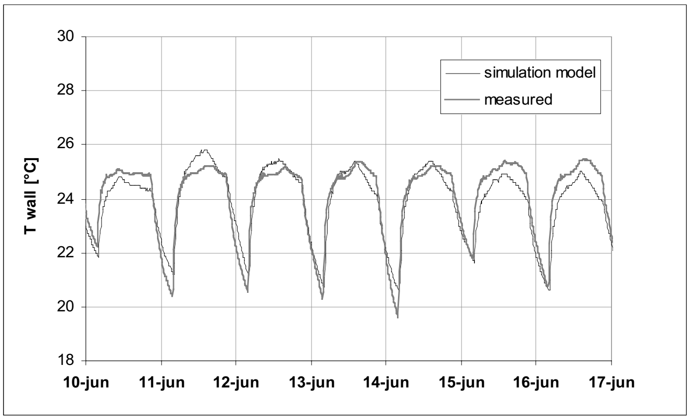

Figure 6. *Calculated and measured indoor wall temperature for the case of the room with the red façade. The night time drop in temperature is due to night cooling.*

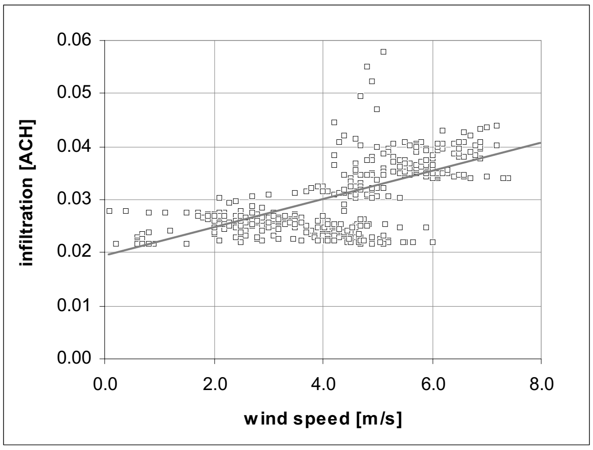

Figure 7. *Air tightness of the room holding the red façade versus wind speed (measured at a height of 10 m).*

ly separated by a staircase extending from the front door. The rooms are thermally well insulated (U=0.15 W/m²K) to minimise heat losses and minimise mutual thermal interaction. Each of the rooms holds a single active façade.

As a special feature, the research facility can be rotated. This way, the effect of orientation, in particular that of solar radiation on energy savings and indoor comfort can be assessed.

Occupant behaviour has a large effect on domestic energy consumption. In fact, in identical dwellings, individual energy consumption can differ by as much as a factor of four, due to differences in occupant behaviour, awareness of energy saving potential and knowledge on how to put that in practice. To eliminate differences in occupant behaviour, a computer simulates occupation of the rooms in the research facility.

The computer controls indoor temperature set point, simulates generation of heat from occupants, lighting, appliances etc. and injects CO_2 to simulate pollution of indoor air by occupants.

For ease of operation, the rooms are electrically heated, allowing accurate control of indoor temperatures and accurate monitoring of energy consumption. Temperatures (of air, wall, floor etc.), energy consumption data as well as weather data (ambient temperature, solar radiation, relative humidity, wind speed) are gathered every 10 minutes using a PC-based data-acquisition system and stored in a database for post-test analysis.

Building simulation program

A building simulation program is used to integrate and analyse the experimental data. To validate the model, data from the research facilities, such as internal heat generation, solar radiation, ventilation and infiltration rates etc. are used as input to the model. From this data, the model calculates the variations in indoor temperature for periods of up to a month, which are compared to the measured values.

An example of calculated and measured indoor wall temperatures is shown in Figure 6 for the room with the red façade during a week when the window was opened at night for night cooling. Reasonably good agreement is found between calculated and measured values.

The analysis shows that the model is indeed able to describe the temperature variations of the room using the values experimentally found for air tightness, thermal insulation, ventilation rates etc. Throughout the experiments, this simulation is carried out as a check on the experimental data, which are not always easy to determine accurately.

Validation of the simulation model is described in detail in [KOENE 2005 1].

Results

More than a year of measurements and analysis has yielded an abundance of results. The main results are discussed is detail below.

AIR TIGHTNESS

The degree of air tightness is determined from the analysis of the decay of the CO_2 concentration after a certain amount of CO_2 (as tracer gas) is injected. The better the air tightness, the lower the infiltration rate, expressed in ACH (Air Changer per Hour). Figure 7 shows that the rate of infiltration is in the order of 0.03 ACH, showing a slight increase with wind speed. This is a factor of 10 better than that realised in regular dwellings.

THERMAL INSULATION

The overall thermal insulation of each room is determined by measuring the amount of heat that is required to keep the room at a constant temperature (generally for a period of at least a week).

Initially, the research facility was fitted with four closed façades of well-known insulation value. With this configuration, the conduction losses of the side walls, floor and ceiling were determined (the bottom part of the bars in Figure 8). The range shown is twice the standard deviation calculated from the results of three different experiments. The building simulation model is used in the analysis to account for the effect of infiltration losses, even though infiltration losses are relatively small (approx. 5% of conduction losses).

After exchanging the closed façades with the 'active' façades, again the total conduction losses were determined. In the analysis, the building simulation model is used to take into account the effects of infiltration losses and solar heat gains. The range shown (at the top of the bars) is twice the standard deviation calculated from the results of six different experiments.

Figure 8 shows that the total conduction losses of a room are approximately 14 W/K. That means that with an indoor temperature of 20ºC and freezing conditions outside (0ºC), the heat released by an adult (approx. 120 W) and a PC (160 W) suffice to keep the room heated (apart from other heat gains and heat losses).

Less than half of the conduction losses are due to losses through the side walls, floor and ceiling. The remaining part is due to losses through the active façade. The yellow façade with its 'triple glazing' performs particularly well in this respect. This façade performs also quite well on acoustic insulation. With the window closed, the noise reduction (for traffic type of noise) is 37-38 dB(A), which can be further improved by adding extra wallboards.

DEMAND CONTROLLED VENTILATION

In the majority of experiments, CO_2 as a tracer gas is injected at a rate of 0.015 Nm³/hr. This corresponds roughly to the CO_2 breathed out by a single adult. The CO_2 concentration measured in the four rooms is shown in Figure 9 during an experiment in September 2004.

Apart from a few peaks, the ventilation system is capable of keeping the CO_2 concentration down at the preset level of 800 ppm (parts per million). The ventilation system, which allows a band width of ± 100 ppm, apparently functions well. The drop in CO_2 concentration during the nights, in some cases approaching the ambient concentration of 400 ppm, is due to the opening of the window or panels for night cooling.

HEAT RECOVERY UNIT

Efficiencies of the Climarad ® heat recovery unit have been measured for a period of nearly half a year. The average temperature efficiency found in a number of experiments lies between 60 and 70%.

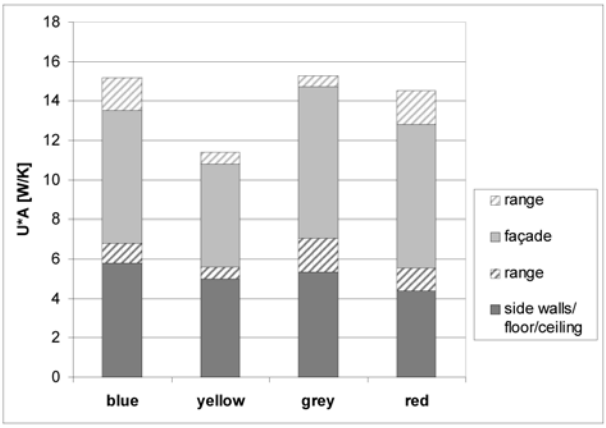

Figure 8. *Conduction losses of the four rooms in the research facility. The range equals twice the standard deviation from the results of the different experiments.*

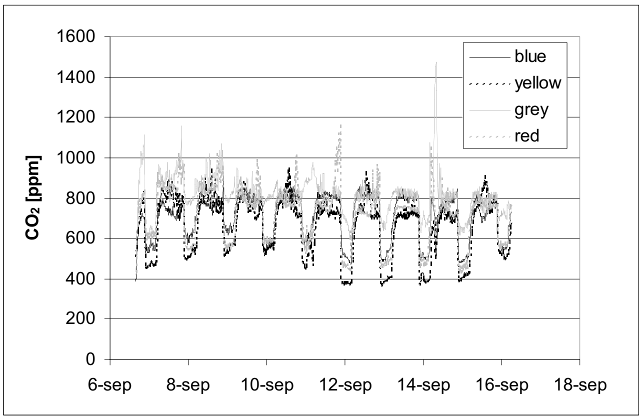

Figure 9. *CO_2 concentration in the four rooms during 10 days in September 2004. In the night the CO_2 concentration drops due to night cooling.*

These efficiencies are not as high as those reported on central units. One reason is the fact that the unit tested is a first prototype, which is plagued by internal leaks. According to the manufacturer, later models have been improved in this respect. Secondly, the wall lead-throughs used may cause differences between inlet and outlet airflow rates, which can negatively affect the efficiency.

Finally, it is common for field measurements, carried out under non ideal circumstances, to yield lower efficiencies than measurements under laboratory conditions.

G-VALUES OF GLAZING AND SUN SHADING

Experiments show that sun shading is of crucial importance to prevent overheating, especially for south oriented façades. An important characteristic of sun shading is its g-value, which is the fraction of incoming solar energy that is transmitted.

G-values for the glazing and the different sun shading devices are determined in two ways. In the first method, the building simulation program is used to find (by trial and error) which g-values best describe the heating of the rooms on sunny days. First, the g-value of the glazing is deter-

Table 2. Day averaged g-values of glazing and sun shading for the four different façades. Values are determined with the model and by direct measurement.

Façade	Type of sun shading	Glazing g-value		Sun shading g-value	
		model	measured	model	measured
Blue	Screen	60±5%	58±2%		12±2%
Yellow	Blinds	50±5%	50±2%	50-70%	55-75%
Grey	Awning	60±5%	60±2%		14±2%
Red	Awning	60±5%	62±2%	30±5%	13±2%

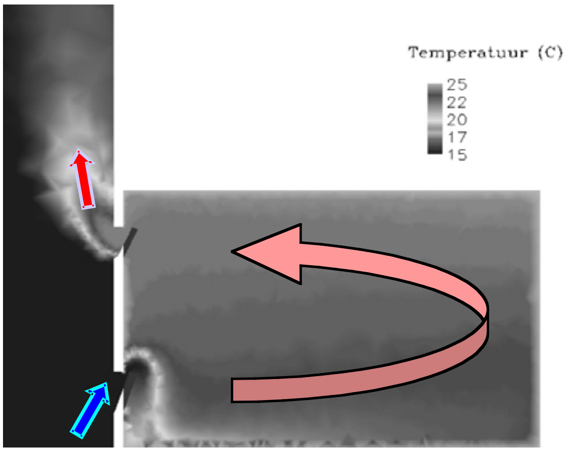

Figure 10. CFD-calculation of the temperature in the room with the blue façade, shown in a plane through the middle of the panels. The blue rectangle on the left is part of the outside world at 15ºC. [Source: NRG, Petten]

mined (with the sun shading up) and then the combined value of glazing and sun shading is determined (with the sun shading down).

In the second method, the indoor and outdoor irradiance levels (on a vertical plane) are simultaneously measured, using two pyranometers. The g-value is the ration of both levels. In addition, the temperature of the indoor glass surface is measured. Using a heat transfer coefficient of 7.7 W/m^2.K, the secondary heat transfer (due to convection and radiation) is calculated and included in the g-value. The results are shown in Table 2.

The two middle columns in Table 2 show there is excellent agreement between both methods for the determination of the g-values of the glazing. The values also agree with factory data sheets, proving the validity of the methods.

For the g-values of the sun shading, there is good agreement for the yellow façade. The value found is rather high and appears to depend strongly on weather conditions. As the double glazing sits on the outside, the cavity in between the glass layers heats up considerably on hot and sunny days. As a result, the secondary heat transfer becomes dominant, hence the high g-values. The cavity in between the layers of glass holding the blinds should have been vented to achieve acceptable g-values.

For the g-values of awning in the red façade there is much less agreement. The value directly measured is roughly half the value that the model yields. This discrepancy is consistently observed in a number of experiments. No satisfactory explanation is found for it.

No values for the sun shading of the blue and grey façades were determined with the model. Most of the summertime, these façades have been facing north, so the sun shading devices have not been lowered often enough to accurately determine their g-values with the model. The measurements of the g-values for the blue and grey façades with the pyranometers were carried out with these façades facing south, after rotating the research facility by 180 degrees.

NIGHT COOLING

As mentioned before, CO_2 is injected as a tracer gas. In a (quasi) equilibrium situation, the rate of CO_2 injected equals the rate of CO_2 vented out of the room. Assuming ideal mixing of CO_2 and air, the ventilation rate can easily be calculated from the rate of injection and the difference between ambient and indoor CO_2 concentration. This way, the ventilation rate (expressed in ACH) due to night cooling is experimentally determined.

In addition, night cooling has been simulated for two of the rooms using a commercial CFD (Computational Fluid Dynamics) program [FLUENT 2001]. The rooms modelled are the ones containing the blue façade (fitted with a set of panels for night cooling) and the yellow façade (using the parallel window for night cooling).

As an illustration of the CFD calculations, Figure 10 shows the distribution of temperature in the interior of the room in a plane perpendicular to the façade through the middle of the panels. It shows cool outside air flowing through the lower panel into the room, and air heated to approx. 25°C leaving the room through the upper panel.

Measurements and CFD calculations are described in detail in [KOENE 2005 2]. The main conclusion is that CFD calculations can be said to adequately describe and predict the performance of different geometries with respect to night cooling.

The ventilation rates achieved in both geometries (by means of natural ventilation) range from approx 1 ACH (at a difference of 4ºC between indoor and ambient temperature) to 2.2 ACH (at a difference of 14ºC between indoor and ambient temperature). Note that in the present cases there are openings in only one façade (one sided ventilation). Higher ventilation rates are possible with openings in more than one façade or with openings in different floors.

In spite of the relatively small opening of the parallel window (approx. 3 cm all round when fully opened), ventilation rates are comparable to those in the case of the two panels. Apparently, the parallel window design effectively combines inlet and outlet opening into a single component, simplifying the actions needed for night cooling (manual or automated). Ventilation rates with larger openings will be measured in the future.

Finally it should be noted that prevention of burglary is a point of attention with windows open during the night for night cooling. A number of tests are currently in progress.

Potential for regular dwellings

The research facility obviously is not representative of a regular dwelling and the data obtained from it cannot be used directly to assess the potential of an active façade for regular dwellings. To answer that question, the building simulation model and data from one of the ECN research dwellings are used.

The research dwellings on the ECN premises, shown in Figure 11, consist of a row of four dwellings that are typical for the type of dwelling built in the Netherlands. These research dwellings serve to test various types of HVAC (Heating, Ventilation And Cooling) systems. Dwelling A, to the left in Figure 11 is of concrete construction and is heated by a gas-fired boiler. Because a lot of experimental data are available for this dwelling, it is used to assess the potential of 'active' façades in a regular dwelling.
The following steps are taken:

Step 1. The building simulation model is fed with experimental data from dwelling A including measured values of the heat generated by the gas-fired boiler. The model then calculates the indoor temperature, which is compared to the measured value. Figure 12 shows that the calculated indoor temperature agrees well with the measured value for an experiment of nearly 3 weeks in October 2004.

Alternatively, the indoor temperature could have been used as input to the model in order to calculate the energy consumption. This figure could then have been compared to the measured energy consumption. The procedure followed here (to use the energy consumption as input) has the advantage that it shows if the model can adequately describe the dynamic thermal behaviour of the dwelling, which is crucial when addressing the issue of overheating.

The agreement between measured and simulated values in Figure 12 shows the ability of the building simulation model to describe the thermal behaviour of dwelling A, which in turn gives confidence that the potential of an active façade in this dwelling can also be assessed using the model.

Step 2. The dwelling, retaining the relatively large glass surfaces shown in Figure 11, is hypothetically fitted with active façades on the south and the north. The characteristics of the blue façade such as thermal insulation, air tightness, g-value of glazing and sun shading etc. are fed to the model. For the efficiency of the heat recovery unit, a value of 65% is used. For night cooling, the ventilation rates experimentally found are used (1.5 ACH at 4°C difference between indoor and ambient temperature and 2.2 ACH at 14°C).

Simulation of representative occupant behaviour is quite a challenge. An energy conscious and knowledgeable occupant, who is at home seven days a week and who can afford to spend time to operate the sun shading, open windows for night cooling, optimise ventilation rates etc. can hardly be surpassed where energy savings or indoor comfort are concerned. In this case, the main advantage of using an active façade may be convenience for the occupant.

Figure 11. ECN research dwellings facing south. Dwelling A is to the left.

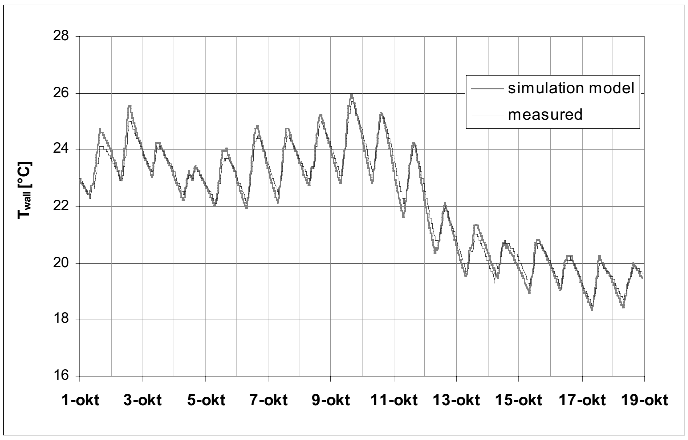

Figure 12. Calculated and measured indoor wall temperature for dwelling A.

For less energy conscious, less knowledgeable or even less present occupants (probably the majority of people), the advantages of the active façade will manifest themselves. As a reference ('base case') therefore, the occupants are assumed to be absent 4 days a week during day time. No automated sun shading device is assumed in this case and, when the occupants are absent, the sun shading is not lowered. When the occupants are present, the sun shading is lowered whenever the sun shines too bright (over 200 W/m^2 on the façade). No form of night cooling is applied and the dwelling is vented with a constant ventilation rate (150 m^3/hr, approx. 0.5 ACH).

Step 3. With the characteristics of the dwelling and occupants fed to the building simulation model, the performance of the dwelling is simulated in the test reference year for De Bilt. The latter contains weather data that are typical of the Dutch climate.

The annual heating demand for space heating and the degree of overheating (expressed as the number of hours where the indoor temperature is over 25ºC) are determined for the 'base case' and a number of cases where various functions of the 'active façade are activated. The results of the simulations are shown in Table 3.

Table 3. Simulations of heating demand and overheating of a conventional dwelling fitted with active façades with various functions activated.

Case	Description	Heating demand [kWh/m^2·a]	Reduction compared to base case	Overheating (T>25°C) [hr/a]
0	Base case	53	0%	1 500
1	'Active' sun shading (g-value 15%), no night cooling	44	-17%	370
2	'Active' sun shading + night cooling	44	-17%	20
3	'Active' sun shading + night cooling +heat recovery (efficiency 65%)	22	-59%	40
4	'Active' sun shading + night cooling +demand controlled ventilation	28	-46%	50
5	'Active' sun shading + night cooling +demand contr. ventilation + heat recovery (efficiency 65%)	17	-68%	60

In the base case, the dwelling suffers from considerable overheating (1500 hr which is the equivalent of two months), with indoor temperatures reaching 33ºC. This agrees with actual indoor temperatures in dwelling A in the summer when the sun shading is not lowered.

In case 1, the intelligent algorithm maximises the solar heat to assist the heating system in wintertime, which decreases the heating demand by an ample 15% compared to the base case. Also, a sun shading device operating 7 days a week drastically reduces the amount of overheating.

Case 2 shows the additional effect of night cooling, further reducing the amount of overheating. Since night cooling takes place almost exclusively in summertime, there is little or no effect on heating demand. Up to a certain degree, sun shading and night cooling appear to be competitive techniques. The more effective the sun shading, the lower the additional cooling effect due to night cooling. In practice however, the effect of night cooling is expected to be larger than in the simulations e.g. because occupants may leave doors or windows open in summertime, allowing summer heat to enter the dwelling. Here, night cooling can provide the necessary additional cooling.

Case 3 shows that application of a heat recovery unit in the ventilation system is a very effective way to reduce energy demand for space heating. The reason being that with good thermal insulation of modern dwellings, ventilation losses make up a substantial part of the total heat losses. With a thermal efficiency of 65%, the heat recovery unit reduces heating demand by approx. 50%, compared to case 2.

Case 4 shows the substantial reduction on heating demand that can be achieved by implementing demand-controlled ventilation. The figure should be taken as indicative however, since it strongly depends on the size of the family and the presence of its members.

Finally, case 5 shows the reduction that can be achieved by the combination of demand controlled ventilation and heat recovery, which is typical for the Climarad ® unit. Note that the combination of heat recovery and demand controlled ventilation saves less than the sum of the individual techniques because both techniques are competitive. However, the additional 9% reduction of case 5 compared to case 3 is still well worth considering. Overheating in cases 3, 4 and 5 is higher than in case 2 because in summertime, less heat is carried away by the ventilation system.

Conclusions

The active façades built and tested focus on 1) reducing ventilation losses, 2) intelligent algorithms for sun shading, and 3) application of environmentally friendly night cooling. The techniques implemented appear to function well with the exception of the sun shading in the yellow façade. Here, the cavity should be vented to be able to carry away excess heat in summertime.

The main difference found among the four façades is the additional effect on energy savings due to the heat recovery unit in the blue façade. The yellow façade shows good thermal and acoustic insulation, which may be beneficial in areas of high noise levels.

Furthermore, simulations using a validated building simulation program show the high potential of these façades to reduce energy consumption and improve indoor comfort in a regular dwelling. Intelligent algorithms for both sun shading and night cooling can practically prevent overheating from occurring in the case studied. Maximising the amount of solar heat to enter the dwelling in wintertime can decrease heating demand in the order of 10-20%.

Minimising ventilation losses considerably reduces the heating demand. Ventilation losses are most effectively reduced by application of a heat recovery unit. Where this is not possible or undesirable (perhaps because of claims of negative effects on IAQ) demand controlled ventilation offers a second best option. The total effect of this technique depends on the size of the family and the presence of its members. The combination of heat recovery and demand controlled ventilation offers the highest reduction of energy consumption.

With fully functional 'active' façades, the heating demand of 17 kWh/m^2.a is nearly as low as that of a Passive House (15 kWh/m^2.a), while overheating is practically eliminated.

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Glossary

ACH	Air Changes per Hour
IAQ	Indoor Air Quality
g-value	fraction of solar energy passing through glass, sun shading etc.