Closed translucent façade elements with switchable U-value – a novel option for energy management via the facade

Thibault Pflug[1*], Tilmann E. Kuhn[1], Ralf Nörenberg[2], Andre Glück[4], Nikolaus Nestle[3], Christoph Maurer[1]

[1] Fraunhofer Institute for Solar Energy Systems ISE, D-79110 Freiburg, Germany

[2]BASF New Business GmbH, D-67056 Ludwigshafen, Germany

[3]BASF SE Advanced Materials and Systems Research, D-67056 Ludwigshafen, Germany

[4]Stockwerk GmbH, Richard-Wagner-Straße 1, D-68165 Mannheim, Germany

* Corresponding author. Phone number: +49 (0) 761 4588 5868. Fax : +49 (0) 761 4588 9950. Email address: thibault.pflug@ise.fraunhofer.de

Abstract

To prevent the overheating of a well-insulated building in summer, façade elements with switchable U-value are a possible solution. A new translucent element with switchable U-value is presented. The convection around a translucent insulation panel is controlled by moving this panel vertically within the double glazing unit. Measurements of such elements show a possible switching of more than +100% of the U-value between the insulating and conducting state. Various geometries have been measured, and the influence of CO_2 in the cavity has also been investigated. Based on the experimental results, TRNSYS simulations have been performed to investigate the overall performance

of such a new element integrated in a real building. An optimized element could lead to a reduction of the cooling demand of up to 29.6% of the useful energy and to large improvements in the summer comfort.

Keywords

Switchable U-value, translucent element, optical and U-value measurement, TRNSYS Simulations, passive cooling

Abbreviations

FESU: façade element with switchable U-value.

g [-] the g-value.

G [W/m²] the solar irradiance on the element surface.

h_i=7.7 [W/(m²*K)] the interior heat transfer coefficient, as given by norm EN673 [1].

h_e=25 [W/(m²*K)] the exterior heat transfer coefficient, as given by norm EN673 [1].

q_i [-] the solar secondary heat gain.

Q_{int} The energy transmitted from the element to the interior through convection, conduction and IR radiation.

solRadIn [W/m²] the total transmitted solar energy

U [W/(m²*K)] the U value of the component.

$\Delta\theta=\theta_{warm} - \theta_{cold}$ [°C] temperature difference between the warm surface temperature and the cold surface temperature of the test model.

θ_{int} [°C] the room temperature.

θ_{ext} [°C] the ambient temperature.

$\theta_{i\ max}$ [°C] the operative temperature of the room.

θ_{ma} [°C] the moving average of the external air temperature.

τ_{sol} [-] transmission in the solar spectrum (integral value), calculated with EN410.

τ_{vis} [-] transmission in the visible spectrum (integral value), calculated with EN410.

1 Introduction

Reducing the energy consumption of buildings has become a key political priority in the course of the debate on reducing the emission of greenhouse gases. This has led to legal requirements such as the European Directive 2010/31/EU [2] on the Energy Efficiency of Buildings which demands that after 2020, new buildings have to be ”nearly zero-energy buildings”.

Thermal insulation has been proven as a very effective measure to reduce heat losses from buildings in winter [3]. Similarly, heat flow from the exterior into air-conditioned rooms can also be effectively reduced by insulation. However, it is important to be aware that insulation will not only reduce these unwanted heat flows but also limit possibly beneficial heat flows across the wall. The most important situation in which heat flow from the building is beneficial is during nighttime hours in summer where heat accumulated by solar gains and internal loads during the daytime hours can escape again from a poorly insulated building. In a well insulated building, by contrast, the overnight heat flow is reduced to a fraction while solar gains through the windows and internal loads are still essentially the same. Due to this effect, control of solar gains and other thermal loads inside buildings becomes an increasingly important challenge in the struggle for further improving the energy balance of the built-up environment.

Presently available solutions include the use of glazing solutions with reduced g-values [4] and various forms of shading devices such as e.g. external blinds [5]. The remaining thermal loads are dealt with by ventilation and air-conditioning, which contributes to the building’s energy consumption. If the thermal insulation of a building could be switched off during nighttime in summer conditions, active cooling measures could be reduced and the energy balance of the building would be improved.

One way to switch insulation properties is the change of gas pressure inside a vacuum insulation panel which was presented over 10 years ago [6]. Microscopic switching of thermal conductivity by ordering effects [7] is also a possible way to switchable U-values; however until now the absolute values of the thermal conductivities of such systems are not attractive for insulation applications. Further ways to switch U-values include loading and unloading of macroscopic cavities with insulating material [8] or the seasonal removal of insulating materials [9]. Also changing the medium between double-glazed windows from gas to liquid such as described in [10, 11] effectively leads also to a dramatic change in the U-value of the window element. This aspect is only very indirectly addressed in [10, 11]. If the bowing of the glass due to fluid expansion and the aesthetic effects of the drying fluid can be handled, buildings could benefit from such a system. In this contribution, a new way to achieve a Facade Element with Switchable U-value (FESU) is presented and evaluated by simulations and experiments.

2 Facade element with switchable U-value

The principle of functioning of the FESU is based on controlled convection inside a closed module containing one or several insulating panes [12]. Basically, the element can be in two states, insulating or conducting, depicted in Figure 1:

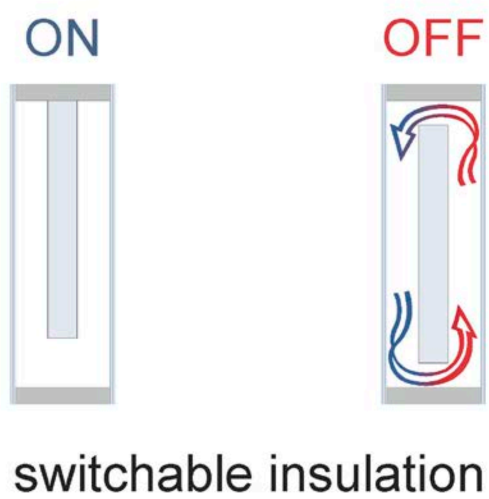


Figure 1 - Translucent facade element in the insulating state (left) and in the conducting state (right).

- In the insulating state (left) the insulation panel is at the top. In this state, no large-scale convection around the panel is possible and the element behaves like a system with three insulating layers (two thin air layers and an insulation panel).

- In the conducting state (right), the insulation panel is in a vertical middle position, with air gaps at the top and the bottom. In this state, large-scale spontaneous convection around the insulation panes is possible. This large-scale convection is due to the difference of density between the front and back gas column, which results in a driving pressure difference between back and front.

The translucent insulation material used for the test models was Basotect ®, which is an insulation and sound absorption material developed by BASF. It is a low-density, open pore melamine foam and has a thermal conductivity at 20°C of 0.035 W/(m*K).

3 Modeling and simulation condition

Building-scale simulations of the energetic benefits achieved with FESU were conducted in TRNSYS [13]. In this part, the simulation conditions as well as the modeling of the translucent element with switchable U-value are discussed.

3.1 Simulation of a well-insulated office

The simulation object was a single-room office in Ludwigshafen, Germany.

The office was simulated with a high insulation level, corresponding to the Passive House Standard.

In a second step, variants were simulated by replacing part of the facade by our translucent element with switchable U-value.

Geometry and facade:

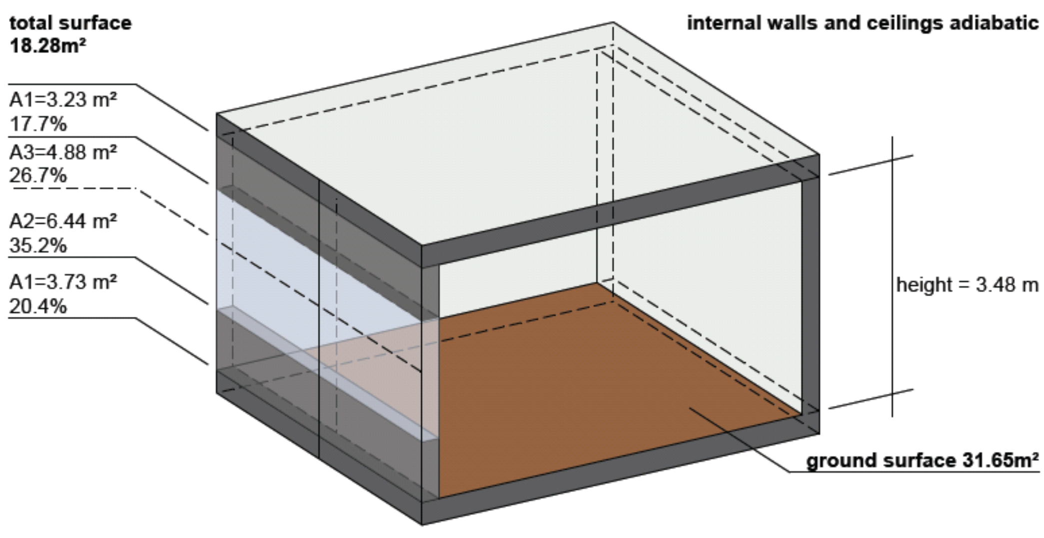


Figure 2 – Simplified geometry of the simulated room.

The external facade is oriented 20° west. The main features of the simulated room are the following:

- All opaque walls (area A1) of the external façade are equipped with insulation, and have a resulting U-value of 0.17 W/(m²*K). Coldbridges are neglected in this case.

- A2 and A3 are windows with the following features:
    - U_g=1.2 W/(m²*K).
    - g-value=0.42.
    - τ_{vis} =0.71.
    - τ_{sol} =0.39.
    - Ratio frame/window=0.3. U_{frame}=2.2 W/(m²*K).

Ventilation:

The ventilation is equipped with heat recovery (details can be seen in the Appendix).

Others simulation conditions:

Other simulation conditions are described in the Appendix.

3.2 Modeling and simulation of the translucent element with switching U-value

3.2.1 Replacement of the upper part of the existing window

Starting from the well insulated reference, variants were simulated with the new translucent Facade Element with Switchable U-value (FESU).

Starting at 2.2 m height, the existing window was replaced by the new translucent element (Area A3). This represents 4.9 m² and 26.7% of the external façade. While this part of the façade is only of minor relevance for visual contact to the outside environment, it is highly relevant for the supply of daylight. Scattering elements are advantageous here as they increase light distribution deep into the room.

3.2.2 Optical considerations

The solar energy directly transmitted through the FESU was directly calculated as $solRadIn = \tau_{sol,FESU} * G$ with a transmittance in the solar range $\tau_{Sol,FESU}$ of 0.05. This value results from multiple reflection calculation between two float glass panes and the 30 mm thick Basotect ® layer. This value was estimated according to EN410[14]., The direct-hemispherical transmittance of Basotect was measured with the TAUWIN equipment [15]. This equipment is used for angle-dependent direct-hemispherical transmittance measurements. This equipment combines a coated integrating sphere and a diode-array spectrometer. The optical properties derived from measurements and used for the EN410 multiple reflection calculation where the following:

- Basotect: direct-hemispherical transmittance of 0.05, diffuse-hemispherical transmittance of 0.04, direct-hemispherical reflectance of 0.82, diffuse-hemispherical reflectance of 0.87.
- Glas: direct-hemispherical transmittance of 0.90, diffuse-hemispherical transmittance of 0.81, direct-hemispherical reflectance of 0.08, diffuse-hemispherical reflectance of 0.15.

The diffused-hemispherical values were derived from measurement with direct incoming irradiance at 60° incident angle. The irradiance reflected by the Basotect was considered as perfectly diffuse for the multiple reflection calculation.

Much of the irradiance is reflected by the Basotect layer, especially if the incoming light is diffuse.

With direct incoming irradiance at 0° irradiance, the absorbed energy in the outer glass, Basotect and inner glass layers calculated with EN410 where respectively 0.06, and 0.12. The quantity absorbed at the inner layer is negligible (below 0.005). This situation with normal incoming completely direct light is very rare. If the incoming light is diffuse or with 60° incidence angle, the energy absorbed in the outer glass and in the Basotect layer are respectively 0.08 and 0.09. The measured U-value functions (see 3.2.3) where then used to calculate the thermal resistances in the system and deduct the secondary heat gain. For incoming direct light at 60° incidence angle or diffuse light, the secondary heat gain was found to be 0.04 as well in the insulating than in the conducting state.

3.2.3 Thermal considerations

The heat flux from the element to the interior through convection, conduction and thermal IR radiation, in W/m², is given by:

$$Q_{int} = U * (\theta_{ext} - \theta_{int}) + q_i * G \qquad \textit{Equation 1}$$

In the absence of a detailed model of the element, the secondary heat gain q_i was estimated to a constant value of 0.03 in an early stage. This order of magnitude of q_i has been later confirmed by the EN410 calculation, with constant thermal resistances derived from the U-value measurements. However, if the transparency of the insulation material should be increased in future, a detailed model should be used to calculate the temperature dependent and angle dependent secondary heat gain.

The U-values in the insulating and in the conducting states were determined experimentally and depend on the temperature difference between inside and outside. The U-value functions chosen for the simulations were derived from the measurements of the first test models (see 4.1.1), by fitting linear functions to the measurements values:

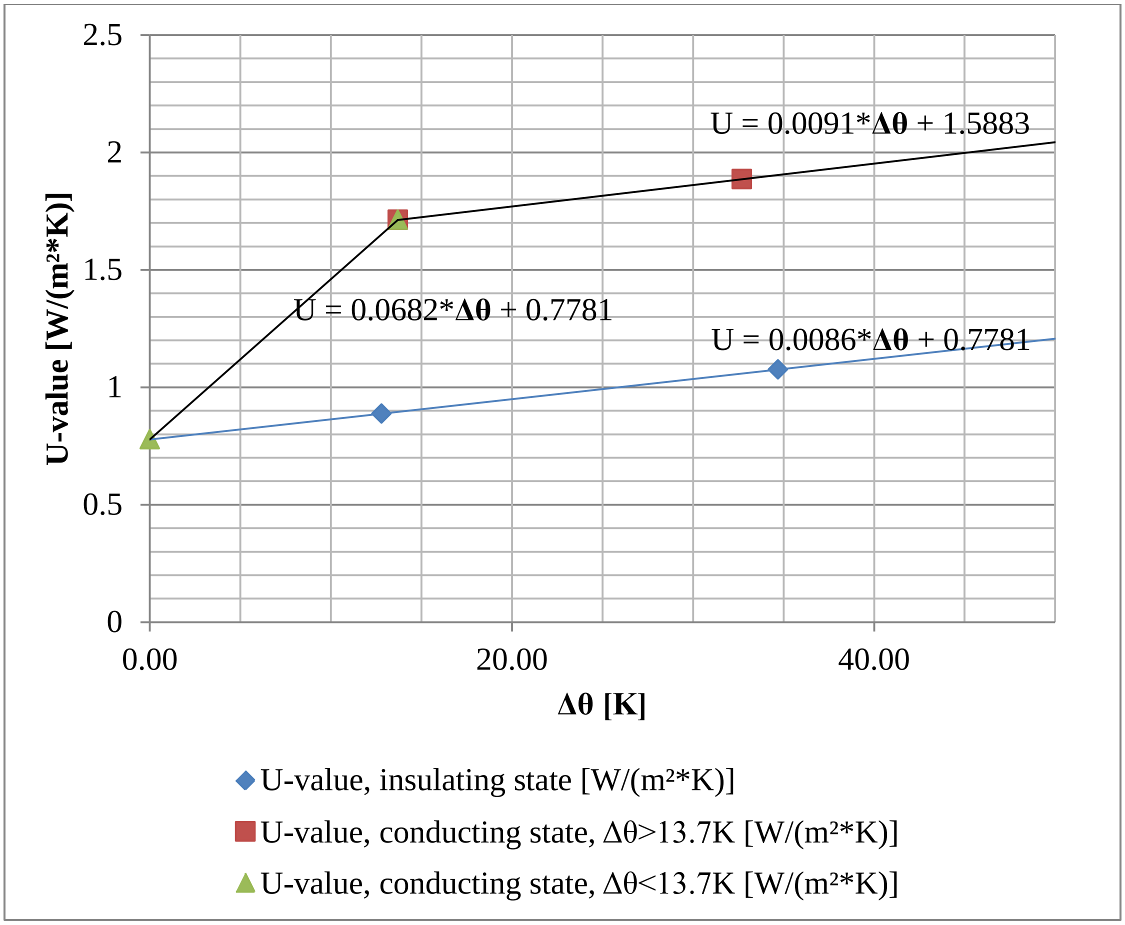


Figure 3 - U=f(Δθ) functions used for the TRNSYS simulations.

These functions were used to calculate the heat transfer through the element for every time step, depending on the temperature difference between room air temperature and exterior air temperature. The influence of the absorbed solar energy on the convective heat transfer has not been considered, due to the facts that the absorbed energy in each layer was low and that the high U-value with high temperature differences in summer is mostly activated during night time.

The temperature dependence of the U-value in the high U-value state is due to the fact that the convection needs a finite temperature difference to begin. In this way, one can expect the U-value to approximate the U-value of the insulating state at very small temperature differences. The linear approximation probably underestimates the U-value: for low temperature differences, the pressure drops in the system are low and thus the mass flow rate and the large-scale convection develops fast. For higher temperature difference, the pressure drops temperate the convection.

3.2.4 Variants simulated

Compared to the reference, following variants have been simulated:

- Variant A:

  The translucent element has a lower transmission within the solar spectrum, which is 4.5% instead of 37.7% for the glazing. The translucent element also has a lower U-value in the insulating state: about 0.99 W/(m²*K) by $\Delta\theta$=24 K instead of U_g=1.23 W/(m²*K) for the glazing. Thus, without even switching to the high U-value, replacing part of the façade by the translucent element has an influence on the simulation result. This influence is evaluated with control strategy A, where the U-value is never switched to the high value.
- Variant B:

Variant B uses the previously defined U-value functions, with the following control strategy:

- Heating period :
    - When $\theta_{ext} > \theta_{room}$: high U-value.
    - If not, low U-value.
- Cooling period:
    - When $\theta_{ext} < \theta_{room}$: high U-value.
    - If not, low U-value.

The heating period is defined as the month where the heating load is superior to the cooling load. The rest of the time was then considered as the cooling period.

- Variant C:

This variant uses the same control strategy as variant B, but 3 W/(m²*K) is set as a constant value for the high U-value function. This arbitrary value corresponds to non-insulating double glazing. The goal was to simulate the potential of the element, if in the conducting state the convection is optimized or if a small ventilator is used. A small ventilator would allow us to get an U-value quite independent of the difference of temperatures at the boundaries, and would allow us to reach higher U-value due to higher convective heat transfer. This value was not measured in laboratory and is only theoretical.

3.2.1 Comparison with a free-cooling strategy

In order to compare the effect of switching the U-value with a conventional solution: variant A, where the upper part of the window is replaced by the translucent element without switching, was simulated with a free-cooling strategy, in order to compare the effect of free cooling to the switchable U-value.

For this variant, the air change rate of the room was raised from 2 to 4 vol/h when the outdoor air temperature was inferior to the indoor temperature. In order not to overcool the building, this strategy is only activated when the outdoor air temperature is above 19°C.

4 Results and discussion

4.1 U-value measurements

The U value was measured in a vertical position in the Taurus equipment (TAURUS instruments - TLP 800 S) at Fraunhofer ISE.

The measured values are center of glazing values, the heat flux being measured over a 500*500 mm² central area, and the prototype area being 800*800 mm². For this U-value measurement, the maximal absolute error was 0.040 W/(m²*K), the minimal absolute error was 0.017 W/(m²*K) and the mean absolute error was 0.031 W/(m²*K).

4.1.1 Test models with a single insulation pane

The test models were composed of two 3 mm thick Plexiglas panes, a 20 mm thick PVC frame and a Basotect ® pane. The dimensions of the test models are detailed in Appendix B.

- A is the thickness of the vertical air layers.
- B is the thickness of the translucent insulation layer.

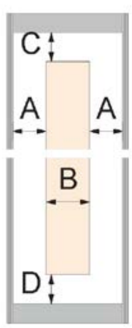
- C is the dimension of the upper air gap.
- D is the dimension of the lower air gap.

The test models were all measured in a vertical position.

This first test model was then measured with two positions of the insulation plate within the test model:

- Translucent insulation pane in the lower position (C=60 mm, D=0 mm).
- Translucent insulation pane in a middle position (C=30 mm, D=30 mm).

Each position was measured with a high (about 35 K) and a low (about 12-15K) temperature difference. The results can be seen in Table 1 below:



N°	**A**	**B**	**C**	**D**	**Δθ**	**U-value**
-	**mm**	**mm**	**mm**	**mm**	**°C**	**W/(m²*K)**
1I	30	30	60	0	13	0.89
2I	30	30	60	0	35	1.08
3C	30	30	30	30	14	1.71
4C	30	30	30	30	33	1.89

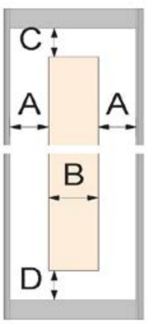
Table 1 - Measurement results of the first test models. I=Insulating state, C= Conducting state.

For the lower temperature difference, a switching of the U-value of +93 % can be observed between the two positions. For the high temperature difference, a switching of the U-value of +75 % can be observed.

These measurement values were used for the TRNSYS Simulations.

4.1.2 Parameter variation for one plate-test models

New test models were then been built, with a much thinner translucent insulation layer and much thinner total thickness. The goals with these new test models were to have a better translucence and to investigate the influence of several parameters. The direct-hemispherical visible transmittance of a 10 mm Basotect plate, measured with the TAUWIN equipment, is 0.172. The results are presented in Table 2:



N°	A	B	C	D	Δθ	U-value
-	Mm	Mm	mm	mm	°C	W/(m²*K)
5I	17.5	10.0	0.0	35.0	15	1.33
6I	17.5	10.0	0.0	35.0	29	1.44
7C	17.5	10.0	17.5	17.5	14	1.72
8C	17.5	10.0	17.5	17.5	29	1.86
9C	30.0	10.0	30.0	30.0	14	1.83
10C	30.0	10.0	30.0	30.0	28	2.03
11C	17.5	10.0	35.0	35.0	14	1.58
12C	17.5	10.0	35.0	35.0	29	1.77
13I	17.5	10.0	0.0	0.0	15	1.31
14I	17.5	10.0	0.0	0.0	34	1.41
15I	17.5	10.0	35.0	0.0	15	1.44
16I	17.5	10.0	35.0	0.0	29	1.57

Table 2 - Measurement results of the second measurement campaign. I=Insulating state, C= Conducting state.

Measurements 5I and 6I are the references in the insulating state: the insulation plate is at the top, with a 35 mm air gap at the bottom. The U-values are 1.33 and 1.44 W/(m^2*K) for respectively the low and the high temperature difference.

Measurements 7C and 8C represent the conducting state, with the insulation panel in the middle. The switching of the U-value represents +29 % for both the low and the high temperature differences. The U-value are respectively 1.72 and 1.86 W/(m^2*K). This decrease in switching compared to the first test models with thicker insulation and thicker air gaps was predictable: indeed, thicker insulation leads to a lower U-value in the insulating state, and the thicker air gaps favors convection in the conducting state.

The influence of the thickness of the vertical and horizontal air gaps are investigated with measurements 9C and 10C. Compared to measurements 7C and 8C, the air gaps are now 30 mm thick instead of 17.5 mm. This results in increasing U-value through better convection, with respectively 1.83 and 2.03 W/(m^2*K).

The influence of the ratio between the thickness of the horizontal air gap and the thickness of the vertical air gap is investigated with measurements 11C and 12C. In the conducting state, doubling the ratios C/A and D/A results in a decreasing of the U-values, with values of 1.58 and 1.77 W/(m^2*K). Compared to measurements 7C and 8C, this represents a decrease of -8% and -5%.

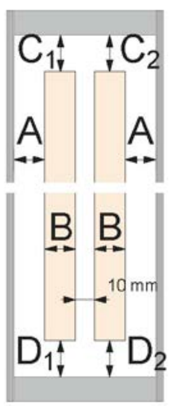
One would expect an increase of the U-values with larger horizontal air gaps, due to lower pressure drops in the flow reversal area. This is not the case. One possible explanation is that turbulence zones appear in these upper and lower areas, which counteracts the natural convection.

Experiments 13I to 16I were conducted in order to explore the convection effect inside the gap region of the element when switched into the insulating state: compared to measurements 13I and 14I without gaps, the U-value of the element with a gap in the top position (15I and 16I) is about 8 % larger, while the U-value for the gap in the bottom position (5I and 6I) is only 2.5% larger.

4.1.3 Test models with two plates

Based on the experiences with the first sets of elements, further test models with two translucent insulation layers were built and measured. A 10 mm additional air gap between the two insulation layers provides additional insulation while not reducing the translucence further.

The results are shown in Table 3:



N°	A	B	C_1	C_2	D_1	D_2	Δθ	U-value
-	**mm**	**mm**	**mm**	**mm**	**mm**	**mm**	**°C**	**W/(m²*K)**
17I	15	15	30	0	0	30	15	0.71
18I	15	15	30	0	0	30	29	0.80
19C	15	15	15	15	15	15	14	1.44
20C	15	15	15	15	15	15	28	1.60
21I	15	15	0	0	0	0	15	0.72
22I	15	15	0	0	0	0	29	0.80

Table 3 - Measurement results of the test models with two insulation plates. I=Insulating state, C= Conducting state.

Measurements 17I and 18I show the two-plate test model in the insulating state, with the front insulation panel at the top and the back insulation panel to the bottom, to prevent convection. The U-value are respectively 0.71 and 0.80 W/(m²*K) for the low and high temperature difference. This value can be compared to that of triple glazing.

Measurements 19C and 20C show the two-plate test model in the conducting state, with both insulation panels in a middle position, with air gaps at both ends. The switching of the U-value represents respectively +103 % and +98% for the low and the high temperature difference. The U-values are then 1.44 and 1.60 W/(m²*K), which corresponds to a poorly insulating double glazing.

Measurements 21I and 22I where performed using continuous insulation panels, in order to verify that no “slalom” convection occurs in the situation of measurements 17I and 18I. The differences between the two situations are low, with respectively 2.1% and 1.2% difference for the low and the high temperature difference.

4.1.4 Measurements with CO_2

Measurements the elements 17I to 20C were also run with CO_2 instead of air. CO_2 has several advantages compared to air:

- A lower thermal conductivity in the insulating state: 0.0162 W/m*K at 20 °C, 1 atm.
- A lower thermal diffusivity: $105.4*10^{-7}$ m²/s. This favors the convection by carrying the heat away more slowly, allowing the gas to heat. Compared to air, the lower heat capacity (0.85 kJ/(kg*K) at 20°C) is compensated by a higher density (1.84 kg/m³ at 20°C, 1 atm) and the lower thermal conductivity.

- A lower dynamic viscosity ($14.69*10^{-6}$ Pa*s at 20°C). Compared to air, this also favors the convection.

Particular attention has been paid to the tightness of these test models. Results are shown in Table 4:

N°	**A**	**B**	**C_1**	**C_2**	**D_1**	**D_2**	**Cold side**	**Warm side**	**Δθ**	**U-value**
-	**mm**	**mm**	**mm**	**mm**	**mm**	**mm**	**°C**	**°C**	**°C**	**W/(m²*K)**
23	15I	15	30	0	0	30	3.4	18.0	15	0.65
24	15I	15	30	0	0	30	7.4	36.9	30	0.74
25	15C	15	15	15	15	15	4.3	18.0	14	1.45
26	15C	15	15	15	15	15	9.6	37.8	28	1.67

Table 4 - Measurement results with two test models with two insulation panels and CO2. I=Insulating state, C= Conducting state.

Measurements 23I and 24I in the insulating state show a better insulation than the air-filled test models. The difference to measurements 17I and 18I are respectively -8.3% and -7.5%, with U-value of 0.65 and 0.74 W/(m²*K).

Measurements 25C and 26C show the two-plate test model in the conducting state, filled with CO_2, with both insulation panel in a middle position and gaps at both ends. The switching of the U-value compared to measurements 23I and 24I represents respectively

+123 % and +125% for the low and the high temperature difference. The U-values are then 1.45 and 1.67 W/(m²*K).

For the low temperature difference, the value is in the same range as the air value. The better insulation properties counteract the convection-favoring properties. With higher temperature differences, the convection is larger in the CO_2 case, improving the U-value compared to air. So CO_2 showed as expected better performances in both the insulating and the conducting state.

4.2 TRNSYS Simulation results

Hereafter are presented the results of the reference well-insulated room, as well as different variants with switchable U-value. The first test models, with one thick insulation plate were implemented, to investigate its potential.

4.2.1 Reference well-insulated south-oriented room

The reference room has a low heating demand of 8.1 kWh/(m²*year). This corresponds to the Passive-House level. For this well-insulated, south oriented office room, the cooling load then prevails with 28.1 kWh/(m²*year). The room has an office usage with 3 people between 7:00 and 18:00 on working days.

4.2.2 Variants with the translucent element with switchable U-value

With the variants described in the simulation conditions, we find following results:

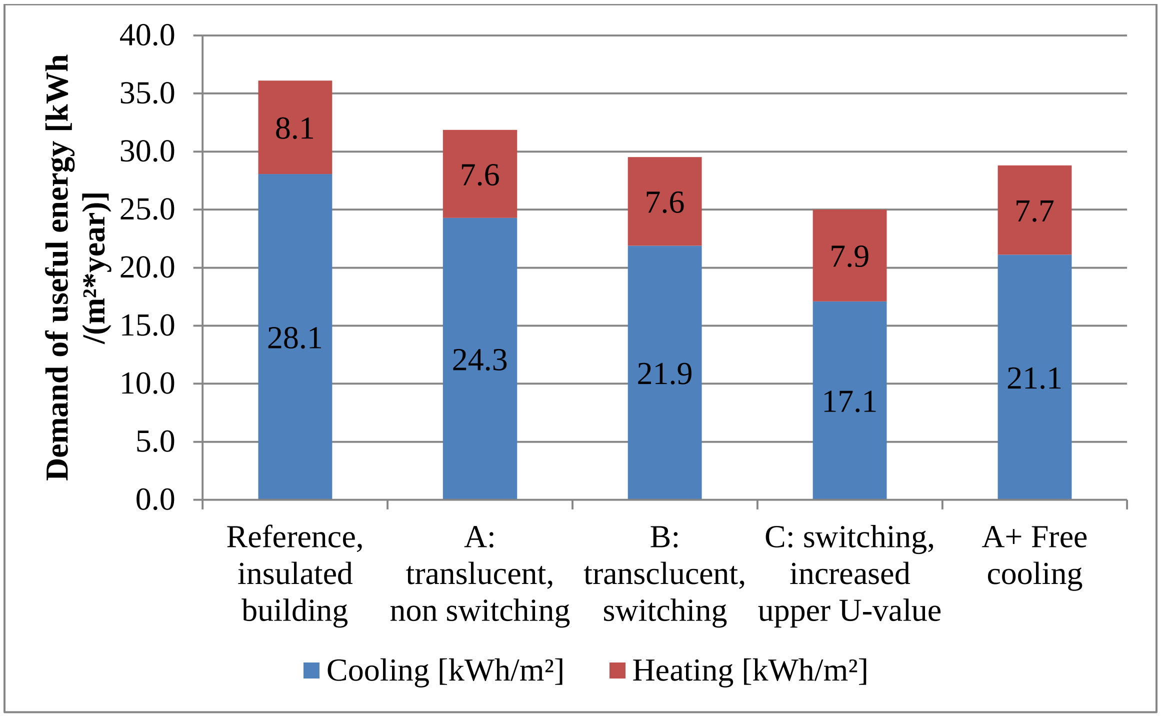


Figure 4 - Annual sum of heating and cooling for the insulated reference office and several variants. Useful energy.

The difference between the reference and variant A show us that by replacing part of the glazing by our translucent element without switching, we decrease both the cooling and the heating demand. The decrease of the cooling demand is mainly due to the lower solar transmission, whereas the decrease of the heating demand is mainly due to the higher U-value of the element in the insulated state, compared to the window.

Variant B, where we switched between the high and low U-value, shows a decrease of 9.8% of the cooling demand compared to variant A. This low reduction of the cooling demand is partly explained by the fact that in Germany, when the outside temperature is lower than the indoor temperature in summer, the difference is often low (under 5 K). According to Figure 3, the U-value is then near to 0.69 W/(m²*K), due to the linear interpolation chosen for this first approach. The assumption is that the heat transfer coefficient of the element with no temperature difference is the same in the insulating and conducting state, because in the conducting state there is no large-scale convection without the driving temperature difference. The consequence is that the heat transfer is low for these small temperature differences. In a further step, the heat transfers in the element will be modeled to give a better prediction of the thermal behavior for low temperature differences, since the linear interpolation between the measured points may be far from reality and may significantly distort the simulation results.

Variant C, where an element is simulated with forced convection, shows a decrease of 29.6% of the cooling demand compared to variant A. Compared to the reference, this represents a decrease of 39.1%. In this case, the high U-value is not temperature dependent.

The comparison of variant A (with translucent element, without switching), variant B (switching U-value) and the free cooling (applied on variant A) shows us that the effect of the switching U-value is comparable with the effect of free cooling with a doubling of the air change rate from 2 to 4 vol/h. The savings of cooling demand are respectively 9.8 and 13%. In the case of free-cooling, the additional electrical consumption of the fan has to be taken into account. To estimate the additional consumption of the electrical fan, the fan consumption can be estimated at 0.45 W/(m^3/h), which is the upper limit allowed for a german PassivHaus [16]. Based on this fan power and on the 1031 hours of functioning of the free cooling function, an additional electrical consumption of 3.2 kWh/(m^2*year) is calculated. This would more than compensate the thermal gain. To relativize these results, we can point out that the reference air change rate was already quit high (2 vol/h).

Concerning the variant B and C, the switch to the high U-value does not occur in the heating period. This is due to the fact than the situation $\theta_{ext}>\theta_{int}$ never occurs during these months for the Ludwigshafen's weather data. During the cooling period, the high U-value is set more than 94% of the time for variant B and C, so that a biannual control strategy may be considered, with the insulating state during the heating period and the conducting state during the rest of the time. A biannual switching would lead to a slightly variation of the cooling load from 21.89 kWh/m² to 21.90 kWh/m² while the heating demand stays the same. Concerning the use of dynamic switching during the cooling period, this is not efficient since when it is warmer outside, the temperature difference to the inside is small, and so the heat transfer coefficient of the element stays low. In this case, a biannual switching seems sufficient.

The influence on comfort has also been calculated, based on the DIN EN15251[17] adaptive model: this standard gives an upper limit for the operative temperature of the room, $\theta_{i\ max}$, depending on the moving average of the external air temperature, θ_{ma}, and includes the fact that the sensibility of people to indoor boundary conditions depends on the external temperature. The equations used were the following:

$$\theta_{i\ max} = 0.33 * \theta_{ma} + 18.8 + 3 \quad \textit{Equation 2}$$

With the moving average θ_{ma} given for a certain day by:

$$\theta_{ma} = 0.2 * \theta_{ed-1} + 0.8 * \theta_{am-1} \quad \textit{Equation 3}$$

θ_{ma} being the moving average of the external temperature of the day before, and θ_{ed-1} being the mean external temperature of the day before. Simulations without cooling have been performed, and the hours of the year where the

operative temperature of the room is higher than the DIN EN15251 limit have been summed, as shown in Figure 5:

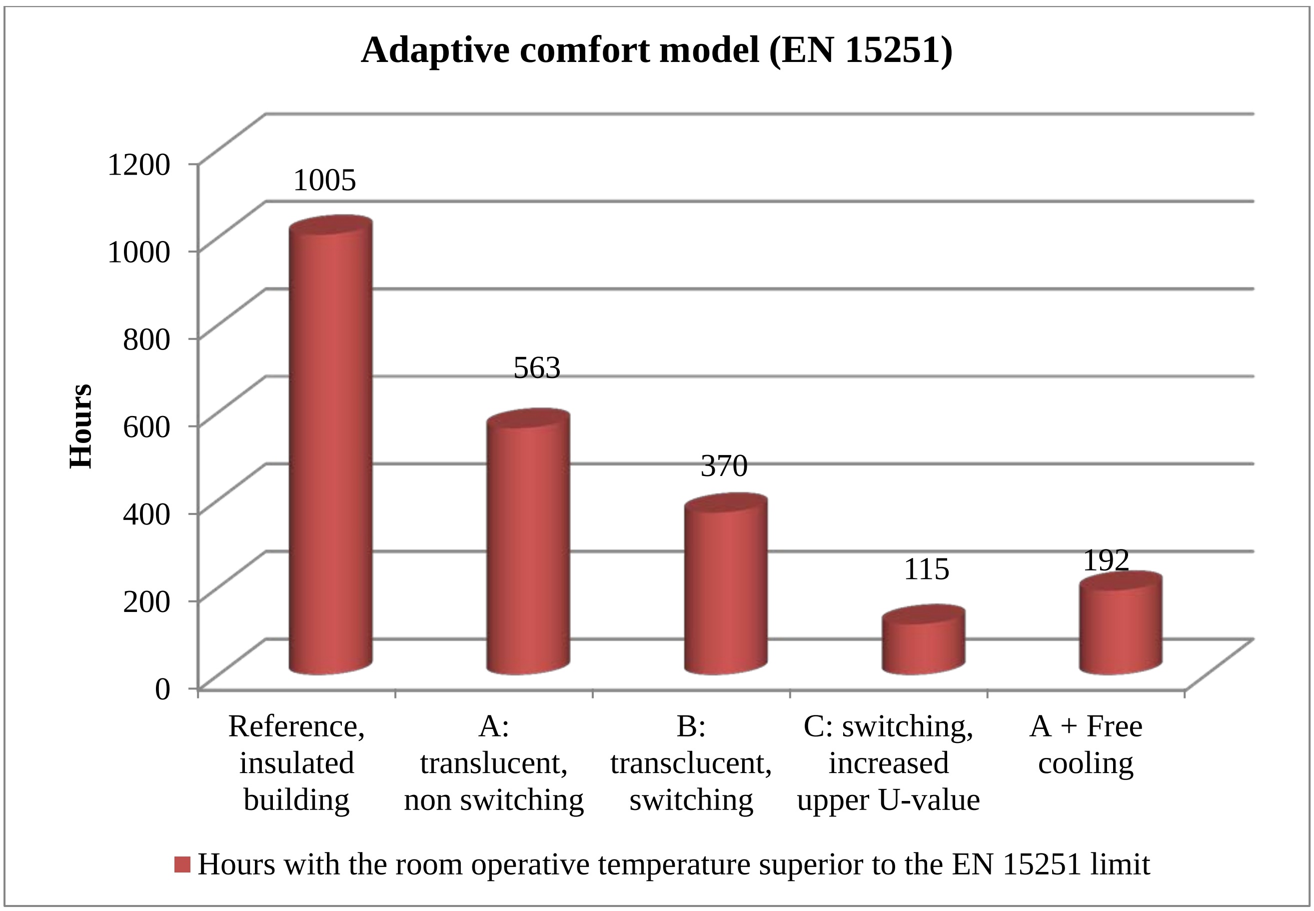


Figure 5 - Hours in the year where the operative temperature is superior to the limit calculated with the DIN EN 15251 standard.

Variant A, where we only replace part of the window by the translucent element without switching to the high U-value, shows a decrease of the hours over variable operative temperature limit. This is due to the lower transmission of the translucent element.

Variant B shows a decrease of more than 193 hours compared to variant A, by switching between the low and high U-value. Variant C shows an even better improvement, with 115 hours of discomfort. Such an element could be even more competitive than a free-cooling strategy.

This high impact of the switching on the comfort is due to the high influence of the façade's internal surface temperatures on the operative temperature and on the comfort.

5 Conclusions

In this paper, a new translucent element with switchable U-value has been presented. The element enables or prevents convection by moving a translucent insulation panel vertically.

U-value measurements of the translucent element with switchable U-value have been presented. The influence of the dimension of the air gaps has been investigated. Test models with one and two insulation plates have been measured, with a factor of two between the U-value of the insulating and of the conducting state. Different geometrical configurations have been measured to assess the impact on the performance. One test model has additionally been measured with CO_2 in the cavity, leading to a lower U-value in the insulating state and a higher U-value in the conducting state.

Several building simulations have been performed, using the TRNSYS simulation environment.

One measured configuration of the translucent element with switchable U-value has been simulated on a well-insulated building. With this non-optimized configuration, a reduction of about 10 % of the cooling demand and large improvement in the summer operative temperature. A better modeling for the low temperature difference regime should lead to larger predicted savings on the cooling demand. An optimized element with switchable U-value could lead to a reduction of about a third of the cooling demand. Compared to the traditional free-cooling solution, even the non-optimized element is competitive since free cooling strategies imply additional fan electrical consumptions.

In a next step, the impact of the translucency on the artificial lighting should be discussed. Finally, the ideal translucent element with switchable U-value would be a compromise between insulation in winter, a high U-value during cool summer time and translucency. Non-translucent elements based on the same principle and with better insulation may allow switching between U-values of around 0.2 and 2 W/(m^2*K).

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Appendix: Simulation details of the well-insulated office

Internal walls:

The internal walls are composed of:

- Light partition wall: 39.3 m².
- Concrete internal wall: 21.5 m²
- Concrete ceiling: 63.3m²

Ventilation:

A heat recovery system was implemented, with an efficiency of 75 % and four different cases:

- Heating: 75% heat recovery.
- Heating: 0-75% heat recovery: it is not advisable to introduce air with more than 20°C in winter, because this could lead to cooling loads in winter.
- Cooling: No heat recovery
- Cooling: 75% recovery.

The ventilation rate is constant at 2 vol*h^{-1}.

Occupation:

3 Persons between 7:00 and 18:00 on working days.

Cooling:

Cooling temperature: 24°C between 5:00 and 18:00 on working days, 28°C otherwise.

Unlimited cooling power.

Heating:

Heating temperature: 20°C between 5:00 and 18:00 on working days, 16°C otherwise.

Unlimited cooling power.

Infiltration

The new infiltration is 0.1 vol*h^{-1}.

Internal gains by occupation and computers:

The internal gain through occupation were calculated with the Norm ISO 7730 (seated, light work, typing). The internal gains through computers are equal to 3*150 W when the office was occupied.

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