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Thermal Induced Climatic Loads of Insulated Glazed Units in Energy Efficient Facades

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Climatic loads on Insulated Glazed Units (IGU) have been investigated since the early 1990s. Beginning in 1996 a German technical guideline defined the procedure to respect climatic loads in static design of IGUs. Furthermore the required values of climatic changes and thermal changes of Double Glazed Units (DGU) have been determined. In practice, those values have been applied to other systems like Triple Glazed Units (TGU) as well as Double Skin Facades (DSF). In the last two decade's those values haven not changed. This paper presents the results of a study on IGU's in summer conditions, evaluating the thermal performance recent constructions. The upgrade from DGU to TGU causes a significant change of the thermal behavior. By adding a third glass layer, the middle glass gets insulated on both sides. In case of solar radiation the middle glass layer absorbs energy and is disabled to release energy. As a result, higher temperatures can be reached on TGU. By considering ventilated or not ventilated DSF's, external or internal shading devices can influence further changes in the thermal behavior. This paper shows the development of an iterative calculation model by including present European standards. The model is able to deal with factors mentioned above. The results of different facade studies are shown and compared to the DIN 18008 standard. Furthermore the ongoing changes through European prestandards were discussed. Over all the study shows that a more sophisticated approach is necessary to determine correct temperature and climatic loads.

Keywords: Climatic Loads, Insulated Glass Units, IGU, Thermal Behavior IGU, Double Skin Facades DSF

1. Introduction

1.1. Climatic loads on Insulated Glazed Units

The climatic load, also called Insulating Glass Effect, is mechanical stress in the glass layers of an IGU caused by climatic changes in the environment. During the production of IGUs the interspace between the glass panes is sealed hermetically. As a result, the enclosed gas has a conserved gas state (volume, pressure, temperature). By varying environmental pressure or temperature the panes react like membranes that bulge in and out. This effect can be attributed to the ideal gas law (p*V/T = constant). The expanding or contracting gas volume causes deformation, which in turn results in mechanicals stress due to the climatic load.

This effect has been a known fact for a long time. Various papers and scientific articles addressed this topic and made this effect manageable for practical appliance. Some of the most important studies are from Feldmeier (1991), Feldmeier (1995) and Feldmeier (2000). The amount of the climatic load is characterized as internal load by the isochoric pressure p_0. The isochoric pressure accounts for the pressure difference between internal and environmental pressure in case the glass panes does not allow deformation. The isochoric pressure can be calculated from three factors; change of altitude ΔH, meteorological pressure change Δp_{met} and temperature difference ΔT (see Formula 1).

$$p_0 = 0.012 \frac{kN}{m^2 \cdot m} \cdot \Delta H - \Delta p_{met} + 0.34 \frac{kN}{m^2 \cdot K} \cdot \Delta T \qquad (1)$$

1.2. State of the Art

As Oberacker (2010) mentioned, the consideration of climatic loads first appeared in the Technical Rules for Linear Supported Overhead Glazing (TRÜko) from the German Institute of Construction Technique (DIBt) in 1996. In 1998 the Guideline changed to the Technical Rules for the Use of Glazing on Linear Supports (TRLV, DIBt (1998)). Since then, the Formula 1 and the needed calculation values have not changed. However in 2010 the German Standard DIN 18008 replaced the TRLV. For static design of IGU two load cases were considered; production in summer / use in wintertime and production winter / use in summertime. For deviating states of use correction values for temperature are mentioned. Beside the calculation of isochoric pressure p_0 also various formulas for load distribution on DGU by dealing with the coupling effect are given. The coupling effect describes the specific feature of IGU to transmit external loads from one pane to the next. To distribute loads on TGU, Feldmeier (2006) is referred. In case of TGU the formulas are not straightforward to handle and software tools are needed. This shows the much higher complexity of TGU.

The calculation values in DIN 18008, which are needed for the Formula 1, are based on a DGU with U_g = 1.8 W/m^{2}K. Regardless of the technical improvements in the past years, those values are still used for TGU with U_g << 1.0 W/m^{2}K. In face of increasing dissemination of TGU no studies about this adoption from DGU design temperatures to TGU were found. Only Feldmeier (2009) mentioned that TGU reach marginally higher temperatures in summertime. But the general calculation with isochoric pressure of p_0 = ±16 hPa is still applicable. In special cases this assumption has to be reassessed. From a constructive point of view, the DIN 18008 as well as the old TRLV are restricted to DGU in combination with ventilated or unventilated internal blinds, higher absorption classes of IGU and thermal insulation behind the IGU.

On the European level in prEN 16612:2013, analytical formulas for temperature calculations of DGU and TGU as single elements are announced. The added calculation example still uses the standard p_0 = -16 kPa from DIN 18008.

1.3. Goals of the Study

Regarding the three components of the Formula 1 the thermal climatic load becomes the most influential part with 43% for the summer case and 53% for the winter case. This warrants a closer look at those temperatures. It is not only the outside temperature and solar radiation which define the warming in IGUs. Also the IGU system (DGU / TGU), the thickness of panes, applied coatings and constructive composition has an impact on IGU warming. At this point the case study starts. The standard situations of climatic loads in DIN 18008 are unchanged since 1998 and used in various German standards, books and articles. By adopting the climatic load calculations from TRLV to DIN 18008 the design concept changed from a global to semi-probabilistic safety concept. This still did not initiate the need for adjusting the guide lines.

Therefore, this paper responds to IGU temperatures under up-to-date performance's and recent constructions. The boundary conditions for IGUs in ventilated or not ventilated DSF are not comparable to IGUs in single skin facades. The goal of the study, which was carried out at Lucerne University of Applied Science and Arts (Wüest 2015), was to investigate the warming of DGUs and TGUs under standard condition's from DIN 18008 and to compare it with recent constructions. The study demonstrated how the different combinations of facade elements behave together in thermal aspects. Therefore an adequate calculation model, which considers those different construction elements, was developed.

2. Methodology

For all calculations the related standards have to be taken into account. The most relevant ones will be further explained in following sections. These standards often contain both, explicit and iterative formulas. The combination of all these calculation models turned out to be a challenging task. Consequently, the additional effort of using a sophisticated programming language is not considered. Therefore, the implementation as an iterative Excel-Tool was reviewed. With up to 32'767 iterative calculations in each step and the ability to use Visual Basic, programming Excel proved suitable. Moreover, the simple and flexible organization allows further pre- and post-processing with the same tool.

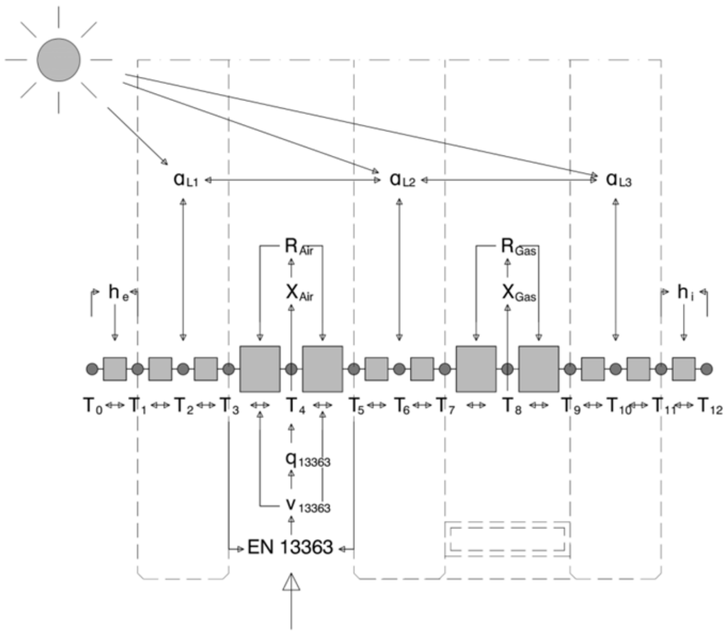


Fig. 1 Scheme of the calculation model in Excel shown as DSF with DGU.

The implementation as an iterative calculation in Excel also allowed the direct incorporation of temperature-dependent Properties into the main calculation steps. In Figure 1 a short overview about the different iterative loops in a natural ventilated DSF with DGU is shown. Each temperature-node is represented by a circle and thermal resistances are shown as squares. The dependencies are depicted as arrows; a one-sided arrow shows a straightforward reliance, a double arrow means an iterative reliance. The different loops where presented in the following sections. Beside the layer structure of the facade only outer and inner air temperature as well as solar irradiation is needed.

2.1. Heat flow

The heat equation is derived from Fourier's law and the conservation of energy. In case of one-dimensional problems the heat flow flux $\dot{q}$ can be written as in equation 2. The finite-difference method offers an appropriate method to solve the heat equation with a numerical approach. The facade is divided into different sections for the computational grid which is required for the finite-difference method. In this case each layer gets an own core-node and shared surface-nodes. Each node has to fulfill the heat equation so that the sums of all heat flows from node i-1 to i, i to i+1 and external heat flows have to be equal to zero (Formula 3). External heat flows are the product of solar absorption or cooling trough natural ventilation. With the condition that thermal losses are positive and gains are negative, Formula 3 can be written as Formula 4.

$$\dot{q} = \frac{\lambda}{d} \cdot \Delta T \tag{2}$$

$$\sum \dot{q}_i = \dot{q}_{i,i-1} + \dot{q}_{i,i+1} - \dot{q}_{ex,i} = 0 \tag{3}$$

$$\sum \dot{q}_i = \frac{1}{R_{i,i-1}} \cdot (T_i - T_{i-1}) + \frac{1}{R_{i,i+1}} \cdot (T_i - T_{i+1}) - \dot{q}_{ex,i} = 0 \tag{4}$$

For this calculation procedure, no limitations of nodes are given. All thermal resistances R of Gas or air cavities are temperature-dependent (see 2.2). Also the thermal resistance of external surfaces R_{Se}, R_{Si} (see 2.2) and cooling trough natural ventilation (see 2.4) are temperature-dependent. Out of Formula 4 the system can be written in matrices where the temperature-dependent properties still generate an iterative calculation. Instead of matrices Formula 4 can be transformed in an explicit function for the temperature of each node i (Formula 5) in function of neighbor nodes an external heat flows $\dot{q}_{ex}$.The Formula 5 can easily be implemented to Excel calculations.

$$T_i = \frac{\frac{1}{R_{i,i-1}} \cdot T_{i-1} + \frac{1}{R_{i,i+1}} \cdot T_{i+1} - q_{ex,i}}{\left(\frac{1}{R_{i,i-1}} + \frac{1}{R_{i,i+1}}\right)} = 0 \tag{5}$$

2.2. Thermal resistance of Gases and Surface's

The thermal transmittance of IGUs is well known and determined by EN 673. This calculation model refers to standard conditions for comparability of different IGUs. By changing the gas temperature in the interspace also changes in the conductivity behavior of the gas causes. So if the gas temperature changes, the conduction coefficient of the interspace h_s and the system temperature itself changes too. The temperature-dependent gas properties can be respected by EN 13363-2 Annex D and Formula 6.

$$X_{Gas}(T) = X_{Gas,20} + \frac{\partial X}{\partial T} \cdot (T - 293) \tag{6}$$

In EN 673 the external and internal thermal surface resistance R_{Se} / R_{Si} are also fixed. In this case, the definition for the thermal surface resistance according to EN ISO 6946 is used. The difference under standard conditions is only marginal. The definition of EN ISO 6946 allows us to use a temperature-dependent definition of long wave radiative heat exchange of the surface to the environment. The surfaces are considered as black bodies according to Formula 7. For internal and external environment temperature the air temperature is taken into account. This definition prevents overestimation of system overheating.

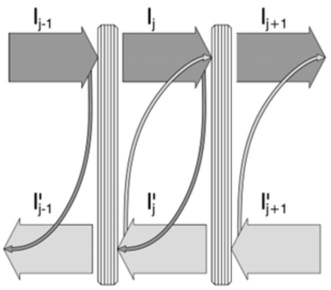
$$h_{se,si}(T) = h_c + \varepsilon \cdot 4 \cdot \sigma \cdot {T_m}^3 \tag{7}$$

2.3. Optical Model

For calculations of different facade layer combinations - which are not temperature-dependent - also the different optical properties have to be considered. Therefore an integrated optical model is needed. Calculation models of solar characteristics for glazing are given in EN 410 and combined with solar protection devices in EN 13363. The equation system of Stoll (2005) (see Figure 2) can be extended to any number of layers, as only boundary conditions $I_0 = 1$ and $I'_n = 0$ are needed.

The models which can be found in EN 410 require the spectral characteristics of each pane. Therefore a large amount of data for different glass panes and coatings are necessary. Other difficulties are the values for shading devices. In practice often no differences are made for luminous and solar characteristics. The EN 13363-2 notes that integrated values can be used if spectral values are missing. Additionally some general values for solar characteristics are given in EN 13363-1 Annex A under condition, that luminous and solar characteristics can be assumed equal to each other.

I this case, a similar simplification is made for glass panes. The solar characteristics of different panes with or without low-emission coatings are calculated by glaCE (Glas Trösch AG, 2015) and collected as integrated values. These values are used as basics to combine them to IGUs according to the system of Figure 2. This simplification gives comparable but slight higher absorptions in collected panes. This deviation is accepted as a conservative approach to determine the required values.



$$I'_{j-1} = \rho_j \cdot I_{j-1} + \tau_j \cdot I'_j$$
$$I_j = \tau_j \cdot I_{j-1} + \rho'_j \cdot I'_j$$
$$\alpha_j = (1 - \tau_j - \rho_j) * I_{j-1} + (1 - \tau_j - \rho'_j) \cdot I'_j$$

a) b)

Fig. 2 a) Scheme of the optical Model and b) formulas

2.4. Natural Ventilation

In DSF with connection to outside air a natural convection (stack effect) takes place. The size of the stack effect depends on the temperature difference between the internal and external air and also on the height of the column of internal air. Simplified as nearly perfect piston flow this effect can be calculated by the model of EN 13363-2 Annex B. The model considers air speed, heat transition and cooling capacity. This model is also iterative in itself and coupled with the iterative calculations of the main tool.

By using the cooling capacity of the stack effect some geometrical restrictions have to be made. In this tool the height of the facade is fixed at 3 m with 20 mm wide openings at the top and bottom. The reliability of this model can only be assured at the middle of the chosen facade height. By considering higher facades, the differences in center part results are not large but the effect of overheating in the upper part of the facade remains unconsidered. A second point is that natural ventilated and not ventilated DSF can be compared directly. The natural ventilation of inner glare protection devices can also be calculated with this model. Therefore a height of 2.5 m and openings of 20 mm width are used.

3. Facade Studies

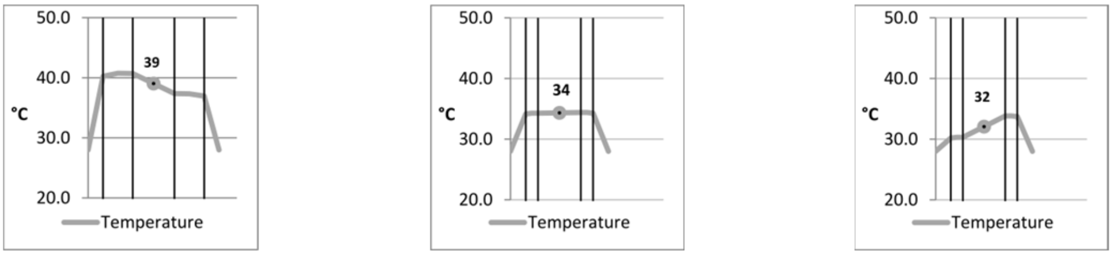
3.1. Existing Basics

The goal of this study is, to review the existing temperatures of gas in the interspace in IGUs and expand the view to other constructions to improve the climatic load calculation. In a first step, the existing temperature values of DIN 18008 have to be considered. On this basis, the effects of changing conditions and facade structure can be directly compared. The boundary conditions during summertime in DIN 18008 are described as solar irradiation of 800 W/m^2 under angle of 45° by total absorption of 30% of the DGU. The surrounding air temperature is given as $\vartheta_e = \vartheta_i$ = 28 °C and thermal resistance of the surface of $R_{Se} = R_{Si}$ =0.12 m^{2}K/W. The applicability of those values will be discussed at the end of this paper. The relationship between solar irradiation and inclined surfaces can be simplified as cosine function in Formula 8.

$$I_\alpha = I_{TRLV} \cdot \alpha = 800\, {}^{W}\!/_{m^2} \cdot \cos(45^\circ) = 565.7\, {}^{W}\!/_{m^2} \quad (8)$$

Based on this information the standard summer situation of DIN 18008 can be calculated. The unknown emissivity of class coating in the interspace can be derived from the given U_g-Value of 1.8 W/m^2K. Consequently, for the case during summertime with temperature-dependent gas properties, the emissivity has to be around $\varepsilon = 0.2$. The border of 30% absorption by the DGU is slightly exceeded with two times 10 mm float glass (32.4%). In agreement to TRLV and DIN 18008 a middle gas Temperature of 39 °C is calculated (see Figure 3a).

Today, modern IGUs are rarely made with 10 mm float glass. A more accurate construction of DGU is two times 4 mm float glass with a total solar absorption of around 18%. Furthermore low-emission coatings can be made up to 1 % ($\varepsilon = 0.01$ on Pos. 3). In these calculations, the interspace is considered as 14 mm wide with 90% argon gas filling. These changes alone reduce the gas temperature from 39 °C to 34 °C, see Figure 3b. The excessive temperature between gas and environment (28 °C) drops from 11 K to 6 K. By adapting the thermal surfaces resistance by the model of EN ISO 6946 (almost $R_{Se} = 0.04$ m^2K/W and $R_{Si} = 0.13$ m^2K/W according to EN 673) a further temperature lowering to 32 °C happens (Figure 3c). This surface values are also recommended by the prEN 16612:2013. Regarding the standard summer climatic load of DIN 18008 and Formula 1 a temperature difference of 20 K is used. With the calculations of Fig 3c that drops to 13 K. This causes a reduction by thermal climatic load of 35% and 15% over the whole climatic load.



a) b) c)

Fig. 3 DGU according to TRLV conditions with a) 2x 10 mm Glass, b) 2x 4mm Glass and c) with EN 6946 surface heat transfer coefficient

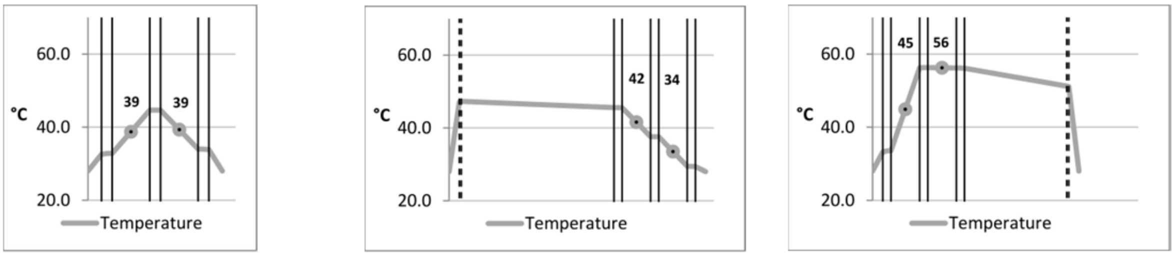
The influences of inner blinds are covered in DIN 18008. Therefore an additional temperature difference has to be added. In case of ventilated interior blinds 9 K (= 48 °C gas) and not ventilated blinds 18 K (= 57 °C gas) are added. These temperatures can be reached by non-transparent black blinds under DIN 18008 conditions. By recalculating this with modern boundary conditions, much lower temperatures can be reached. Depending on the intensity of the blind color, a DGU reaches gas temperatures of 37 °C to 42 °C with ventilated and 40 °C to 46 °C with not-ventilated blinds. Beside the thickness of the panes, the higher exterior surface heat flow is the major cause of this temperature lowering.

About exterior shading devices no information is given in DIN 18008. On single skin facades a non-transparent shading device can also heat up the IGU. Depending on the colour, 0 to 5 K higher temperatures as in Figure 3c can be reached. This is mostly independent of IGUs absorption and only driven by thermal flow from the shading device to the interior space. Because those temperatures are still lower than 39 °C they are not considered in DIN 18008. The effect of exterior shading devices in double skin facades will be investigated later in this paper.

3.2. System expansion to Triple Glazed Units

For the calculations of TGU still 14 mm wide interspaces with 90% argon gas filling and low emission coatings $\varepsilon = 0.01$ at Pos. 2 and 5 are considered. The standard construction is given by three times 4 mm float glass and a total solar absorption of 29.3%.

Under summer conditions with solar irradiation the TGU behaves different to DGUs. As shown in Figure 4a, the middle pane absorbs radiation and heats up. The middle pane is insulated on both sides by the interspaces and is disabled to release energy. In consequence the pane heats up to conserve Fourier's law (Formula 2) by a higher temperature difference ΔT. By heating up the pane, the surrounding gas also heats up and reaches higher values as in DGU under same conditions.



a) b) c)

Fig. 4 TGU according to TRLV climate as a) single TGU, b) with black non transparent external sunscreen and c) with black non transparent, non-ventilated internal glare shield

The Figures 4b and 4c show how a TGU reacts in combination with an exterior shading device or an interior blind. With a non-transparent external shading device the temperatures in TGU are given by thermal flow from the shading device to the interior space and are still independent from IGUs absorption. In this case, a temperature gradient between the interspaces toward the inside occurs. In combination with an interior blind the gradient changes its direction towards the outside. The Figure 4c shows two main effects; a heat accumulation caused by the non-ventilated airspace and solar reflection from the blind which is also absorbed by the TGU.

As already mentioned, the middle pane is the main cause of overheating in TGUs. Therefore a short parameter study about the influence of glass thickness is shown in Figure 5. There are two different cases of TGU' with thicker panes:

- With thicker outer panes: **X** mm float / gas / 4 mm float / gas / **X** mm float
- With thicker middle pane: 4 mm float / gas / **X** mm float / gas / 4 mm float

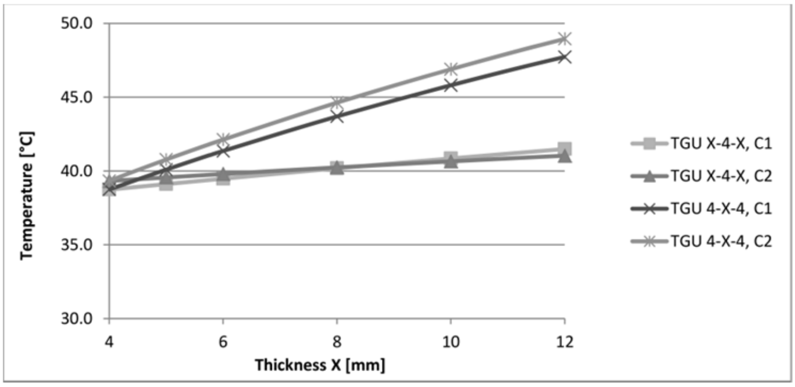


Fig. 5 Influence of Glass-Thickness to Temperature of Cavity's on TGU.

According to DIN 18008 TGUs with float glasses which have a larger thickness than 5 mm, have to be considered in absorption class 30 – 50%. This means that they have an additional temperature difference during summertime of 9 K and resulting gas design temperature of 39 °C + 9 K = 48 °C. The Figure 5 shows that this Temperature can rarely be achieved under modern conditions. The behaviour of the two cases (thicker outer panes or thicker middle pane) is very different. For TGU a classification in absorption classes as it is done for DGU in DIN 18008 can't be made. Instead of those classes, some other formulas to calculate the gas temperatures are given in prEN 16612:2013. This calculation model is completely comparable to the tool described in section 2. In prEN 16612:2013 the thermal surface resistance is mentioned according to EN 673 and the thermal-dependent gas properties according to EN 13363-2. But there are no indications about surrounding temperature, solar irradiation or multi-layer facades. So that those formulas could only be used for single IGUs under self-determined conditions.

3.3. Double Skin Facades

3.3.1. Ventilated DSF

By calculating the U-Value of an IGU in DSF it is common to set the external surface resistance to the same value as the inner surface resistance ($R_{Se} = R_{Si} = 0.13\ m^2K/W$). This simplification can also be made by calculating the gas temperatures of IGUs in DSF (in example by using the model of prEN 16612). The results are only marginally different to a model of DSF with natural ventilation. The limitation for of this simplification is the use of external shadings (or in this case shading between the facade skins). If shading devices in the ventilated air gap are closed, the system can no longer be considered with the prEN 16612. For the following calculations a ventilated (or unventilated) air gap in DSF of 150 mm is used. Shading devices are modelled centered without ventilation between shading and IGU. So that the air gap between shading and IGU acts like a closed air cavity.

Based on our DGU in Figure 3c (32 °C gas) and TGU in Figure 4a (39 °C / 39 °C gas) a closer look is taken at the ventilated DSF's. Alone by changing the system from single skin facade to DSF the temperatures rises. As shown in Figure 6a and 6b an increase of 4 K by DGU and 8 / 2 K by TGU occurs. If an additional closed shading device is present as described previously, the gas temperature in the IGU rises again. The amount of rising temperature is depending on the shadings colour. An extreme situation calculation is done in Figures 6c and 6d with a non-transparent black shading device combined with DGU / TGU. There the temperature rises +15 K. The temperature values of other colors according to EN 13363-2 are given in Table 1.

Table 1: Average Gas Temperature of IGU in combination with non-transparent sunblind's in ventilated DSF's
(Visual sunblind characteristics according to EN 13363-2)

Sunblind	Gas Temperature in DGU	Gas Temperature 1 in TGU	Gas Temperature 2 in TGU
none	36 °C	47 °C	41 °C
White color	38 °C	43 °C	34 °C
Pastel color	43 °C	50 °C	37 °C
Dark color	47 °C	56 °C	40 °C
Black color	51 °C	62 °C	42 °C

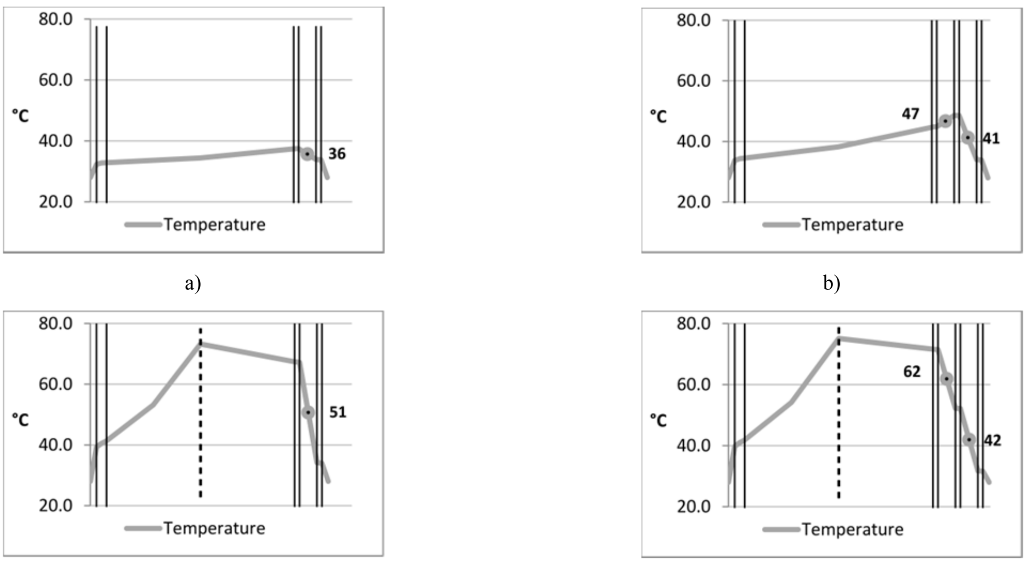


Fig. 6 Natural ventilated DSF with a) DGU, b) TGU, c) DGU with black sunblind and d) TGU with black sunblind

3.4. Not ventilated DSF

A new phenomenon is the not-ventilated DSF or Closed Cavity Facade (CCF). The first facade of this type has been built 2009 by Gartner (D) at the Roche Headquarters in Rotkreuz (CH). The difference between DSF and CCF is the lack of natural ventilation. Without ventilation the air cavity is provided by a low flow of conditioned air to avoid condensation. This low mechanical airflow cannot offer a cooling effect in the airspace. It can be expected that higher temperatures occur.

As mentioned previously, without a solar shading device between the facade skins relatively low warming can be assumed compared to ventilated DSF's (1-3 K). In the case of a closed shading device the previously missing ventilation cooling now is present. The temperatures rise up to 56 °C in DGU and 71 °C in TGU in combination with a non-transparent black shading device. An overview with different shading colours is given in Table 2. Additional the temperature differences from DSF to cDSF are listed in Table 2.

Table 2: Average Gas Temperature of IGU in combination with non-transparent sunblind's in CCF's and difference to ventilated DSF (visual sunblind characteristics according to EN 13363-2)

Sunblind	Gas Temperature on DGU		Gas Temperature 1 on TGU		Gas Temperature 2 on TGU	
none	37 °C	+ 1 K	50 °C	+ 3 K	42 °C	+ 1 K
White color	41 °C	+ 3 K	47 °C	+ 4 K	36 °C	+ 2 K
Pastel color	46 °C	+ 3 K	56 °C	+ 6 K	39 °C	+ 2 K
Dark color	52 °C	+ 5 K	64 °C	+ 8 K	43 °C	+ 3 K
Black color	56 °C	+ 5 K	71 °C	+ 9 K	46 °C	+ 4 K

4. Discussion

At present the results encompass the gaps and needs for catching up on this topic. As can be seen in Figure 3 the choice of boundary conditions can have a significant difference on the results. By using the current standards (EN 410, EN 673, EN 13363 and EN 6946), the guidelines of DIN 18008 can be regarded as very conservative. On the other hand the climatic conditions (566 W/m^2, ϑ_e = 28 °C) are not suitable for European climate. To support that theory, a climatic year in METEONORM for Zürich (CH) was generated. Results show that air temperature up to 31.5 °C and solar irradiation up to 840 W/m^2 can influence a south oriented facade between July and September. A similar result was given for a climatic year in Berlin with 830 W/m^2 und 34.5 °C.

It is therefore essential that all presented results are relying on DIN 18008 meteorological conditions. To compare the results to the METEONORM conditions, the simplification that the excessive temperature (environment – IGU-gas) depends linear to solar radiation is used. For the Zürich facade a correction factor of 840 / 565.7 = 1.48 ≈ 1.5 is calculated. Looking at the TGU from Figure 4a with gas temperatures of 39 °C, the excessive temperature is 11 K. The simplified calculation for the Zürich south facade gives 11 K * 1.5 = 16.5 K added to 28 °C surrounding air temperature results in a gas temperatures around 45 °C instead of 39 °C.

4.1. Construction

This paper presents the results of several different combinations of layers in the facade. To show an overview over all constructions, Figure 7 is now presented. All combinations of IGU (DGU / TGU), external shading, ventilated or not-ventilated internal blinds, DSF and cDSF are shown. Twelve of them, each time DGU and TGU, are highlighted as most significant. Only 4 are covered by DIN 18008 in combination with DGU. In practice, those temperatures have been used for all these situations and TGU as well. This extended use was not proposed by the DIN 18008, but also not excluded. By referring to Feldmeier (2006) in DIN 18008-2 for load distribution on TGU, the expanded use is confirmed.

On the other hand, the formulas in prEN 16612:2003 do not take in account constructional elements beside the IGU. The tool presented in this paper could be seen as extension to the prEN 16612:2003 with an extended set of features.

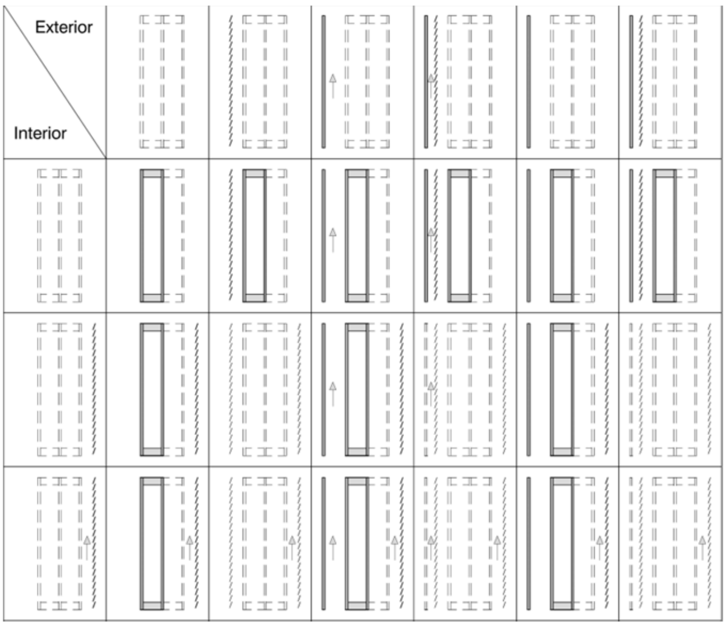


Fig. 7 Overview of different facade construction's with DGU / TGU

4.2. Safety

Another aspect is safety of constructional elements. By replacing the TRLV through DIN 18008 also the safety concept changed from a deterministic to semi-probabilistic concept. The adopted design values of TRLV now have to be charged with a load safety factor γ_Q. Meanwhile the design resistance of float glass didn't change that way. Due to the finalized introduction of DIN 18008 in Germany the climatic load case became highly relevant. Additional different time-depending material resistances also caused more different load cases to be calculated.

As Reick (2015) mentioned, the climatic load case in DIN 18008 is erroneously overvalued. This is so, because no complaints were made in the past. This theory may be able to be confirmed for the usual DGUs. In case of TGU and / or DSF's the conservative assumptions in TRLV saved many IGU from breaking. The prEN 16612:2013 not only contains temperature formulas, but also different load safety factors for facades are mentioned. For facade infill in consequence class CC1 lower γ_Q are presented. This reduction is very useful for the case of solar heating as discussed in the beginning of chapter 4. Furthermore, this study points out that in various constructions higher temperatures have to be expected. So if load safety factors are reduced without revising the climatic load calculations the static design of IGU can be considered unsafe.

5. Conclusions

This study demonstrated how the different combinations of facade elements behave together in thermal aspects. The developed calculation model deals with the related standards, thermal conductivities and optical properties of the different facade layers. Between DGU and TGU as well as single skin and double skin facades significant different results are shown. For TGU and DSF's much higher temperatures and as consequence higher climatic loads have to be considered.

Before the new standards are implemented in practical use, the climatic loads have to be revised and construction-dependent temperature calculations have to be made. The presented results are still based on DIN 18008 climatic conditions. In a first step, a common basis to identify climatic scenarios has to be prepared. In a second step, temperature calculations can be performed. In the author's opinion, two factors still prevented IGUs from breaking, which are luck and hidden reserves. The static design of facades and IGUs is getting more and more complex and it will not slow down in future. Facade engineering is not just a niche aspect; it has become a specified subcategory of civil engineering. To satisfy this position also standards have to fulfill practical requirements.

Once more, the presented calculation tool does not compete or question the prEN 16612:2013. It is based on the same needs but it just covers a wider range of current facade technology. Simplified models or standard situations are still required for early stages of facade design.

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