BESTFAÇADE

Best Practice for Double Skin Façades

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WP 4 Report “Simple calculation method”

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Introduction

Innovative façade concepts are today more relevant than ever. The demand for natural ventilation in commercial buildings is increasing due to growing environmental consciousness while at the same time energy consumption for buildings has to be reduced. An advanced façade should allow for a comfortable indoor climate, sound protection and good lighting, while minimising the demand for auxiliary energy input. Double skin façades (DSF) have become an important and increasing architectural element in office buildings over the last 15 years.

They can provide a thermal buffer zone, solar preheating of ventilation air, energy saving, sound, wind and pollutant protection with open windows, night cooling, protection of shading devices, space for energy gaining devices like PV cells and – which is often the main argument – aesthetics.

Motivation

Commercial and office buildings with integrated DSF can be very energy efficient buildings with all the good qualities listed above. However not all double skin façades built in the last years perform well. Far from it, in most cases large air conditioning systems have to compensate for summer overheating problems and the energy consumption badly exceeds the intended heating energy savings. Therefore the architectural trend has, in many cases, unnecessarily resulted in a step backwards regarding energy efficiency and the possible use of passive solar energy.

The BESTFAÇADE project will actively promote the concept of double skin façades both in the field of legislation and of construction thus increasing investor's confidence in operating performance, investment and maintenance costs.

Definition

"A double skin façade can be defined as a traditional single façade doubled inside or outside by a second, essentially glazed façade. Each of these two façades is commonly called a skin. A ventilated cavity - having a width which can range from several centimetres to several metres - is located between these two skins.
Automated equipment, such as shading devices, motorised openings or fans, are most often integrated into the façade. The main difference between a ventilated double façade and an airtight multiple glazing, whether or not integrating a shading device in the cavity separating the glazing, lies in the intentional and possibly controlled ventilation of the cavity of the double façade".[1]

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[1] Belgian Building Research Institute - BBRI: Ventilated double façades – Classification and illustration of façade concepts, Department of Building Physics, Indoor Climate and Building Services, 2004

“Essentially a pair of glass “skins” separated by an air corridor. The main layer of glass is usually insulating. The air space between the layers of glass acts as insulation against temperature extremes, winds, and sound. Sun-shading devices are often located between the two skins. All elements can be arranged differently into numbers of permutations and combinations of both solid and diaphanous membranes”.[1]

“The Double Skin Façade is a system consisting of two glass skins placed in such a way that air flows in the intermediate cavity. The ventilation of the cavity can be natural, fan supported or mechanical. Apart from the type of the ventilation inside the cavity, the origin and destination of the air can differ depending mostly on climatic conditions, the use, the location, the occupational hours of the building and the HVAC strategy. The glass skins can be single or double glazing units with a distance from 20 cm up to 2 meters. Often, for protection and heat extraction reasons during the cooling period, solar shading devices are placed inside the cavity”.[2]

Objectives of Bestfaçade

The state of the art of double skin façades in different countries and climatic regions will be evaluated and a coherent typology of double skin façades will be developed.

A centralised information system database containing details and performance data collected from a survey of double skin façades built in the European Union will be established.

An assessment method will be developed, which on the one hand can be integrated in the assessment methods of the EPBD (Energy Performance Building Directive) and on the other hand offers sufficient accuracy of the thermal behaviour and the energy performance of the system.

Benchmarks will be made available to allow users and operators to compare their energy consumption levels with others in the same group, set future targets and identify measures to reduce energy consumption.

Non-technological barriers will be identified, solutions to overcome them will be presented and the results will be incorporated in the dissemination strategy.

A design guide including best practice examples will be compiled, providing the target group with a common basic scientific, technical and economic knowledge on double skin façades.

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[1] Harrison K. & Meyer-Boake T.: The Tectonics of the Environmental Skin, University of Waterloo, School of Architecture, 2003

[2] Harris Poirazis: Double Skin Façades for Office Buildings – Literature Review. Division of Energy and Building Design, Department of Construction and Architecture, Lund Institute of Technology, Lund University, Report EBD-R--04/3, 2004

First of all the results of the project will be delivered to the main target groups:
The Primary Target Group with architects and designers, consultants, façade and HVAC industry, Investors, general contractors, building industry, standardisation bodies and The Secondary Target Group with building owners, building users, authorities, knowledge providers (Universities, Research Centres).

At the same time the project results will be disseminated by different strategies, like website, CD-ROMs, workshops and presentation at conferences, e.g. Energy Performance and Indoor Climate in Buildings.

Tasks

The project is structured along eight main work packages (WPs). The aim of WP1 "State of the Art" was to collect information on double skin façades and double skin façade related issues like energy consumption, user acceptance, etc. It has been running over a period of 12 months. The following WPs are WP2 "Cutback of non-technological barriers", WP3 "Energy related benchmarks and certification method", WP4 "Simple calculation method", WP5 "Best practice guidelines", WP6 "Dissemination", WP 7 "Common dissemination activities". All of them get their basic information from WP1 according to their objectives.

The interaction of the WPs is shown in the following picture and ensures a strong commitment of all partners.

Work package		year	1				2				3			
		quarter	**1**	**2**	3	4	5	6	7	8	9	10	11	12
WP1	State of the Art		■	■	■	■								
WP2	Cut-back of non-technological barriers				■	■	■	■	■	■				
WP3	Benchmarks and certification method				■	■	■	■	■	■				
WP4	Simple calculation method				■	■	■	■	■	■				
WP5	Best practice guidelines								■	■	■	■		
WP6	Dissemination		■	■	■	■	■	■	■	■	■	■	■	■
WP7	Common Dissemination Activities		■	■	■	■	■	■	■	■	■	■	■	■
WP8	Management		■	■	■	■	■	■	■	■	■	■	■	■

1 Why is a simple calculation method for the energy assessment of double skin facades necessary?

Presently the assessment of the thermal behaviour and the energy-efficiency of naturally ventilated double skin facades is only possible by using complex simulation tools, which allow interconnections between fluid dynamics, energy balances and optical transport mechanisms. The performance assessment of mechanically ventilated double skin facades is slightly easier but still requires simulation tools. Because of the interaction of separate calculation results, extensive iterations are often necessary. This makes it impossible to have reliable predictions on energy efficiency and impacts on comfort in the early planning phase and to reduce uncertainties for designers and investors.

Therefore the goal of the BESTFACADE work package 4 was to develop an assessment method, which on the one hand can be integrated in the calculation methods of the EPBD (Energy Performance Building Directive) and on the other hand offers sufficient accuracy of the thermal behaviour and the energy performance of the system.

Experience from innovations in the past has shown that it is helpful for the increased implementation of new technologies (to which the double skin facades still can be counted) to be assessable within the national energy performance assessment methods. An assessment method for the very early planning stage contributes to the reliability and therefore also the trust of the architects and clients into the technology.

The work in the BESTFACADE project foresaw the development of a method similar to the standardised approach for the wintergardens, trombe walls and the ventilated building envelope parts of the ISO 13790, annex F, which is a monthly balanced calculation procedure. It had to be evaluated based on sensitivity studies performed in earlier projects of the consortium partners. The calculation procedure had to harmonise with the currently developed CEN standards for the implementation of the EPBD. The results of the developed methods had to be compared to results from simulations.

The method shall then be applied in an energy design guide, an interactive usable internet and user-friendly tool for giving impressions on the influence of different façade types on the energy performance of the zone behind the façade.

2 Analysis of existing approaches (Erhorn, Flamant)

The BESTFACADE approach should be provided in a way, that an implementation into the current standards (regarding the EPBD) will be easily possible. Therefore in this chapter a review was made of existing approaches in different standards or guidelines designated. Important is, that the energy performance calculation is not a design procedure, where minimum or maximum thermal or load requirements have to be calculated, but an energy calculation over a certain periode (heating or cooling periode) which allow a calculation under medium (monthly, seasonal or yearly) conditions and does not explicitly need a hourly simulation. During the energy performance calculation and optimisation process of a building the designer or engineer has to compare different strategies for improving the energy efficiency. This can be different façade technologies as well as components from the building technical systems. Therefore the structure of the calculation procedure has to be able to be integrated in an overall energy performance calculation and not to need an extra set of formulas or calculation routines.

The CEN standards for calculating the energy performance of buildings are structured in that way, that the EN/ISO 13790 is the central standard for calculating the net energy demand for heating and cooling of a zone. In this standard all influences caused by a façade is covered. Besides this the prEn 15193 calculated the influence of the façade on the daylight availability of the zone. The graph below shows the interconnections of the CEN standards in the new set of EPBD standards.

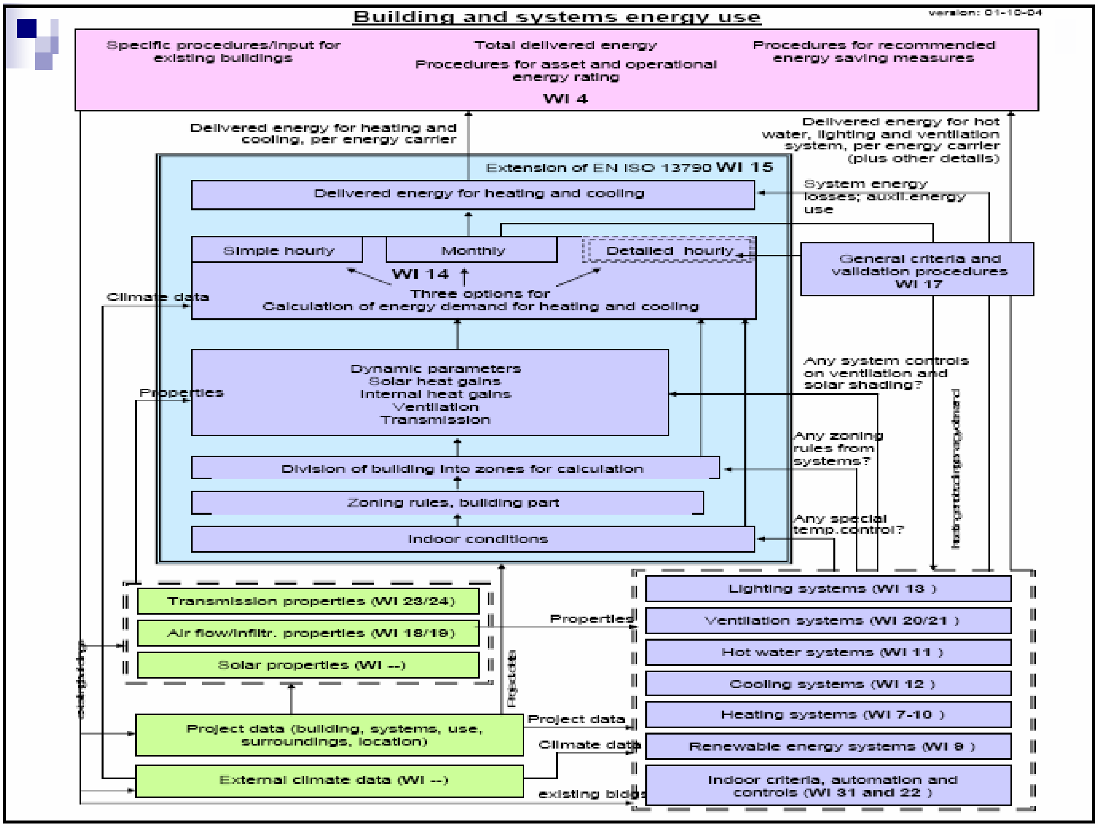


Figure 1 — Structure and interrelation of the CEN standards for calculating the energy performance of buildings

2.1 EN/ISO 13790: Energy performance of buildings

In the current document of CEN TC89/ISO TC 163, EN/ISO 13790: 2007, the calculation of the energy demand of buildings with double skin facades (DSF) are not explicitly foreseen. The calculation of the net heating and cooling demand is described by an energy balance of a conditioned zone, using the elements transmission and ventilation losses and solar and internal gains. The facades are integrated in the calculation by using characteristical values for the balance parts like U- and g- values and air permeability values. All these values are generated by steady-state calculations or measurements. Dynamic behavoiur of facades can be taken into account by mixing fixed values of different situations to a standard usage profile, like open and closed shatters, or via a published simplified approach for unconditioned sunspaces, which may be transferred to DSF constructions.

The normative annex F gives the explanation of the calculation of the solar gains through unheated sunspaces (direct solar gains and indirect solar gains). The indirect solar gains depend on the b-factor calculated according to ISO/FDIS 13789. This b-factor is calculated as a function of the transmittance and ventilation coefficients between the interior and the sunspace on one hand and between the sunspace and the exterior on the other hand.

It is also mentioned "…if there is a permanent opening between the heated space and the sunspace, it shall be considered as part of the heated space, and this annex does not apply...". This statement is placed for loggias or comparable situation, where doors to the sunspaces or windows are open over a longer time, without knowing the air exchange rate between the heated space and the sunspace. In this case can be expected, that the radiator in the heated room will cover the whole heating demand for the room and the sunspace. For ventilated DSF the ventilation rate between room and DSF is mostly controlled and therefore this paragraph is not relevant. Mechanically ventilated DSF, which are connected to HVAC systems can't be directly calculated by this standard, because of the pre-conditioned inlet air and the extracted energy flow by the outlets. For these systems dynamic simulations or alternativ calculation methods have to be performed.

2.1.1 Energy balance of a conditioned zone

Energy need for heating

For each building zone, the energy need for space heating for each calculation period (month or season) is calculated according to:

$$Q_{\mathrm{H,nd}} = Q_{\mathrm{H,nd,cont}} = Q_{\mathrm{H,ls}} - \eta_{\mathrm{H,gn}} \cdot Q_{\mathrm{H,gn}} \qquad (1)$$

where (for each building zone, and for each month or season):

$Q_{\mathrm{H,nd}}$ is the building energy need for heating, in kWh;

$Q_{\mathrm{H,nd,cont}}$ is the building energy need for continuous heating, in kWh;

$Q_{\mathrm{H,ls}}$ is the total heat transfer for the heating mode, in kWh;

$Q_{\mathrm{H,gn}}$ are the total heat gains for the heating mode, in kWh;

$\eta_{H,gn}$ is the dimensionless gain utilisation factor.

Note :" H" = Heating, "nd"=needs, ls=losses, gn=gains

Energy need for cooling

For each building zone, the energy need for space cooling for each calculation period (month or season) is calculated according to:

$$Q_{C,nd} = Q_{C,nd,cont} = Q_{C,gnd} - \eta_{C,ls} \cdot Q_{C,ls} \quad (2)$$

where (for each building zone, and for each month or season)

$Q_{C,nd}$ Is the building energy need for cooling, in kWh;

$Q_{C,nd,cont}$ Is the building energy need for continuous cooling, in kWh;

$Q_{C,ls}$ is the total heat transfer for the cooling mode, in kWh;

$Q_{C,gn}$ are the total heat gains for the cooling mode, in kWh;

$\eta_{C,ls}$ is the dimensionless utilisation factor for heat losses.

Note : "C" = cooling, "nd"=needs, ls=losses, gn=gains

Total heat transfer and heat gains

The total heat transfer, Q_{ls}, of the building zone for a given calculation period, is given by:

$$Q_{ls} = Q_{tr} + Q_{ve} \quad (3)$$

where (for each building zone and for each calculation period):

Q_{ls} is the total heat transfer, in kWh;

Q_{tr} is the total heat transfer by transmission, in kWh;

Q_{ve} is the total heat transfer by ventilation, in kWh;

The total heat gains, Q_G, of the building zone for a given calculation period, are:

$$Q_{gn} = Q_{int} + Q_{sol} \quad (4)$$

where (for each building zone and for each calculation period):

Q_{gn} are the total heat gains, in kWh;

Q_{int} is the sum of internal heat gains over the given period, in kWh;

Q_{sol} is the sum of solar heat gains over the given period, in kWh.

2.1.2 Solar gains and heat losses through facades

Facades of conditioned zones are covered in the energy balance according to ISO/FDIS 13789.

2.1.3 Solar gains and heat losses through unconditioned sunspaces

Unconditioned sunspaces adjacent to a conditioned space, such as conservatories and attached greenhouses separated by a partition wall from the conditioned space. If the sunspace is heated, or if there is a permanent opening between the conditioned space and the sunspace, it shall be considered as part of the conditioned space, and this annex does not apply. The area to be taken into account for the heat transfer and solar heat sources is the area of the external envelope of the sunspace.

Required data

The following data shall be collected for the transparent part of the partition wall (subscript w), and for the sunspace external envelope (subscript e):

F_F frame factor;

F_S shading correction factor;

g effective total solar energy transmittance of glazing;

A_w area of windows and glazed doors in the partition wall;

A_e area of sunspace envelope.

In addition, the following data shall be assessed:

A_j area of each surface, *j,* absorbing the solar radiation in the sunspace (ground, opaque walls; opaque part of the partition wall has subscript p);

α_j average solar absorption factor of absorbing surface *j* in the sunspace;

I_i solar irradiance on surface *i* during the calculation period(s);

U_p thermal transmittance of the opaque part of the partition wall;

U_{pe} thermal transmittance between the absorbing surface of this wall and the sunspace.

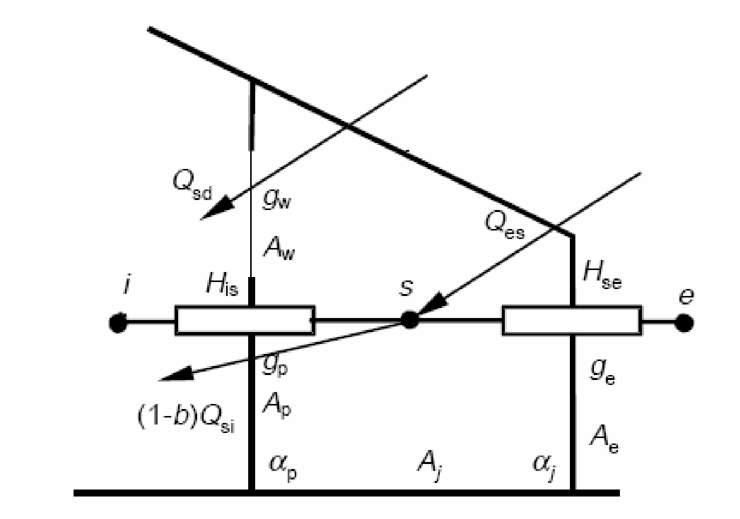


Figure 2: Attached sunspace with gains and heat loss coefficients, and electrical equivalent network.

Calculation method

The heat transfer by transmission and ventilation is calculated according to Clauses for an unconditioned space. The solar heat sources entering the conditioned space from the sunspace, Q_{ss}, is the sum of direct gains through the partition wall, Q_{sd}, and indirect gains, Q_{si}, from the sunspace heated by the sun:

$$Q_{ss} = Q_{sd} + Q_{si} \quad (5)$$

It is assumed, in a first approximation, that the absorbing surfaces are all shaded in the same proportion by external obstacles and by the outer envelope of the sunspace.

The direct solar gains Q_{sd} are the sum of gains through the transparent (subscript w) and opaque (subscript p) parts of the partition wall:

$$Q_{sd} = I_p F_S F_{Fe} g_e \{F_{FW} g_W A_W + \alpha_P A_P (U_P)/(U_{PE})\} \quad (6)$$

The indirect gains are calculated by summing the solar gains of each absorbing area, *j,* in the sunspace, but deducting the direct gains through opaque part of the partition wall:

$$Q_{si} = (1\text{-}b) F_S F_{Fe} g_e \{\Sigma(I_j a_j A_j)+ I_p \alpha_P A_P (U_P)/(U_{PE})\} \quad (7)$$

The weighting factor (1 − b), defined in EN ISO 13789:2005, is that part of the solar gains to the sunspace which enters the conditioned space through the partition wall.

2.2 ISO/FDIS 13789: Thermal performance of buildings

This standard specifies a method and provides conventions for the calculation of the steady-state transmission and ventilation heat transfer coefficients of whole buildings and parts of buildings.

Section 6 of this standard gives details about the calculation of heat transfer coefficient through unconditioned spaces. The meaning and calculation of the b-factor is given. Only the heat transfer by transmission and ventilation is considered (solar radiation is not considered).

2.2.1 Section 6 'Transmission heat transfer coefficient through unheated unconditioned spaces'

The transmission heat transfer coefficient, H_U, between a conditioned space and the external environments via unconditioned spaces is obtained by:

$$H_U = H_{iu}\, b \qquad \text{with} \qquad b = \frac{H_{ue}}{H_{iu} + H_{ue}} \tag{1}$$

where

H_{iu} is the direct heat transfer coefficient between the conditioned space and the unconditioned space, in W/K;

H_{ue} is the heat transfer coefficient between the unconditioned space and the external environment, in W/K.

NOTE 1 In Equation (1), the adjustment factor, b, allows for the unconditioned space being at different temperature to the external environment (see Annex A of standard). The conditioned space is assumed to be at a uniform temperature.

NOTE 2 Heat transmission through the ground is not included in either H_{iu} or H_{ue}.

H_{iu} and H_{ue} include the transmission and ventilation heat transfers. They are calculated by:

$$H_{iu} = H_{T,iu} + H_{V,iu} \qquad \text{and} \qquad H_{ue} = H_{T,ue} + H_{V,ue}$$

The transmission coefficients, $H_{T,ue}$ and $H_{T,iu}$ are calculated according to 4.3 of standard and the ventilation heat transfer coefficients, $H_{V,ue}$ and $H_{V,iu}$, by:

$$H_{V,iu} = \rho\, c\, \dot{V}_{iu} \qquad \text{and} \qquad H_{V,ue} = \rho\, c\, \dot{V}_{ue}$$

where

ρ is the density of air, in kg/m³;

c is the specific heat capacity of air, in W·h/(kg·K);

$\dot{V}_{ue}$ is the air flow rate between the unconditioned space and the external environment, in m^3/h;

$\dot{V}_{iu}$ is the air flow rate between the conditioned and unconditioned spaces, in m^3/h.

2.2.2 Section 8.4 ‘Air change rates of unconditioned spaces’

In order not to underestimate the transmission heat transfer, the air flow rate between a conditioned space and an unconditioned space shall be assumed to be zero.

$$\dot{V}_{iu} = 0 \qquad (2)$$

The air flow rate between the unheated space and the external environment is calculated by:

$$\dot{V}_{ue} = V_u n_{ue} \qquad (3)$$

where

n_{ue} is the conventional air change rate between the unconditioned space and the external environment, in h^{-1};

V_u is the volume of air in the unconditioned space, in m³.

The air change rate, n_{ue}, is the value from table 1 which best corresponds to the unconditioned space under consideration.

No	Air tightness type	n_{ue} h^{-1}
1	No doors or windows, all joints between components well-sealed, no ventilation openings provided	0,1
2	All joints between components well-sealed, no ventilation openings provided	0,5
3	All joints well-sealed, small openings provided for ventilation	1
4	Not airtight due to some localised open joints or permanent ventilation openings	3
5	Not airtight due to numerous open joints, or large or numerous permanent ventilation openings	10

Table 1: Conventional air change rates between the unconditioned space and the external environment

2.3 EN 15293: Energy requirements for lighting – Part 1: Lighting energy estimation

This European standard was devised to establish conventions and procedures for the estimation of energy requirements of lighting in buildings, and to give methodology for the numeric indicator of energy performance of buildings. The methodology of energy estimation not only provides values for the numeric indicator but also input for the heating and cooling load impacts on the combined total energy performance of building indicator.

For each building zone, the energy need for lighting for each calculation period (month or season) is calculated according to:

$$W_{light} = 1/A \; x \; \{\sum(P_n \; x \; F_c) \; x \; \{(t_D \; x \; F_o \; x \; F_D) + (t_N \; x \; F_o)\} \qquad (1)$$

where (for each building zone, and for each month or season)

W_{light}	is the building energy need for lighting, in kWh;
A	is the useful area of the zone, in m²;
P_n	is the luminaire input power, in kW;
F_c	is the constant illuminance dependency factor;
F_o	is the occupency dependency factor for a room, F_O = 1.0 means no control system;
F_D	is the daylight dependency factor for a room, F_D = 1.0 means no daylight available;
t_D	is the time when daylight is generally available (daytime), in h;
t_N	is the time when daylight is generally not available (nighttime), in h;.

6.4.2 Determination of the daylight dependency factor F_D

The daylight dependency factor F_D for a room or zone in the building is determined as a function of the daylight supply factor $F_{D,S}$ and the daylight dependent electric lighting control factor $F_{D,C}$ and is calculated according to:

$$F_D = 1- (F_{D,S} \times F_{D,C}) \qquad (2)$$

where

F_D	is the daylight dependency factor for a room;
$F_{D,S}$	is the daylight supply factor that takes into account the general daylight supply in the zone. It represents for the considered time interval the contribution of daylight to the total required illuminance in the considered zone;
$F_{D,C}$	is the daylight control factor that accounts for the daylight depending electric lighting

6.4.4 Daylight supply

According to annex C.1.1 of the standard $F_{D,S}$ can be determined as a function of the *daylight penetration* classification I according to Table C1, the maintenance value of illumination, the climatic properties and control strategy. Other occupation times may be regarded considering C.1.2. Where available suited and validated more detailed methods accounting for facade systems, facade orientation etc. may as well be employed. Appendix C.2 contains a simple and more refined method exemplarily for the location of Frankfurt, Germany. Daylight penetration has to be classified as according to I_r in equation (13) and Table C1.

2.4 DIN V 18599: Energy efficiency of buildings

Following the philosophy of the EN/ISO 13790 in the German standard DIN V 18599 a holistic calculation approach is developed. The balance calculations take into account the energy demand and consumption for:

- heating,
- ventilation,
- regulation and control of the indoor climate conditions (including cooling and humidification),
- heating the domestic hot-water supply, and
- lighting

of buildings, including the additional electric power consumption (auxiliary energy) which is directly related to the energy supply. The DSF constructions are a subsystem of unheated glazed annexes.

Solar heat gains via unheated glazed annexes (conservatories)

Heated conservatories or glazed annexes without a dividing wall to the heated space must be evaluated as heated building zones. A subclause contains information on evaluating glazed curtain walls. The glazing of the annex (conservatory) must be taken into consideration when calculating the heat gains of the heated or cooled building zones due to solar radiation. The direct solar heat gains via transparent building components are thus calculated using equation (4).

Direct solar heat gains due to opaque components of the dividing wall should be ignored. These are evaluated indirectly by including them in the temperature increase within the glazed annex. The mean temperature in the glazed annex is calculated as described below using equation (8). Equation (9) is applied for glazed annexes and conservatories bordering on several zones. When calculating the heat flow Φ_{u} which is needed in order to determine the temperature, the entire radiant heat entering through the external glazing of the annex must be taken into account, as well as any internal heat sources (see equation (5)). The radiant heat $Q_{\mathrm{S,tr}}$ which is transferred directly via transparent building components into the building zone being evaluated must be subtracted from this.

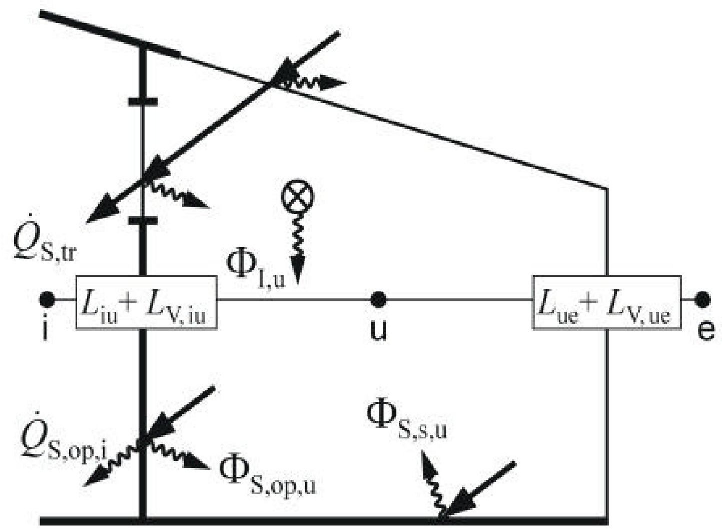


Figure 4: Diagram representing the thermal quantities to be taken into consideration for glazed annexes and conservatories

Building-related shading and measures to protect against solar radiation must be calculated for the respective component under consideration, i. e.:

The shading and solar protection devices of the transparent components of the dividing wall must be accounted for when calculating the direct heat gains $Q_{S,tr}$ in the building zones. The solar protection devices must be taken into consideration when calculating the total energy transmittance g_{tot} of the internal glazing. For external solar protection, no distinction is made as to whether this is located inside the glazed annex or completely outside of the building .

When calculating the heat flow Φ_u into the annex, the shading and solar protection factors of the external glazing must be determined. Solar protection and shading of the external glazing must be taken into consideration in the calculations for the total energy transmittance of the external glazing. The solar protection of the internal glazing need not be included here.

Direct solar heat gains in the building zone

The solar heat gains $Q_{S,tr}$ due to transparent components of the dividing surfaces are calculated as described in section heat sources due to solar radiation entering through transparent surfaces, taking due consideration of the additional glazing (between the annex and the external environment).

$$Q_{S,tr} = F_{F,iu} A_{iu} g_{eff,iu} F_{F,ue} \tau_{e,ue} I_S t \qquad (4)$$

where

$F_{F,iu}$ is the correction factor accounting for the proportion of the frames of the internal glazing (corresponding to the ratio of the transparent area to the total area A_{iu}); where no exact data are known, $F_{F,iu}$ is assumed to be 0,7;

A_{iu} is the area of the component of the surface separating the evaluated building zone from the unheated glazed annex (the clear raw carcass dimensions should be used here);

$g_{eff,iu}$ is the effective energy transmittance of the transparent section of the component, taking the following into consideration:

- the total energy transmittance g_{tot} of the internal glazing including solar protection devices,
- the activation of solar protection devices,
- shading by surroundings and parts of the building,
- deviation of the radiation incidence from the perpendicular,
- dirt on the glazing (pollution);

$F_{F,ue}$ is the correction factor accounting for the proportion of the frames of the external glazing (corresponding to the ratio of the transparent area to the total area); where no exact data are known, $F_{F,ue}$ is assumed to be 0,9;

$\tau_{eu,e}$ is the transmittance of the external glazing (see table for standard values);

I_S is the global solar radiation intensity for the orientation of the respective dividing surface as defined in DIN V 18599-10.

Heat gains affecting the unheated annex or conservatory

The heat flow through the glazed annex or conservatory must be calculated in order to determine the temperature in that space.

$$\Phi_u = \sum \Phi_{S,u} - \frac{\sum Q_{S,tr}}{t} + \sum \Phi_{I,u} \qquad (5)$$

where

$\Sigma\Phi_{S,u}$ is the sum total of solar incident radiation in the annex or conservatory for all transparent external components of the respective part of the building calculated using equation (6);

$\Sigma Q_{S,tr}$ is the sum total of solar radiation passing through the glazed annex or conservatory into the adjacent building zone, calculated using equation (4) for all transparent components of the surface separating the building zone under evaluation and the unheated glazed annex or conservatory;

$\Sigma\Phi_{\mathrm{I,u}}$ is the sum of the heat flows due to internal heat sources in the glazed annex or conservatory (normally zero, or determined as quoted).

The solar radiation entering the annex or conservatory must be calculated using equation (6):

$$\Phi_{\mathrm{S,u}} = F_{\mathrm{F,ue}}\, A_{\mathrm{ue}}\, g_{\mathrm{eff,ue}}\, I_{\mathrm{S}} \qquad (6)$$

where

$F_{\mathrm{F,ue}}$ is the correction factor to account for the proportion of the frames of the external glazing (corresponding to the ratio of the transparent area to the total area). Where no exact data are known, $F_{\mathrm{F,ue}}$ can be assumed to be 0,9;

A_{ue} is the area of each external surface of the annex with a specific orientation;

$g_{\mathrm{eff,ue}}$ is the effective total energy transmittance of the transparent section of the external glazing, taking the following factors into consideration:

- shading,
- the effective total energy transmittance of the external glazing taking into account solar protection devices and their activation,
- deviation of the radiation incidence from the perpendicular,
- dirt on the glazing (pollution);

I_{S} is the global solar radiation intensity for the orientation of the respective dividing surface as defined in DIN V 18599-10.

Calculation of glazed curtain walls

As long as no generally approved method of calculating energy characteristics of double-layer glazed facades are available, all façades of this type which are subdivided into individual storeys can be included in the calculations by treating them as unheated glazed annexes as described above, however with the following deviating boundary conditions:

when using equation (8) to calculate the heat transfer coefficient of ventilation, an air change rate of n_{ue} = 10 h^{-1} must be assumed (independent of the temperature resulting within the glazed curtain wall);

if no accurate data are available the frame correction factor $F_{\mathrm{F,ue}}$ must be assumed to be equal to 0,95.

Detailed calculation of the temperature in the unheated building zone

The mean temperature in the unheated building zone must be calculated as described in EN ISO 13789, using equation:

$$\vartheta_{\mathrm{u}} = \frac{\Phi_{\mathrm{u}} + \vartheta_{\mathrm{i}}(H_{\mathrm{T,iu}} + H_{\mathrm{V,iu}}) + \vartheta_{\mathrm{e}}(H_{\mathrm{T,ue}} + H_{\mathrm{V,ue}})}{H_{\mathrm{T,iu}} + H_{\mathrm{V,iu}} + H_{\mathrm{T,ue}} + H_{\mathrm{V,ue}}} \qquad (8)$$

where

Φ_{u} is the heat flow (from heat sources) into the unheated building zone (e. g. due to solar heating or internal heat sources); in the case of unheated glazed annexes (conservatories) this is the heat flow calculated using equation (5). Where there are also internal heat sinks in such zones, they must also be taken into account, paying attention to the direction of the heat flows (i.e. signs of the quantities);

$H_{\mathrm{T,iu}}$ is the heat transfer coefficient of transmission of the components between the zone being evaluated and the adjacent unheated building zone;

$H_{\mathrm{T,ue}}$ is the heat transfer coefficient of transmission of the building components between the unheated building zone and the exterior; it corresponds to $H_{\mathrm{T,D}}$ as described in EN ISO 13789;

$H_{\mathrm{V,iu}}$ is the heat transfer coefficient of ventilation between the building zone being evaluated and the adjacent unheated building zone (normally, $H_{\mathrm{V,iu}} = 0$ can be assumed);

$H_{\mathrm{V,ue}}$ is the heat transfer coefficient of ventilation between the adjacent unheated building zone and the outside atmosphere;

NOTE The components of the wall between the heated and unheated building zones must be treated as internal structural components.

If the unheated zone borders on several other zones, equation (8) may be extended accordingly. To do this, the weighted temperatures and heat transfer coefficients of all adjacent building zones and of the section bordering on the exterior must be totalled and the sum total must be used in the balance calculations:

$$\vartheta_{\mathrm{u}} = \frac{\Phi_{\mathrm{u}} + \sum_{j} \vartheta_{\mathrm{i},j}(H_{\mathrm{T,i}j} + H_{\mathrm{V,i}j})}{\sum_{j}(H_{\mathrm{T,i}j} + H_{\mathrm{V,i}j})} \qquad (9)$$

Note: This temperature is the mean temperature of the unheated zone (DSF gap) and not the temperature in the outlet of the DSF construction. The excess temperature in the outlet can be approximated as the double of the temperature difference between inlet and mean gap

$$\Delta\vartheta_{\mathrm{out}} = 2 \times (\vartheta_{\mathrm{u}} - \vartheta_{\mathrm{in}}) \qquad (10)$$

2.5 Platzer DSF Guideline for energy performance characterisation

Platzer has proposed a comparable method to characterise glazed double skin facades with the help of building component characteristics, area information and the air change rate in the façade.

Chapter 2.5.1 describes the physically sensible and necessary corrections of the winter garden modell. Chapter 2.5.2 contains the real model equations that also allow the taking into account of shading systems within the facade gap.

Model without increased temperature in the gap
This model is basically equal to the model of unheated glazed annexes out of EN/ISO 13790.

Equation parts for solar irradiation and energy gains (in kWh)

$$E_{sv} = 0.024 \cdot I_v \cdot F_S \cdot F_{Ce} \cdot F_{Fe} \cdot \tau_{e,e} \cdot t_M$$

at vertical surfaces

$$E_{sh} = 0.024 \cdot I_h \cdot F_S \cdot F_{Ce} \cdot F_{Fe} \cdot \tau_{e,e} \cdot t_M$$

at horizontal surfaces

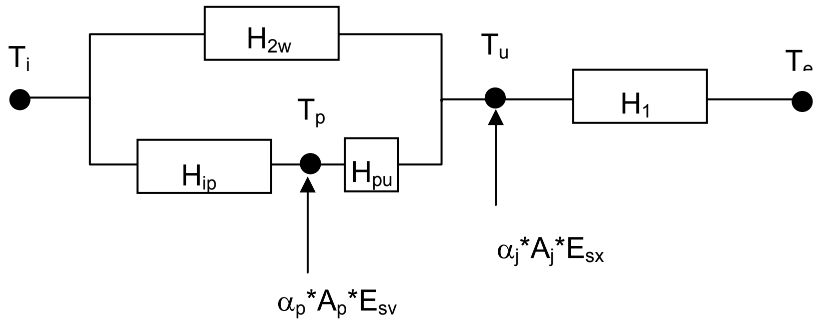
$$Q_{Ss} = Q_{Sd} + Q_{Si} \quad (1)$$

$$Q_{Sd} = E_{sv} \cdot \left(F_{Cw} \cdot F_{Fw} \cdot g_w \cdot A_w + \alpha_{sp} \cdot A_p \frac{U_p}{h_{pg}} \right) \quad (2)$$

$$Q_{Si} = (1 - F_u) \cdot \left(E_{sj} \cdot \alpha_j \cdot A_j + \alpha_{sp} \cdot A_p \cdot E_{sv} \cdot \frac{U_p}{U_{ip}} \right) \quad (3)$$

Eq. (2) describes the direct gains through a window in the partition wall to the glazed annex (1. term) and the solar gain of the absorbed radiation on the opaque partition wall (2. term) if the façade temperature would be equal to the outside temperature.
Eq. (3) describes the rate of the absorbed radiation in the double skin facade (e.g. floor, 1. term) and again the absorbed radiation at the partition wall, that reaches despite the insulation effects of the glazed envelope indirectly the heated zone and reduces the losses.

b) Equivalent circuit



With:

$$H_{2p} = \frac{1}{\left(H_{ip}^{-1} + H_{pg}^{-1}\right)} = \frac{A_p}{\left(R_{ip} + R_{pu}\right)}$$

$$H_2 = H_{2p} + H_{2w}$$

$$H_{ges} = \frac{H_1 \cdot H_2}{H_1 + H_2}$$

Remarks:

1. H_1 equals to the specific heat loss (transmission plus ventilation) of the unheated annex (H_{ue}= $H_{ue,T}$ + $H_{ue,V}$); H_2 equals to the specific heat loss (transmission plus ventilation) of the heated room to the unheated room H_{iu}. The prefactor $H_2/(H_1+H_2)$is then a temperature correction factor (1-F_u) or (1-b) according to DIN EN ISO 13789.
2. The indices were chosen according as follows:

Index i:	interior room
Index e	exterior room
Index u	facade gap
Component j:	internal component in the facade gap (e.g. solar shading, walking platform)
Component p:	opaque panel construction or sill at the wall to the room
Component w:	Window in the wall to the room
Component e:	external glazing

2.5.1 Improved model including temperature increase in the facade gap

The solar irradiation is calculated with the correct approach of the solar transmission, however globally without consideration of angle influences and geometries. (For the heat flows in W is now used Φ:

$$\Phi_{Ss} = \Phi_{Sd} + \Phi_{Si} \quad (1)$$

$$\Phi_{Sd} = I_v \cdot F_S \cdot F_{Ce} \cdot F_{Fe} \cdot \tau_{e,e} \cdot \left(F_{Cw} \cdot F_{Fw} \cdot g_w \cdot A_w + F_{Cp} \cdot \alpha_{e,p} \cdot A_p \cdot U_p \cdot R_{pu}\right) \quad (2)$$

$$\Phi_{Si} = \left(1 - F_u\right) \cdot F_S \cdot F_{Ce} \cdot F_{Fe} \cdot \Phi_u \quad (3)$$

$$\Phi_u = \Phi_{abs,u} + \Phi_{abs,p} + \Phi_{qe,w} + \Phi_{qi,e}$$
$$with$$
$$\Phi_{abs,u} = \tau_{e,e} \cdot I_j \cdot \alpha_j \cdot A_j$$
$$\Phi_{abs,p} = \alpha_{e,p} \cdot A_p \cdot \tau_{e,e} \cdot I_v \cdot U_p \cdot R_{ip} \qquad (4)$$
$$\Phi_{qe,w} = A_w \cdot F_{Fw} \cdot q_{e,w} \cdot \tau_{e,e} \cdot I_v$$
$$\Phi_{qi,e} = A_w \cdot q_{i,e} \cdot I_v$$

Description of the source terms in the facade gap Φ_u:

$\Phi_{abs,u}$ all direct absorbed irradiation in the facade gap (e.g. by the frame construction, solar shading systems in the facade gap, cover of the floor, walking platform, etc.)

$\Phi_{abs,p}$ the part of the heat imported into the facade gap of the absorption at the opaque wall component or the panel between the room and the facade gap

$\Phi_{qe,w}$ the secondary heat loss of the window w between room and façade gap towards the outside. A simple estimation of the secondary heat loss to the outside $q_{e,w}$ is:

$$q_{e,w} = 1 - \tau_{e,w} - \rho_{e,w} - q_{i,w} = 1 - g_w - \rho_{e,w}$$

$\Phi_{qi,e}$ the secondary heat loss of the facade glazing e between the facade gap and the exterior the inside. A simple estimation for the secondary heat loss to the inside $q_{i,e}$ is:

$$q_{i,e} = g_e - \tau_{e,e}$$

The values for $q_{i,e}$ and $q_{e,w}$ are not physically exact, but only an approximation, since the changed heat transfers in the facade gap result in reality in a small change of the heat transfer values in comparison with the standard calculations according to DIN EN 410 (with heat transfer resistance at the external side R_{se}=0.04 m²K/W).

NB: If necessary the absorbed energy of the façade profiles and/or the window frames can be added to the absorbed mean hourly energy in the facade gap. In case of windows frames it can be expected that nearly the total absorbed energy will go to the façade gap, at least for frame class I. In usual calculations of windows, no secondary heat losses of the frame to the inside is expected. At façade profiles that are not thermally separated such a heat loss does theoretically exist. Then the term for secondary heat gains would be more exact as follows:

$$\Phi_{qe,w} = A_w \cdot \tau_{e,e} \cdot I_v \cdot \left(F_{Fw} \cdot q_{e,w} + \alpha_{Fw} \cdot (1 - F_{Fw})\right)$$

$$\Phi_{qi,e} = A_w \cdot \left(q_{i,e} + \alpha_{Fe} \cdot \frac{(1 - F_{Fe})}{F_{Fe}} \cdot U_{Fe} \cdot R_{se} \right) \cdot I_v$$

Both additions can be neglected in practical calculations though. Especially the secondary internal heat loss of the façade profiles with the partial area 1-F_{Fe} should be always small. The equations (4) can be generally used.

Approximation of the mean facade temperature:

An approximation of the mean facade temperature can be done by the ratio of the heat loss coefficients and the mean hourly solar gains Φu in the facade gap. (An eventual internal heat source can be considered, too):

$$T_F = T_{F,0} + T_{F,S}$$
$$with$$
$$T_{F,0} = \frac{H_{ue} \cdot T_e + H_{iu} \cdot T_i}{H_{ue} + H_{iu}} \qquad (5)$$
$$T_{F,S} = \frac{\Phi_u}{H_{ue} + H_{iu}}$$

where $T_{F,0}$ is the balanced temperature without irradiation and $T_{F,S}$ the increase of the temperature in the facade gap on the basis of the solar gains Φ_u.

The heat loss coefficients of the facade gap are defined as follows:

$$H_{iu} = A_p \cdot U_p + A_w \cdot U_w$$
$$H_{ue} = H_{ue,T} + H_{ue,V} \qquad (6)$$
$$H_{ue,T} = \left(A_p + A_w\right) \cdot U_e$$
$$H_{ue,V} = 2 \cdot 0.34 \cdot n \cdot V$$

The loss to the outside because of the ventilation $H_{ue,V}$ has a factor 2 since it is calculated with a mean facade temperature which is approximately between the inlet and the outlet temperature.

2.5.2 Solar shading systems in the facade gap

Dependent on the facade gap and the position of the solar shading system the convective ventilation at open facades will be different. Without a detailed analysis of the facade by measurement or without CFD calculation such systems can't be modeled exactly.

- The transmission factor and the absorption factor of the solar shading system are known: τ_{CW} and α_{CW} for the window part and τ_{Cp} and α_{Cp} for the opaque wall part (e.g. sill); in general the same solar shading system will be used for both façade parts, that means the values are identical
- The solar shading system covers the elements completely and is not only partly closed (otherwise e.g. τ_{Cp}=0)

The absorbed fraction of the transmitted iradiation through the external glazed envelope is added as heat to the facade gap. The solar radiation on the windows or the sill panels is reduced according the transmission factor:

The absorbed radiation at the solar shading system is treated like the otherwise absorbed radiation in the facade gap:

$$F_{Cw} = \tau_{Cw} \qquad (7)$$
$$F_{Cp} = \tau_{Cp}$$
$$\Phi_{abs,u,C} = (\alpha_{Cp} \cdot A_{Cp} + \alpha_{Cw} \cdot A_{Cw}) \cdot \tau_{e,e} \cdot I_v \qquad (8)$$

The irradiation on the windows and the sill is reduced (as before) with F_{Cw} or F_{Cp}. These two values will be most of the time the same if the solar shading system of the façade is same. With high reflecting solar shading systems also the external glazing receives radiation from the inside. This radiation will increase $q_{i,e}$ (increase of the radiation on the glazing because of the backwards reflection of the solar radiation).

2.6 The WIS approach – window calculation tool

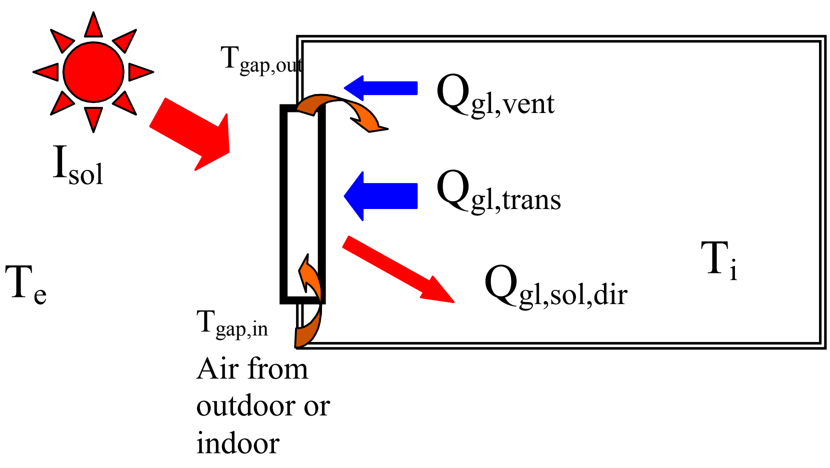
In case of vented windows or vented facades, the heat exchange between the window or façade and the room is influenced by the heat exchange in the vented cavity. The following chapter gives a brief description of the different heat flow components involved, resulting in definitions for:

- the different parts of the U- and g-values: the influence on the energy balance of the room
- the different parts of the energy flows in and out of the window or façade itself: the energy balance of the window or façade system

The content of this document is taken from a report from the EU project WinDat "Windows as Renewable Energy Sources for Europe. Window Energy Data Network" and are originally based on analysis techniques for vented facades developed within the EU project PASLINK/HYBRID-PAS. The definitions have been further developed in IEA SHC Task 27 ("Solar Façade Components" and in studies for Permasteelisa (Scheldebouw B.V.).

2.6.1 Heat exchange with the room

Main energy flows



The symbol gl ("glazing") for the window or façade is used, because of concentrating on the transparent ("glazed") part of the system.

$\mathbf{Q_{gl,trans}}$ is the net transmission heat flow from room to window/façade induced by convective and thermal radiative heat exchange from the room to the window/façade, influenced by indoor-outdoor temperature difference (positive contribution if indoor temperature higher) and by absorbed solar radiation (negative contribution: from window/façade to room).

$\mathbf{Q_{gl,vent}}$ is the net ventilative heat flow from room to window/façade induced by air entering the room from the cavity, which is heated or cooled under influence of indoor-outdoor temperature difference (positive contribution if room air temperature is higher than cavity exit temperature) and absorbed solar radiation (usually[1] positive contribution).

$\mathbf{Q_{gl,sol,direct}}$ is the energy gain to the room by direct (meaning short wave) solar radiation, transmitted into the room via the window/façade.

Then, the total net heat flow from room to window/façade is given by:

$Q_{room,gl} = Q_{gl,trans} + Q_{gl,vent} - Q_{gl,sol,direct}$

Subscript gl:

As long as we confine ourselves to the interaction between room and the transparent part of the window/façade, we could do without the subscript 'gl'. In that case we only have to avoid that Q_{vent} is mistaken for the ventilation heat loss of the room.

Environment temperature:

For simplicity reasons we assume that the indoor air temperature is equal to the indoor mean radiative temperature (and thus to the indoor environment temperature). The same for the outdoor temperature.
If they are not the same, the temperature difference between indoor and outdoor temperature is based on the weighted mean of air and mean radiant temperatures. The weighting is done according to the relative contributions[2] in the heat flow.

Equations

$\mathbf{Q_{gl,trans}}$:
In the simplest case:
$Q_{gl,trans} = (h_{ci} + h_{ri}) * A_{gl} * (T_i - T_{gl,si})$

Where:
h_{ci} is the indoor convective heat transfer coefficient (W/(m^{2}K))
h_{ri} is the indoor radiative heat transfer coefficient (W/(m^{2}K))
A_{gl} is the area of the transparent part of the window/façade (m^2)
T_i is the indoor environment temperature (see earlier footnote) (°C)
$T_{gl,si}$ is the indoor surface temperature of the window (°C)

[1] Usually but not necessarily, because the sun may lead to more ventilative cold brought into the room, in case of thermally induced (free) ventilation, if the sun heats cold outdoor air flowing through the cavity, but at the same time the increase in flow rate induced by the sun is relatively higher; in that case more cold is brought into the room: the contribution to the g-value is negative! Similar for the reverse case (warm air into the cavity and decrease in flow rate outweighing the increase in exit temperature)

[2] In a simple case with a surface that is opaque for IR radiation and impermeable for air (such as glass) the weighting is according to the radiative and convective heat transfer coefficients, h_r and h_c respectively. However, in general there may also be thermal radiation to a second layer, e.g. a glass pane behind a (semi-open) blind

This ‘standard’ simple equation for convective and radiative heat flow from room to window can become more complicated due to infrared transparent layers facing the room, such as porous or venetian indoor blinds. WIS takes this into account in a proper way.

$Q_{gl,vent}$:
$Q_{gl,vent} = \rho * c_p * \phi_v * W * (T_i - T_{gap,out})$

where:
ρ is the volumetric density of air = 1.21 * 273 / (273 + T_{gap}) (kg/m^{3}K) (with T_{gap}: the mean temperature in the gap)
T_i is the indoor environment temperature (°C)
$T_{gap,out}$ is the temperature of the air at the exit of the cavity (°C)
c_p is the thermal capacity of air = 1010 J/(kgK)
ϕ_v is the cavity air flow (m^3/s per m window width[1])
W is window width (m)

Note:
The temperature difference is the difference between the *room* temperature and the exit of the gap. It is this difference that affects the heat balance of the room, irrespective of the *inlet* temperature of the cavity.

$Q_{gl,sol,direct}$:
Standard equation:
$Q_{gl,sol,direct} = \tau_{sol} * A_{gl} * I_{sol}$

where:
τ_{sol} is the direct (short wave) solar transmittance of the window/façade
A_{gl} is the area of the transparent part of the window/façade (m^2)
I_{sol} is the amount of incident solar radiation (W/m^2)

U- and g-values

This paragraph describes how the U- and g-values are defined, using the three components of energy flow between room and window/façade.

The thermal transmittance or U-value is defined as the heat flow through the window/façade under the influence of an indoor-outdoor temperature difference, without solar radiation (“dark”), divided by the window area and indoor-outdoor temperature difference.

The total solar energy transmittance or g-value is defined as the difference in heat flow through the window/façade with and without solar radiation, divided by the window area and the intensity of the incident solar radiation.

[1] The flow rate is given per m width of the window, to emphasize that the ventilation assumes vertical flow movement and is homogeneous in horizontal direction; consequently, in WIS the result of the transparent system with vented cavities does not change with the given width of the transparent system.

The U-value can be split into a part related to the transmission heat flow from room to window/façade, U_{trans} and a part related to the heat flow from room to air from vented cavity(-ies) in the window/façade, U_{vent}.

The g-value can be split into the direct (short wave) solar transmittance, g_{dir} and the additional solar heat gain g_{add} which can be further split into $_{trans}$ and g_{vent}, similar to the U-value.

The U- and g-value components are then defined by the following equations:

$U_{trans} = [Q_{gl,trans}]_{dark} / (A_{gl} * (T_i – T_e))$

$U_{vent} = [Q_{gl,vent}]_{dark} / (A_{gl} * (T_i – T_e))$

$g_{dir} = ([Q_{gl,sol,dir}]_{with\ sun}) / (A_{gl} * I_{sol})$ [note: $= \tau_{sol}$]

$g_{trans} = ([Q_{gl,trans}]_{dark} – [Q_{gl,trans}]_{with\ sun}) / (A_{gl} * I_{sol})$

$g_{vent} = ([Q_{gl,vent}]_{dark} – [Q_{gl,vent}]_{with\ sun}) / (A_{gl} * I_{sol})$

Application of U and g
The U-value and g-value components are used in the following equations, for a given situation with certain T_i, T_e and I_{sol}:

Grouped by type of energy flow:

Heat flow from the room to the window by transmission:

$Q_{gl,trans} = [U_{trans} * (T_i – T_e) – g_{trans} * I_{sol}] * A_{gl}$

Heat flow from the room to the window by air flow from cavity(-ies) to the room:

$Q_{gl,vent} = [U_{vent} * (T_i – T_e) - g_{vent} * I_{sol}] * A_{gl}$

Note that application of this equation does not require input on the cavity air flow rate(s), but of course the air flow rates are implicitly taken into account.

Energy flow into the room by direct (short wave) solar transmittance:

$Q_{gl,sol,direct} = g_{dir} * A_{gl} * I_{sol}$ [note: $= \tau_{sol} * A_{gl} * I_{sol}$]

$Q_{gl,total} = Q_{gl,trans} + Q_{gl,vent} - Q_{gl,sol,dir}$

Note:
The properties U and g change with environment conditions (temperatures, amount and incident angle(s)of solar radiation, wind), so the results should be used with care, if extrapolated to other conditions than those used to determine the numbers.
This restriction is not unique for the vented case, but in a vented case the sensitivity may e higher than in the unvented case!

Same, but grouped by thermal (“dark”) and solar parts of energy flow:

Heat flow from the room to the window under influence of indoor-outdoor temperature difference, without sun (“dark”):

$Q_{gl,dark} = (U_{trans} + U_{vent}) * (T_i – T_e) * A_{gl}$

Heat flow from the room to the window under influence of solar radiation, no indoor-outdoor temperature difference:

$Q_{gl,solar} = - (g_{dir} + g_{trans} + g_{vent}) * I_{sol} * A_{gl}$

$Q_{gl,total} = Q_{gl,dark} + Q_{gl,solar}$

2.6.2 Energy balance of the window/façade itself

Main energy flows

The energy flows in the previous chapter present the effect of the window/façade on the energy balance of the room.

From the interest in the properties of the window/façade, we are interested in the energy balance of the window/façade itself, as a system.

Although some of the energy flows are the same as those presented for describing the energy exchange with the room, there are a few differences.

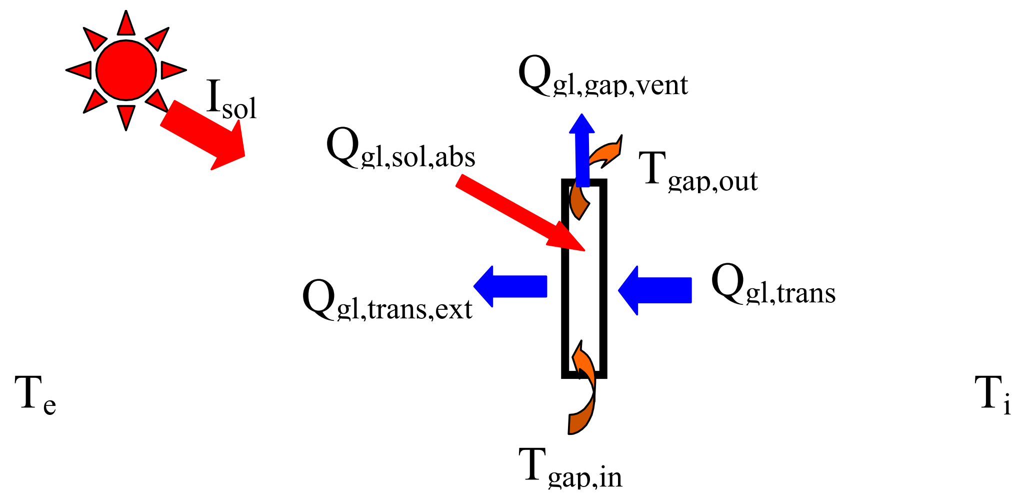
The main applications of the analysis of the enrgy balance of the window itself are:
- To understand the relative sizes of the different parts of the energy flow, which will help to understand the performance of the window/façade
- To be able to compare calculation results with results from measurements or other calculations, at the level of the different components (model validation and development)
- To check the energy balance of the window, for the optical part and the thermal part (verification)

The optical part of the energy balance is simply given by:

Incident solar radiation = transmitted solar radiation + reflected solar radiation + absorbed solar radiation .

The thermal part of the energy balance is given by:

$Q_{gl,sol,abs} + Q_{gl,trans} - Q_{gl,trans,ext} - Q_{gl,gap,vent} = 0$



$Q_{gl,trans}$:
(known already from the energy exchange with the room)
is the net transmission heat flow from room to window/façade (if negative value: net gain) induced by convective and thermal radiativen heat exchange from the room to the window/façade, influenced by indoor-outdoor temperature difference (positive influence if indoor temperature higher) and by absorbed solar radiation (negative contribution: from window/façade to room).

$Q_{gl,gap,vent}$:
$Q_{gl,gap,vent}$ is the net ventilative heat gain in the cavity, from inlet to exit, under influence of indoor-outdoor temperature difference and absorbed solar radiation; if positive: more heat leaves the cavity exit than has been brought in at the inlet.

$Q_{gl,trans,ext}$:
$Q_{gl,trans,ext}$ is the net transmission heat flow from the window at the outdoor surface, under influence of indoor-outdoor temperature difference (positive if indoor temperature is higher) and absorbed solar radiation (positive).

$Q_{gl,sol,abs}$:
The heat gain by solar radiation absorbed in the window system.

Equations

The optical part of the energy balance is simply given by:

τ_{sol} : the direct (short wave) solar transmittance
ρ_{sol} : the solar reflectance
$a_{sol,abs} = \Sigma\ (abs_i)$: the sum of the absorption fractions in all layers of the window system.

$Q_{gl,trans}$:
See paragraph 0.

$Q_{gl,gap,vent}$:
$Q_{gl,gap,vent} = \rho * c_p * \phi_v * W * (T_{gap,out} - T_{gap,in})$

where:
ρ is the volumetric density of air = 1.21 * 273 / (273 + T_{gap}) (kg/m^3K) (with T_{gap}: the mean temperature in the gap)
T_i is the indoor environment temperature (°C)
$T_{gap,in}$ is the temperature of the air at the inlet of the cavity (°C)
$T_{gap,out}$ is the temperature of the air at the exit of the cavity (°C)
c_p is the thermal capacity of air = 1010 J/(kgK)
ϕ_v is the cavity air flow (m^3/s per m window width[1])
W is window width (m)

Note: if positive: more heat leaves the cavity at the exit than enters the cavity at the inlet.

$Q_{gl,trans,ext}$:
Simple case:
$Q_{gl,trans,ext} = (h_{ce} + h_{re}) * A_{gl} * (T_{gl,se} – T_e)$

Where:
h_{ce} is the outdoor convective heat transfer coefficient (W/(m^2K))
h_{re} is the outdoor radiative heat transfer coefficient (W/(m^2K))
A_{gl} is the area of the transparent part of the window/façade (m^2)
T_e is the outdoor environment temperature (see earlier footnote and Annex 1) (°C)
$T_{gl,se}$ is the outdoor surface temperature of the window (°C)

Note: this ‘standard’ equation for convective and radiative heat flow from room to window can become more complicated due to infrared transparent layers, such as porous or venetian blinds.

$Q_{gl,sol,abs}$:
The amount of solar radiation absorbed in the window system.
$Q_{gl,sol,abs} = \Sigma (abs_i) * A_{gl} * I_{sol}$

Where:
$\Sigma (abs_i)$ is the sum of the absorption fractions in all layers of the window system.

Definition of characteristic (h- and a-) components

To avoid confusion with U- and g-value components that are related to the heat exchange between window and room, we define here

h is the coefficient of heat transfer induced by indoor-outdoor temperature difference (W/(m^2K)).
a is the coefficient of heat transfer induced by incident solar radiation (-).

The optical part of the energy balance is trivial and does not require special definitions.

[1] The flow rate is given per m width of the window, to emphasize that the ventilation assumes vertical flow movement and is homogeneous in horizontal direction; consequently, in WIS the result of the transparent system with vented cavities does not change with the given width of the transparent system.

The h- and a-value components are defined by the following equations:

$h_{trans} = U_{trans}$ (see sections on heat exchange with room)

$h_{gap,vent} = [Q_{gl,gap,vent}]_{dark} / (A_{gl} * (T_i – T_e))$

Note: $h_{ap,vent}$ will be negative if the inlet temperature is T_i and T_i is higher than T_e

$h_{trans,ext} = [Q_{gl,trans,ext}]_{dark} / (A_{gl} * (T_i – T_e))$

$a_{trans} = g_{trans}$ (see sections on heat exchange with room)

$a_{gap,vent} = ([Q_{gl,gap,vent}]_{with\ sun} – [Q_{gl,gap,vent}]_{dark}) / (A_{gl} * I_{sol})$

Note: $a_{gap,vent}$ can be negative if the air flow is by free convection and happens to be lower with sun, than in case of dark conditions; the *decrease* in air flow rate should be stronger than the *increase* in temperature in the gap.

$a_{trans,ext} = ([Q_{gl,trans,ext}]_{with\ sun} – [Q_{gl,trans,ext}]_{dark}) / (A_{gl} * I_{sol})$

$a_{abs} = Q_{gl,sol,abs} / (A_{gl} * I_{sol})$

Note that if the inlet air is the room air one should expect:

$Q_{gl,gap,vent} = - Q_{gl,vent}$

➔ $h_{gap,vent} = - U_{vent}$ (see sections on heat exchange with room)

➔ $a_{gap,vent} = g_{vent}$ (see sections on heat exchange with room)

Reconstruction of the equations, using h- and a-components

If we fill in the h- and a-values we obtain the following equations for the different components in the energy balance:

$Q_{gl,trans} = [h_{trans} * (T_i – T_e) – a_{trans} * I_{sol}] * A_{gl}$

$Q_{gl,gap,vent} = [h_{gap,vent} * (T_i – T_e) + a_{gap,vent} * I_{sol}] * A_{gl}$

Note the plus sign!

$Q_{gl,trans,ext} = [h_{trans,ext} * (T_i – T_e) + a_{trans,ext} * I_{sol}] * A_{gl}$

Note the plus sign!

$Q_{gl,sol,abs} = a_{abs} * A_{gl} * I_{sol}$

Application to check the energy balance

An elegant check of the energy balance is now possible, by checking the sum of the coefficients, taking the "dark" and "solar" properties separately:

"Dark" properties:

$h_{trans} – h_{trans,ext} - h_{gap,vent} = 0$

Solar optical properties:

$\tau_{sol} + \rho_{sol} + a_{sol,abs} = 1$

Thermal “solar” properties:

$a_{sol,abs} - a_{trans} - a_{gap,vent} - a_{trans,ext} = 0$

Note: The values of the h- and a-components change with environment conditions (temperatures, amount and incident angle(s) of solar radiation, wind), so the results should be used with care, if extrapolated to other conditions than those used to determine the numbers.
This restriction is not unique for the vented case, but in a vented case the sensitivity may be higher than in the unvented case!

2.7 EN 13830: Curtain walling

The Technical committee 33 of CEN on doors, windows, shutters, building hardware and curtain walling is responsible for the development of standards applying on curtain walling. The definition of curtain walling from EN 13119: 2004 – curtain walling – terminology is the following:

Curtain walling: Usually consists of vertical and horizontal structural members, connected together and anchored to the supporting structure of the building and infilled, to form a lightweight, space enclosing continuous skin, which provides, by itself or in conjunction with the building construction, all the normal functions of an external wall; but does not take any of the load bearing characteristics of the building structure.
This standard gives the following definition to a double-skin facade:

Double-skin facade: A curtain wall construction comprising an outer skin of glass and an inner wall constructed as a curtain wall that together with the outer skin provide the full function of a wall.

According to this definition, the concepts of ventilated double-skin facade are a sort of curtain walling, from the structural point of view (see figure 1).
This means that the standards developed in the scope of the TC 33 have to be applied on DSF.
The existing harmonized technical specifications applying on curtain walling are also applying on DSF.
The standard EN 13830 – curtain walling – Product standard is the harmonized technical specification describing the different performances that have to be defined in order to obtain the CE marking.

Concerning the assessment of the thermal performances, this standard refers to EN 13947.

Figure 1: Example of a concept of ventilated double skin facade whereon the definition of curtain walling applies

2.8 EN 13947: Thermal performance of curtain walling

This standard specifies a method for calculation of the thermal transmittance of a curtain wall system that consists of glazed and/or opaque panels fitted in frames or sashes, both with or without shutters.

The normative annex D describes a simplified calculation of the U-value of a double skin façade, as the sum of thermal resistances (inner façade + air cavity + outer façade). The resistance of the air cavity of the DSF is function of the type of ventilation (unventilated, slightly and well ventilated layers). That means that an assessment of the size of the openings to the exterior environment is required in order to determine the ventilation type of the air cavity. Air spaces (ventilated and unventilated) in a curtain wall, e.g. double skin façade, can be taken into account using their thermal resistance values.

Thermal resistance of air layers

The values given in this annex apply to an air layer which:

- is bounded by two faces which are effectively parallel and perpendicular to the direction of heat flow and which have emissivities not less than 0,8;

- has a thickness (in the direction of heat flow) of less than 0,1 times each one of the other two dimensions, and not greater than 1 m;

- has no air interchange with the internal environment.

Unventilated air layer

An unventilated air layer is one in which there is no express provision for air flow through it. Design values of thermal resistance are given in Table D.1. The values under "horizontal" apply to heat flow directions ± 30° from the horizontal plane.

Table D.1 — Thermal resistance R_s (in m²·K/W) of unventilated air layers: high emissivity surfaces

Thickness of air layer mm	Direction of heat flow		
	Upwards	Horizontal	Downwards
0	0,00	0,00	0,00
5	0,11	0,11	0,11
7	0,13	0,13	0,13
10	0,15	0,15	0,15
15	0,16	0,17	0,17
25	0,16	0,18	0,19
50	0,16	0,18	0,21
100	0,16	0,18	0,22
300	0,16	0,18	0,23
500	0,16	0,18	0,23
1000	0,16	0,18	0,23
NOTE Intermediate values may be obtained by linear interpolation.			

An air layer having no insulation layer between it and the external environment but with small openings to the external environment shall also be considered as an unventilated air layer, if these openings are not arranged so as to permit air flow through the layer and they do not exceed:

- 500 mm² per m length for vertical air layers;
- 500 mm² per m² of surface area for horizontal air layers.

NOTE: Drain openings (weep holes) in the form of open vertical joints in the outer leaf of a masonry cavity wall usually conform with the above criteria and so are not regarded as ventilation openings.

Slightly ventilated air layer
A slightly ventilated air layer is one in which there is provision for limited air flow through it from the external environment by openings within the following ranges:

- 500 mm² to 1500 mm² per m length for vertical air layers;
- 500 mm² to 1 500 mm² per m² of surface area for horizontal air layers.

The design thermal resistance of a slightly ventilated air layer is one half of the corresponding value in Table D.1. If, however, the thermal resistance of the construction between the air layer and the external environment exceeds 0,15 m²·K/W, it shall be replaced by the value 0,15 m²·K/W.

Well ventilated air layer
A well ventilated air layer is one for which the openings between the air layer and the external environment exceed:

- 1 500 mm² per m length for vertical air layers;
- 1 500 mm² per m² of surface area for horizontal air layers.

The total thermal resistance of a curtain wall containing a well-ventilated air layer shall be obtained by disregarding the thermal resistance of the air layer and all other layers between the air layer and external environment, and including an external surface resistance corresponding to still air (see prEN ISO 6946:2005, Annex A). If no other information is available this external surface resistance is he = 8 W/(m2·K)

2.9 ISO 15099: Thermal performance of windows, doors and shading devices

This standard specifies detailed calculation procedures to determine the thermal and optical transmission properties (e.g. thermal transmittance, total solar energy transmittance) of window and door systems based on the most up-to-date algorithms and methods, and the relevant solar and thermal properties of all components.

The case of ventilated cavities is considered. Three types ventilation of the cavity can be represented:

- mechanical ventilation
- ventilation due to temperature difference (stack effect)
- ventilation due to the wind : the model is either very limited (constant air flowrate) or very complicated (CFD simulations) but the standard has the advantage to propose this kind of ventilation.

This standard allows calculating the performances of the whole window, including the frames.

In order to perform the calculations, a lot of data must be introduced (some of them are difficult to determine or to measure). The WIS (www.windat.org) software has implemented the calculations of this standard. The thermal and solar performances of DSF can be determined by this standard. No link with the building is made in this standard.

2.10 (Draft) ISO 18292: Energy performance of fenestration systems - Calculation procedure

This International Standard describes a procedure for the determination of energy rating of window and door products. As the fenestration industry and their clients move towards using energy performance instead of thermal transmittance to assess their products, the acceptance of this superior approach is being hampered by the wide variety of procedures being adopted. There is a need to produce a simple, clear, accurate and transparent procedure that enables the energy performance of these products to be assessed using National Climate data and Nationally selected reference buildings.

Ensuring that fenestration products are selected on the basis of optimizing their energy performance in their specific environment will have a significant impact on achieving the goal to reduce the consumption of energy. The accumulated additional energy loss through poorly selected fenestration products, over their lifetime, is truly enormous, and any steps that can help reduce that loss must be taken as soon as possible.

The scope for developing different procedures for determining energy performance of fenestration, in very specific environments, is very large. The drive to assess these products by considering the net energy flows through them is growing (e.g., the European Building Energy Performance Directive, North American procedures and others) unless ISO can produce a reliable and acceptable generic methodology, many countries will develop their own procedures that will constitute new free trade barriers.

This (draft) International Standard gives detailed procedures for energy ratings of fenestration products. These procedures require the use of reference conditions that are not representative of actual conditions. The rationale for doing it this way is to allow the use of national climatic conditions for the rating of specific products.

The calculation procedure will base in general on the fundamental approach of EN/ISO 13790 and is reduced to only window relevant elements for heating, cooling, ventilation and lighting. A procedure for DSF is not yet introduced, but may be used in the same way as in DIN V 18599.

2.11 Critical review of the analysed standards and guidelines

The above analysed standards or guidelines are covering certain approches which may allow to be extended for calculating the energy performance of buildings with DSF systems. The analysis gave the following strengths and weaknesses for the choice of an appropriated standard for the BESTFACADE approach.

- EN/ISO 13790: no DSF approach foreseen so far, but as shown in the German DIN V 18599 the wintergarden approach in Annex F can be sufficient applied to DSF systems. A DSF extention is strongly recommended for this standard.
- ISO/FDIS 13789: this standard is not applicable to energy performance calculation as solar radiation is not considered in the calculation.
- DIN V 18599: the national application of prEN/ISO 13790 with an useful extention for DSF. Approach is recommended to be transferred as general method for DSF to EN/ISO 13790.
- Platzer guideline: comparable to the DIN V 18599 DSF approach but some physical weaknesses in the calculation of the solar gains through the outer façade. No added value compared to the DIN V 18599 approach. Therefore not recommended.

- WIS approach: only steady state conditions are foreseen for the calculation, no whole year aproach with dynamic characteristics of façade systems. More a tool for calculating product characteristics. Therefore not applicable.
- EN 13830: this standards contains only definitions, no calculation procedures. Not applicable.
- EN 13947: this standard covers only procedures for calculating thermal characteristics; no solar, no energy. Therefore not applicable.
- ISO 15099: this standard covers calculation procedures for thermal, solar and optical characteristics for façade elements, but no energy nor coupling with building behaviour is foreseen. Therefore not applicable.
- ISO 18292: façade rating system on the base of the EN/ISO 13790 philosophy, but only for façade related paramenters of the energy balance. DSF applications can be used in the same way as in EN/ISO 13790

The analysis made evident, that the BESTFACADE approach should be applied in EN/ISO 13790 in the way as done in DIN V 18599, but extended to different kinds of DSF systems. The relevant influence factors will be provided by the analysis in the next chapters.

3 Analysis of existing measurements

3.1 BiSoP Building in Baden, Austria (Kautsch, Dreyer, Hengsberger, Meile, Streicher)

In Baden a naturally ventilated, north facing, 17 m high DSF, fixed as retrofit measure in front of a badly insulated exterior wall with a low window rate, was analysed by calculations and measurements. Inlet dampers could be closed and opened manually. The façade has the following particularities:

Figure 1: North façade of the renovated Baden building with the DSF construction

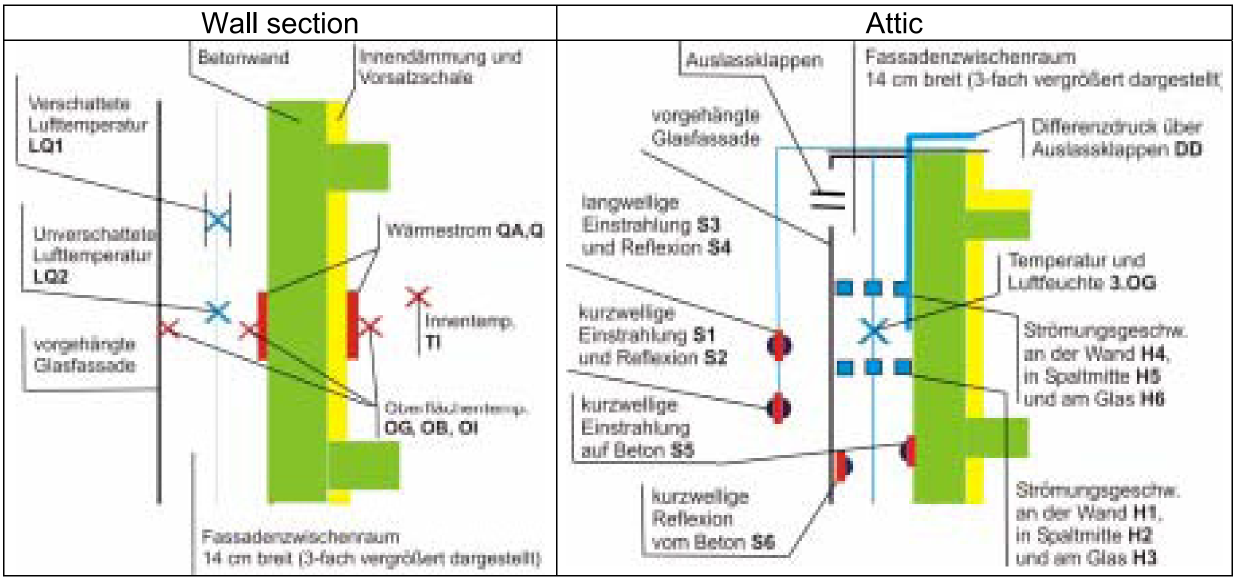


Figure 2: Façade details of the renovated Baden building with the DSF construction. The measurements points for temperature and air velocity are mentioned in the graph

The measurements resulted in the following compressed monthly mean data

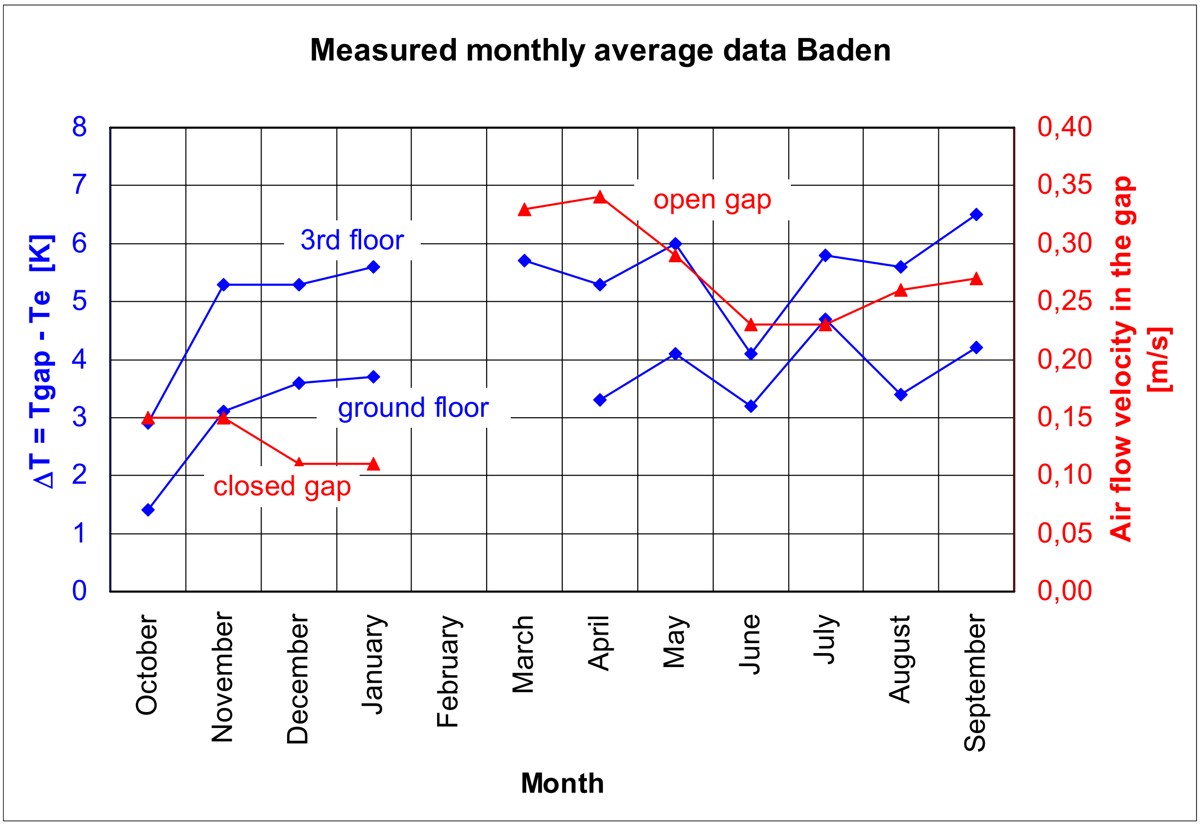


Figure 3: monthly mean temperatures and air velocities in the gap of the façade of the renovated Baden building

The monthly mean excess temperatures are very stable during the whole year. In the ground floor the yearly mean excess temperature is around 3,7 K and in the 3[rd] around 5,5 K above the outside air temperature. The monthly mean excess temperatures in both heights differ mostly less than 1 K from the yearly mean temperature. Also the monthly mean air flow velocity in the façade with open gaps differs only ± 0,05 m/s around the the season mean value of 0,28 m/s in the reported periode (March to September). The monthly mean air flow velocity in the façade with closed dampers differs only ± 0,02 m/s around the the season mean value of 0,13 m/s in the reported periode (October to January). That means the mean air velocity is reduced by factor 2 by closing the gaps.

Reference

Kautsch, Dreyer, Hengsberger, Kouba, Meile, Streicher: Thermisch-hygrisches Verhalten von GlasDoppelFassaden unter solarer Einwirkung. Theorieevaluierung durch Vorort-Messung. Projektbericht, Graz 12/2002.

3.2 The VERU facility in Holzkirchen, Germany (Sinnesbichler, Erhorn)

At the VERU test facility, the mean daily temperatures and the opening times of the outer dampers of a west-oriented double skin facade have been measured for a period of more than 12 months. The dampers are controlled by the outside temperature. Below 10° C the dampers are closed and opened above.

Figure 1: West façade of the VERU test facility with the DSF construction in the ground floor

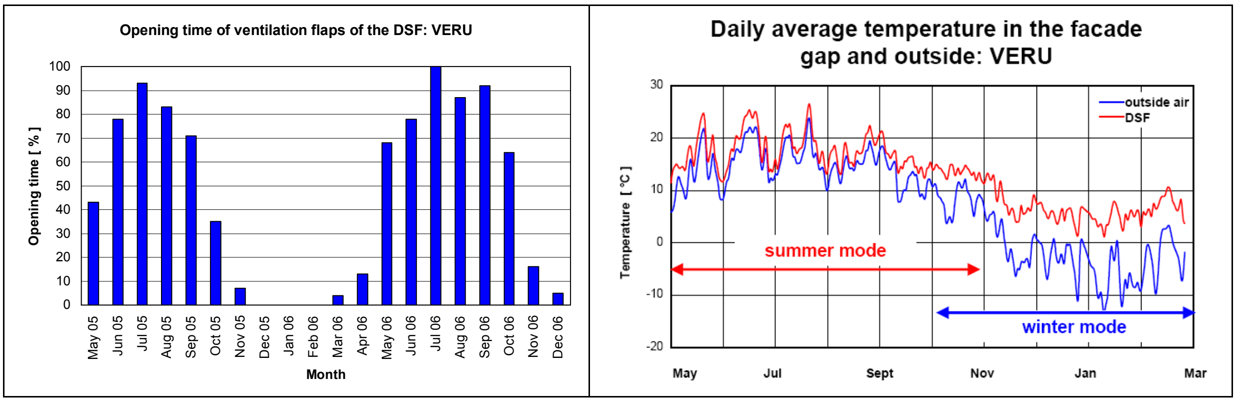


Figure 2: Measured monthly opening ratio of the dampers and mean daily temperatures in and outside of the DSF façade in the VERU test facility

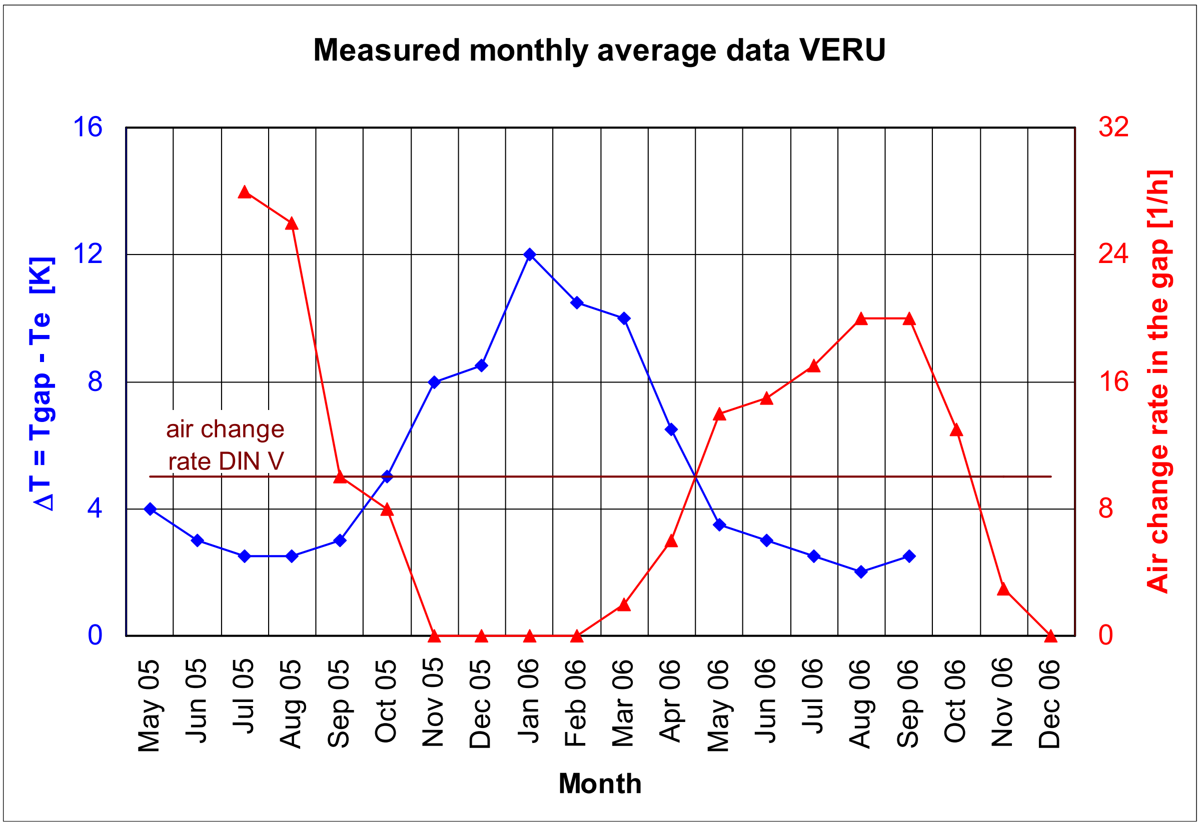


Figure 3: Mean monthly excess temperature and air change rates in the measured DSF construction in the VERU test facility

The mean temperature difference between gap and outside air is small (3 to 4 K) during the summer periode and much higher in the heating season. This depends on the control characteristics of the dampers. The air change rate is just opposite to the measured excess temperature in the gap. Compared to the constant value of 10 h^{-1} used in the standard DIN V 18599, the summer values are always higher the winter values lower. This results in a secure approach as simple approaches has to be designed. Depending on the lower ventilation rate in the calculation in summer the cooling load will be higher and the higher calculated ventilation rates in winter results in extended energy demand for heating. Therefore both energy parts are higher than in the reality.

This effect can be shown, when comparing the measured values with the constant air change rate of 10 h^{-1}. The energy demand for heating is nearly 5 kWh/m²a higher than the measurements and the cooling demand nearly 20 kWh/m²a higher. If the air change rates have been adjusted to the analysed mean monthly values, the results get very close to the measured ones. The results are presented in the following figure.

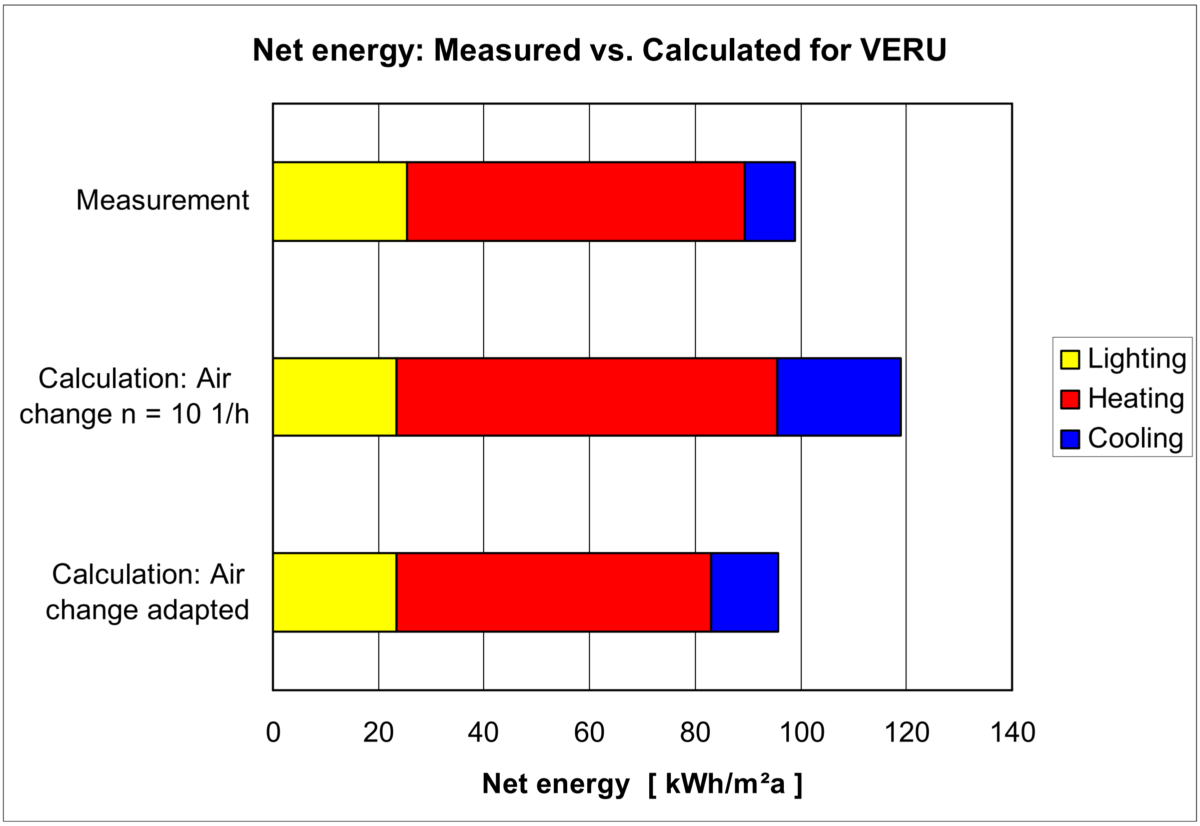


Figure 4: Net energy consumption for lighting, heating and cooling in comparison to the calculated demand of the same room with constant air change rates and with an adapted air change rate

The results show, that the use of mean monthly values in the calculations leads to reliable results for the net heating and cooling demand of a zone. Therefore the method for calculating the annual energy performance characteristic of buildings with DSF can be applied as proposed, if the air change rates or mean air velocities is known or can be predicted. The method is not applicable for the dimensioning of DSF constructions, that means for the extrem design conditions (max. or min. values).

References

H. Sinnesbichler, et alii: Energy performance analysis of different energy concepts for non-residential buildings in the VERU façade test facility. Fraunhofer IBP report 2007, Fraunhofer-Institut für Bauphysik, Holzkirchen, Germany.

3.3 The Postcheque Building in Belgium (Flamant, Prieus)

Introduction

In this chapter monitoring results of a one storey naturally ventilated double skin façade installed in the Postcheque building in Belgium are analysed. The results have been analysed concerning the airflow rate and temperatures in the façade cavity for summer and winter periods. It is based on the PhD performed by Dirk Saelens who finished his work in 2002. Pictures, tables and results shown in this document are extracted from this PhD.

Geometry and characteristics of the façade

The DSF which has been monitored is a one-storey naturally ventilated DSF characterised by:

- Outer glass skin : single glass
- Inner glass skin : double glazing (U=1.3 W/m²K)
- Cavity width : 1.3 m
- Cavity ventilated with outside air
- Venetian blind shading device is hung in the cavity at about 10 cm from the interior glass.

The dimensions of the room behind the façade are 5.6 m (length) x 2.6 m (width) x 2.7 m (height). Permanent openings for the ventilation of the cavity are situated at the bottom and at the top of the façade (see Figure 1).

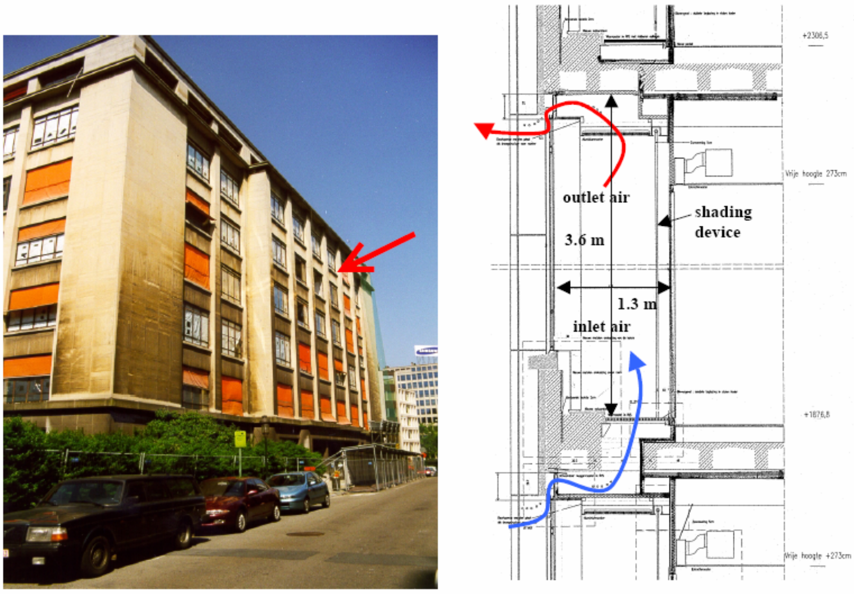


Figure 1: DSF monitored in the Postcheque building

Monitoring of the double-skin facade

Monitoring equipment:

In the office, the temperature, the internal gains and the heat losses were monitored. In the cavity, the average temperature, relative humidity and static pressure difference between the inlet and outlet was monitored. The weather station on the roof of the building measured the exterior air temperature and relative humidity, solar radiation impinging on the facade and the wind speed and direction.

Monitoring periods:
Measurements were taken during summer and winter. During summer, measurements were taken with raised (first period) and lowered (second period) venetian blind. During winter (third period) the venetian blind was raised at all times.

Climatic conditions

	shading device	data				
period 1	up	13/05/1999 till 21/05/1999				
period 2	down	23/06/1999 till 09/07/1999				
period 3	up	14/12/1999 till 20/12/1999				
		period	average	st dev	min	max
exterior temperature (°C)		1.	13.8	2.4	7.7	20.8
		2.	18.8	3.0	11.2	26.3
		3.	3.1	2.0	-1.1	7.5
daily averaged solar radiation incident on facade (W/m²)		1.	152	56	44	235
		2.	144	52	64	223
		3.	54	35	6	103
wind speed (m/s)		1.	3.9	1.2	1.4	9.1
		2.	2.9	1.2	0.5	7.4
		3.	4.3	1.7	1.9	12.5
prevailing wind direction		1.	south west and north east			
		2.	south west			
		3.	south west			

Table 1: Overview of measurements periods and climatic conditions

Measurements

	period	shading	average	st.dev.	min	max
air-change rate (1/h)	1.	up	8.7	2.3	3.3	16.9
	2.	down	7.0	2.1	2.9	22.4
	3.	up	7.7	1.6	2.5	12.9
cavity temperature (°C)	1.	up	18.1	2.8	13.2	26.4
	2.	down	22.4	3.5	16.2	41.6
	3.	up	5.5	1.3	2.6	9.7
temperature difference between the cavity and the exterior (K)	1.	up	4.4	2.0	1.3	12.7
	2.	down	4.1	2.1	-0.6	18.3
	3.	up	2.4	1.0	-0.2	4.2
absolute pressure difference between the inlet and outlet grid (Pa)	1.	up	0.78	0.57	|-0.93|	3.30
	2.	down	0.82	0.47	|-1.18|	4.05
	3.	up	0.40	0.38	|-2.74|	2.96

Table 2 : Overview of measurements

Airflow measurements:
The airflow varies between 7 and 9 air-change rate (h^{-1}) in function of the period.
In summer (periods 1 and 2), the air-change rate reflects the daily course of the exterior temperature and solar radiation. The difference between the exterior temperature and the average cavity temperature (DT) shows a reasonable agreement with the air-change rate (ach) suggesting that thermal buoyancy is the main driving force in summer.

In winter (period 3), the average temperature difference between the cavity and the exterior is significantly lower than in summer and the agreement with the temperature difference is less pronounced. Consequently, the buoyant driving force is lower. Wind induced flow is more important in winter. There exists a real difficulty to find a simple relationship between the airflow rate and the wind speed or direction.

Temperature measurements:
In winter, the measured thermal buffer effect is small. The average temperature difference between the cavity and the exterior is small, even for sunny days. This is partly caused by wind induced flow.

In summer, the airflow should prevent overheating of the cavity. The airflow is related to the square root of temperature difference between the exterior and the cavity. Consequently selfregulation becomes less efficient for higher temperature differences. Particularly when the shading device is lowered, the cavity temperature sometimes reaches quite high values (up to 41°C).

References

D. Saelens, Energy performance assessment of single storey multiple-skin facades, PhD, 2002, Katholieke Universiteit Leuven, Belgium

3.4 The Vliet Test Building in Belgium (Flamant, Prieus)

Introduction
In this chapter the monitoring results of two single storey ventilated double skin façades (one naturally ventilated and the other one mechanically ventilated) installed in the Vliet test building of the Laboratory of Building Physics in Leuven, Belgium are analysed. It is based on the PhD performed by Dirk Saelens who finished his work in 2002. Pictures, tables and results shown in this document are extracted from this PhD.

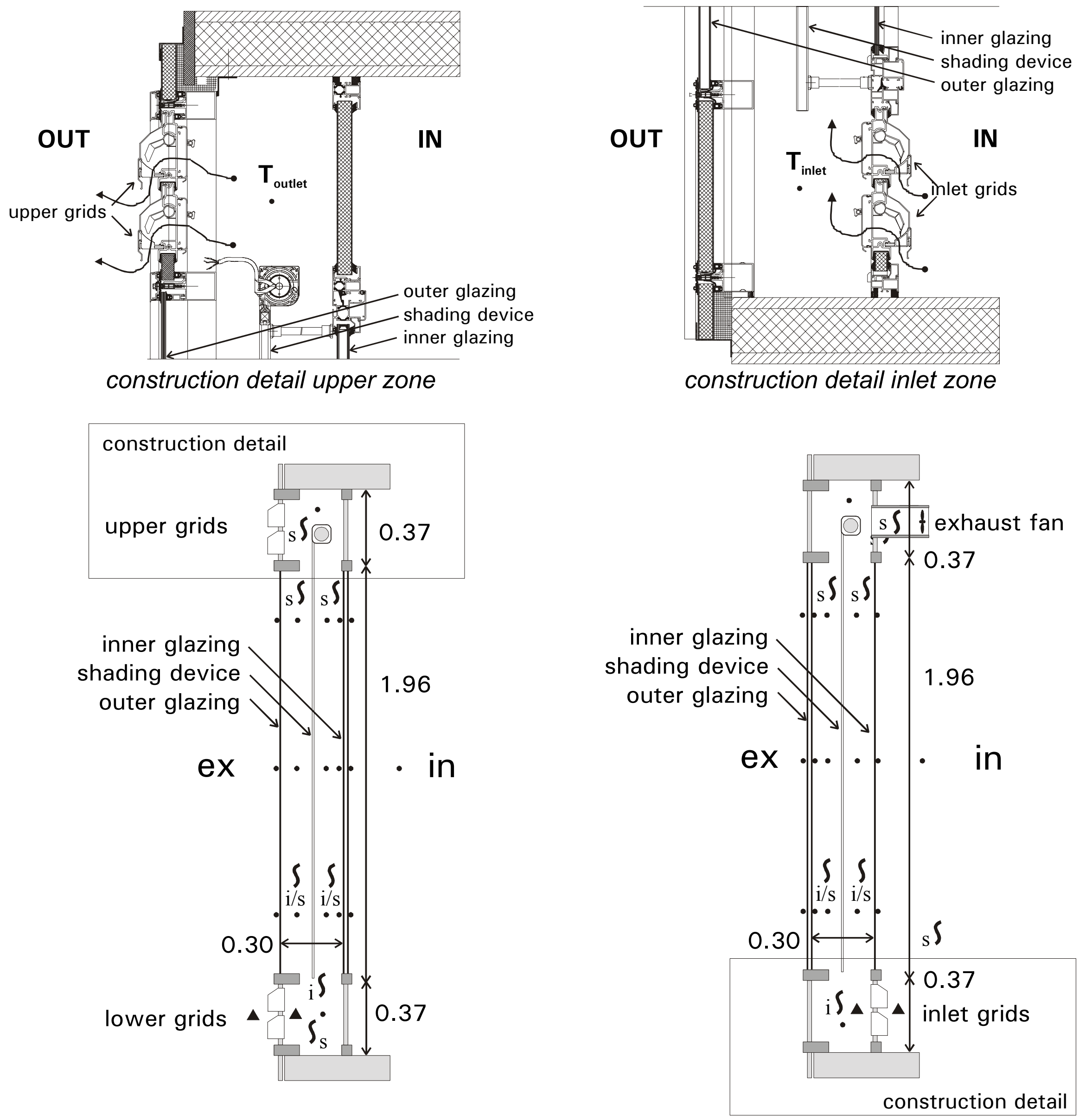
Measurement set-up
At the Vliet test building of the Laboratory of Building Physics in Leuven, Belgium, three facade systems have been built: (a) a classical cladding system with external shading device, (b) a mechanically ventilated multiple-skin facade and (c) a naturally ventilated multiple-skin facade (Figure 1). The envelopes face south-west. The cells, in which the envelope systems were built, measure 1.2 m wide by 2.7 m high by 0.5 m deep.

Figure 1: The Vliet test building. The position of the experimental set-up at the south west facade: (a) classical cladding system, (b) mechanically ventilated facade and (c) naturally ventilated facade.

In this chapter, the discussion is restricted to the evaluation of both double-skin facades. The terminology will be the following :

- Facade (c) called “double-skin façade”: ventilated with exterior air (“from outside to outside – no air transfer between the cavity and the room behind the façade). To vary the airflow rate, two pairs of adjustable grids are built in at the bottom and the top of the cavity. The number of opened ventilation grids is always the same for the lower and upper grids.
- Façade (b) called “airflow window”: ventilated with interior air by means of a speed adjustable fan (ventilation from indoor to the HVAC system – no air transfer between the cavity and the outdoor environment).

The temperature profiles as well as the airflow rates were continuously measured during winter and summer conditions.



construction detail upper zone *construction detail inlet zone*

cross section *cross section*

a. double-skin facade (naturally ventilated) *b. airflow window (mechanically ventilated)*

Figure 2: Cross section and construction detail for the multiple-skin facades at the Vliet test building. Points (●) represent thermocouples, pairs of triangles (▲▲) represent pressure difference measurements and S-shaped curves show tracergas inlet (i∫) and sampling (s∫) points. Main dimensions are given in metres.

component	*double-skin facade*	*airflow window*
exterior glazing	single pane (8 mm), clear float glass, central glass U-factor = 5.67 W/(m²·K).	double pane (4 – 15 –4 mm), clear float glass, argon filled, low-E coating (ε = 0.09), central glass U-factor = 1.23 W/(m²·K), g-value = 0.64, thermally insulated spacer (U_{lin} = 0.042 W/(m·K)).
shading device	roller blind with automated control, the shading device is lowered if the solar radiation exceeds 150 W/m².	roller blind with automated control, the shading device is lowered if the solar radiation exceeds 150 W/m².
interior glazing	double pane (4 – 15 –4 mm), clear float glass, argon filled, low-E coating (ε = 0.09), central glass U-factor = 1.23 W/(m²·K), g-value = 0.64, thermally insulated spacer (U_{lin} = 0.042 W/(m·K)).	single pane (8 mm), clear float glass, central glass U-factor = 5.67 W/(m²·K).
upper grids	2 parallel ventilation grids at the outside, length 1.1 m. (airflow rate = 111 m³/h at 2 Pa).	none.
lower grids	2 parallel ventilation grids at the outside, length 1.1 m. (airflow rate = 111 m³/h at 2 Pa).	2 parallel ventilation grids at the inside, length 1.1 m. (airflow rate = 111 m³/h at 2 Pa).
ventilation	natural ventilation.	speed adjustable fan connected to 4 circular exhaust ducts (diameter 100 mm) with identical flow resistance.

Table 1 : Overview of the materials and their properties as used in the measurement set-up at the Vliet test building.

Temperature measurements

Table 2 and Figure 3 give an overview of the exterior (Te) and interior temperature (Ti), the average cavity temperature (Tcav), the temperature difference between the inlet and the outlet (DT) and incident solar radiation (It) for the double-skin facade during winter (Figure 3a) and summer (Figure 3b). Table 3 and Figure 4 show the same variables for the airflow window.

The cavity temperature in both figures is defined as the average temperature over the 6 cavity thermocouples. For the double-skin facade, the temperature difference between the inlet and the outlet (DTdsf) is defined as the temperature difference between the exterior air temperature and the temperature at the top or the bottom of the cavity depending on the airflow direction. For the airflow window, the temperature difference between the inlet and the outlet (DTafw) is defined as the difference between the interior air temperature and the temperature at the top of the cavity.

Double-skin façade (naturally ventilated):

As the double-skin facade is ventilated with exterior air and the thermal break is positioned at the interior glazing, the cavity temperature is closely related to the exterior temperature (Figure 3). During winter and summer, the cavity is warmer than the exterior.

The number of opened grids has been changed between 0, 1 or 2.

In winter (Figure 3a), it acts as a buffer and helps to reduce the transmission losses (it really acts as a buffer when cavity ventilation is disabled). The cavity air could be used in this case as preheated ventilation air. During the night, the increase in temperature is only small. With solar radiation, the increase (DTdsf) easily exceeds 10 K and may even exceed 20 K, introducing indirect solar gains.
Table 2 also gives the averaged (on several days) difference between the mean temperature of the cavity and the external temperature (DTcav-e). The range of this temperature difference depends on the number of opened grids (0, 1 or 2). It varies between 2 and 3 K with 2 opened grids, between 2 and 4 K with 1 opened grid and between 6 and 7 K with 0 opened grid (no ventilation). In the last case, the double-skin facade truly acts as a thermal buffer.
In summer (Figure 3b), the maximum temperatures are higher and the peaks occur more frequently. The increase in temperature (DTdsf) easily exceeds 15 K and may reach 28 K. Especially during daytime, the cavity temperature is usually higher than the interior temperature with indirect solar gains as a consequence. The high temperatures make it impossible to use the cavity air to ventilate the building without a penalty in cooling load.

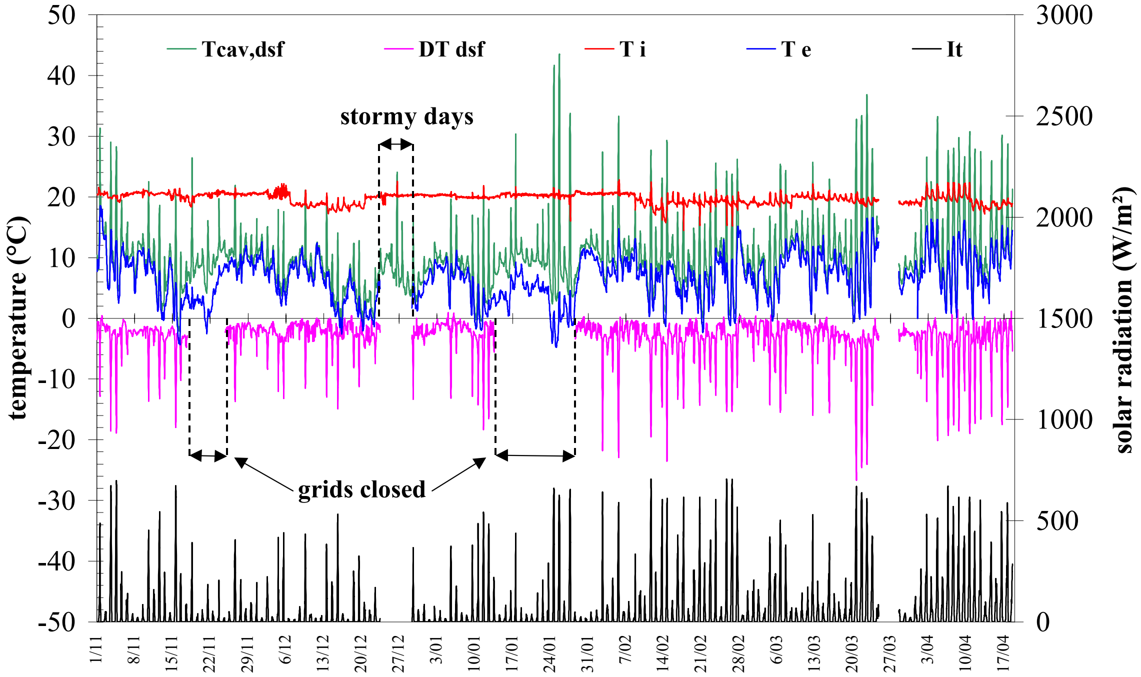
Airflow window (mechanically ventilated):
In winter as well as in summer, the cavity airflow rate was changed. The cavity temperature of the airflow window (Figure 4) tends to the interior temperature because the thermal break is positioned at the exterior glazing and the cavity is ventilated with interior air.
In winter (Figure 4a), the cavity is on average 2.2 K (st.dev. = 4.9 K) colder than the interior. Table 3 also gives the averaged (on several days) difference between the mean temperature of the cavity and the internal (in the room) temperature (DTcav-i).
Towards the spring, the average cavity temperature may surpass the interior temperature from the end of March. Analysing the temperature difference between the inlet and the outlet (DTafw) shows that solar radiation is capable of heating the cavity air by 10 to 15 K. With more intense solar radiation, the cavity temperature easily surpasses 26°C and reaches maximum values of over 35°C.
However, on the whole, in winter the cavity air cools down, while passing through the cavity. This is illustrated by the total enthalpy change during the four winter months (November, December, January and February): the enthalpy loss is 235 kWh while the enthalpy gain is only 32 kWh.

	measuring period	opened grids [-]	$T_{cav,dsf}$ [°C]	DT_{dsf} [K]	T_i [°C]	T_e [°C]	DT_{cav-e} [K]
1 Nov - 17 Nov	winter	2	9.6 (5.4)	-3.2 (3.1)	20.4 (0.4)	7.3 (4.4)	2.3
17 Nov - 24 Nov		0	9.4 (3.1)	NA	20.3 (0.6)	3.5 (2.6)	5.9
24 Nov - 6 Dec		2	9.9 (2.8)	-2.4 (2.0)	20.5 (0.4)	8.0 (2.3)	1.9
6 Dec - 20 Dec		1	7.2 (3.7)	-2.2 (2.1)	18.6 (0.5)	5.5 (3.6)	1.7
20 Dec - 13 Jan		2	7.2 (3.7)	-2.5 (2.7)	20.1 (0.3)	4.7 (3.3)	2.5
13 Jan -28 Jan		0	10.0 (6.0)	NA	20.3 (0.4)	3.3 (3.0)	6.7
28 Jan - 18 Feb		1	10.3 (4.4)	-3.3 (3.6)	19.8 (1.2)	7.5 (2.9)	2.8
18 Feb - 10 Mar		2	9.9 (4.9)	-2.8 (2.9)	19.4 (0.7)	7.3 (3.7)	2.6
15 Mar -24 Mar		1	12.0 (6.9)	-5.0 (4.9)	19.6 (0.5)	8.0 (4.0)	4
28 Mar -18 Apr		2	12.0 (6.2)	-4.0 (4.0)	19.5 (1.1)	8.6 (3.5)	3.4
17 Jul - 30 Aug	summer	1	21.7 (7.6)	-4.5 (5.7)	21.6 (0.3)	18.4 (3.7)	3.3

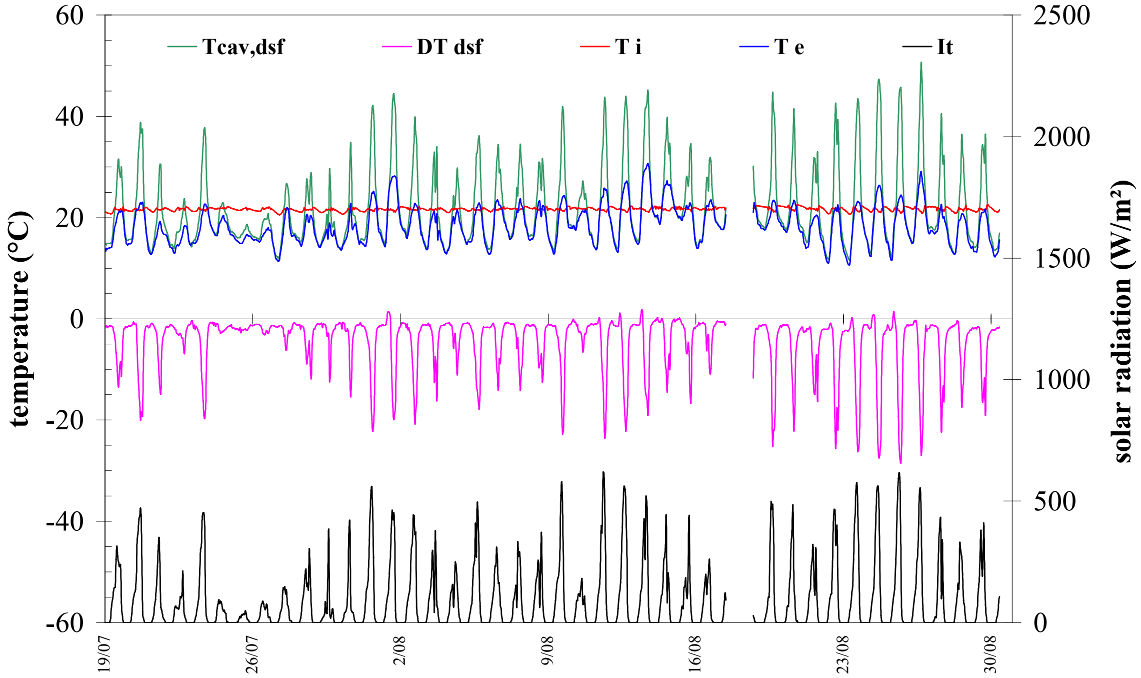
Table 2 : Overview of the measurements on the double-skin facade (st.dev.)

	measuring period	G_a [m³/h]	$T_{cav,afw}$ [°C]	DT_{afw} [K]	T_i [°C]	T_e [°C]	DT_{cav-i} [K]
1 Nov - 17 Dec	winter	164	18.0 (2.2)	1.6 (2.1)	20.0 (0.9)	6.6 (3.8)	-2
17 Dec - 20 Dec		158	16.9 (1.3)	2.0 (1.0)	18.6 (0.5)	2.9 (2.7)	-1.7
20 Dec - 24 Dec		112	17.7 (0.7)	2.7 (1.0)	20.0 (0.4)	1.7 (2.3)	-2.3
24 Dec - 11 Jan		144	17.5 (1.3)	3.1 (1.3)	20.2 (0.3)	5.7 (3.1)	-2.7
11 Jan -13 Jan		112	17.5 (2.5)	2.6 (2.3)	20.0 (0.4)	2.4 (1.3)	-2.5
13 Jan -17 Jan		85	16.7 (1.5)	3.2 (1.4)	20.4 (0.3)	4.0 (1.9)	-3.7
17 Jan - 25 Jan		74	17.7 (2.3)	2.6 (2.4)	20.3 (0.2)	3.8 (3.4)	-2.6
25 Jan - 28 Jan		102	17.2 (2.3)	3.2 (3.9)	20.1 (0.6)	0.8 (1.6)	-2.9
28 Jan - 3 Mar		56	18.5 (3.0)	1.1 (3.8)	19.5 (1.0)	7.1 (3.3)	-1
3 Mar - 28 Mar		32	19.1 (3.8)	0.3 (3.8)	19.6 (0.6)	8.1 (3.7)	-0.5
28 Mar - 8 Apr		112	20.3 (2.5)	-0.1 (2.0)	19.8 (0.9)	7.9 (3.6)	0.5
8 Apr - 10 Apr		124	22.1 (3.2)	-0.5 (2.5)	20.8 (0.9)	11.3 (3.2)	1.3
10 Apr - 18 Apr		86	19.9 (1.8)	-1.5 (2.2)	18.7 (0.5)	8.8 (3.2)	1.2
17 Jul - 17 Aug	summer	37	23.5 (4.0)	-2.5 (5.4)	21.6 (0.3)	18.4 (3.7)	1.9
17 Aug - 30 Aug		128	22.8 (2.0)	-1.4 (2.9)	21.7 (0.4)	18.2 (3.8)	1.1

Table 3 : Overview of the measurements on the airflow window (st.dev.)

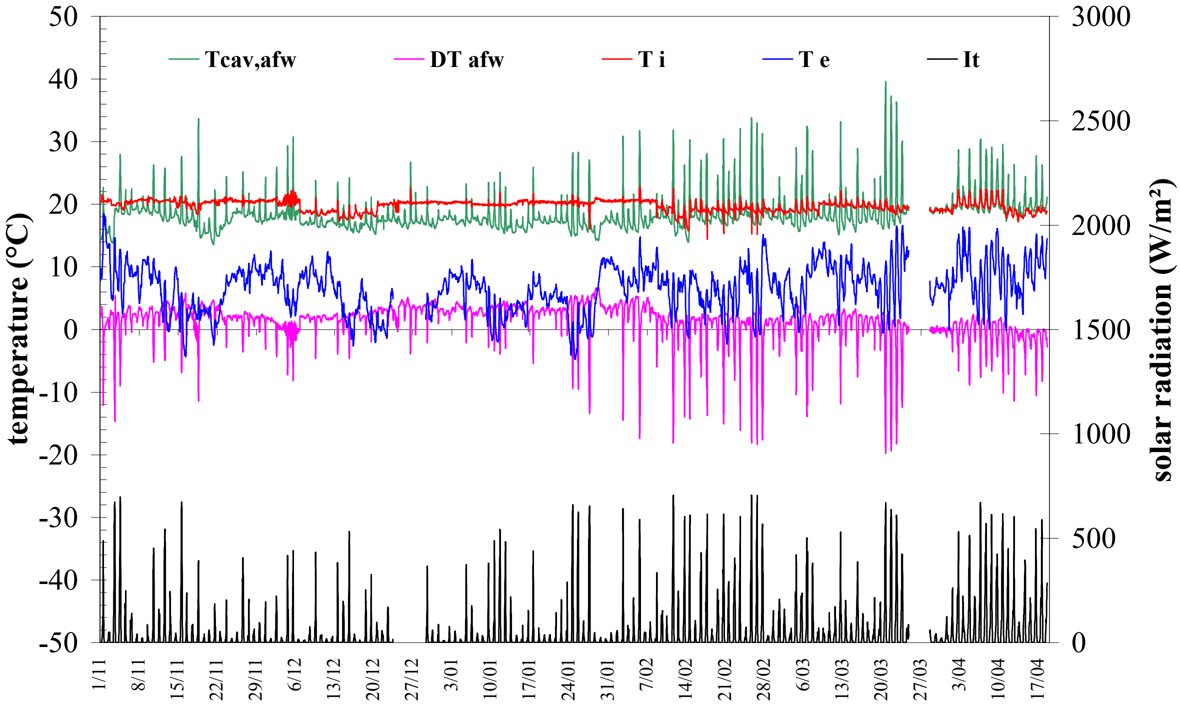


a. winter period (from November 1, 1999 till April 18, 2000)

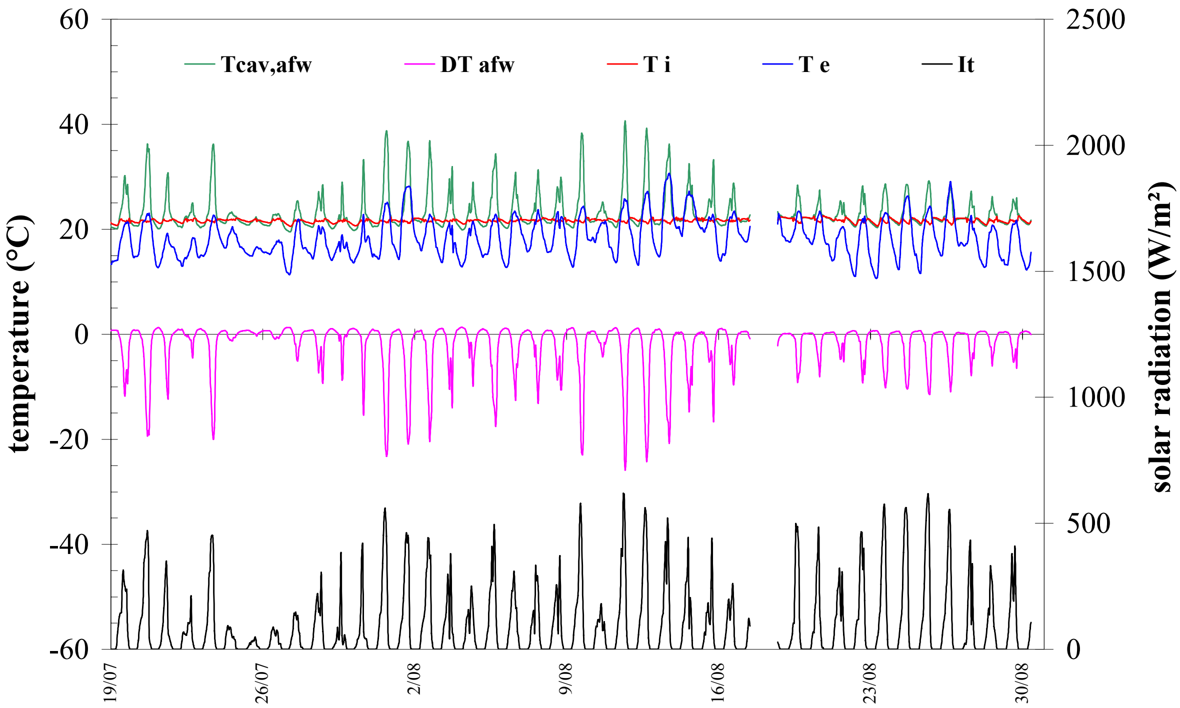


b. summer period (from July 19, 2000 till August 31, 2000)

Figure 3 : Overview of the temperatures in the double-skin facade during winter (above) and summer (below). (Tcav,dsf: average cavity temperature in the double-skin facade (°C), DTdsf: temperature difference between the inlet and outlet of the double-skin facade (°C), Ti and Te: interior and exterior air temperature (°C), It: solar radiation incident on the facade (W/m²))



a. winter period (from November 1, 1999 till April 18, 2000)



b. summer period (from July 19, 2000 till August 31, 2000)

Figure 4 : Overview of the temperatures in the airflow window during winter (above) and summer (below). (Tcav,afw: average cavity temperature (°C), DTafw: temperature difference between the inlet and outlet of the airflow window (°C), Ti and Te: interior and exterior air temperature (°C), It: solar radiation incident on the facade (W/m²))

In summer during the day (Figure 4b), the cavity temperature hardly drops below the interior temperature. This causes important indirect solar gains.
The influence of the airflow rate is most pronounced in summer (Figure 4b). In the first half of the summer, with an average airflow rate of 37 m³/h (st.dev. = 1.0 m³/h), the increase in cavity temperature is substantial, ranging from 15°C to 26°C. In the second half, with an average airflow rate of 128 m³/h (st.dev. = 0.9 m³/h), the average cavity temperature lowers by 0.7°C compared to the first half. The average increase in temperature between the inlet and outlet (DTafw) lowers by 1.1 K. More important, the maximum temperatures and hence the indirect solar gains are reduced significantly.
In summer, the cavity temperature of the airflow window is lower than for the double-skin facade and can be efficiently decreased by increasing the airflow rate. The position of the thermal break (double glazing to outside for airflow rate and to inside for double-skin façade), however, results in high indirect solar gains for the airflow window.

Airflow measurements (in double-skin façade)
This sections deals with the measurement of the airflow rates in the (naturally ventilated) double-skin façade.
The airflow rate is continuously determined from the measurement of the pressure difference over the ventilation grid (measurement with tubes connected to a differential pressure transducer). The position of the tubes is represented by triangles in Figure 2. The pressure difference over the lower ventilation grids has been measured in such a way that a positive pressure difference corresponds to a flow towards the cavity.
The airflow in the naturally ventilated cavity has two driving forces: (1) the pressure difference due to thermal buoyancy and (2) the difference in wind pressure between the upper and lower ventilation grids. The former will mainly cause upward flows as the cavity is ventilated with colder exterior air. The latter may cause either upward or downward flows, depending on wind speed and wind direction.
Thermal buoyancy was shown to be the dominating force. For low wind speeds and upward flow conditions, a linear relationship between the pressure and temperature difference between the cavity and the outdoor air can be demonstrated. In winter, wind effects play a more important role. The airflow due to wind effects is difficult to predict. For higher wind speeds simple models cannot predict the complexity of the airflow in naturally ventilated active envelopes. A detailed knowledge of the pressure distribution on the building envelope should be known as a function of wind speed and wind direction.
Without wind, one can show that the pressure difference for upward flows is proportional to the air temperature difference between the cavity and the outdoor air and that the upward airflow rate is proportional to the square root of the temperature difference.
The difference in wind pressure between the upper and lower ventilation grids is a second cause of airflow.

situation		winter (1 opened grid)		winter (2 opened grids)		summer (1 opened grid)	
flow direction		down	up	down	up	down	up
% of measurements		27	73	30	70	10	90
Δp [Pa]	average	-0.168	0.142	-0.171	0.120	-0.052	0.144
	(st. dev.)	(0.181)	(0.167)	(0.200)	(0.140)	(0.062)	(0.172)
ΔT [K]	average	2.07	3.32	2.06	2.78	1.22	3.61
	(st. dev.)	(1.96)	(4.35)	(2.07)	(3.32)	(2.86)	(5.07)
θ_e [°C]	average	8.28	7.22	7.80	6.40	18.35	18.21
	(st. dev.)	(2.36)	(3.57)	(3.20)	(3.62)	(3.42)	(3.79)
w [m/s]	average	3.28	2.10	2.84	1.82	1.41	0.87
	(st. dev.)	(1.37)	(1.43)	(1.30)	(1.29)	(0.90)	(0.79)
G_a [m³/(h.m)]	average	-19.5	18.9	-67.1	59.8	-6.0	19.2
	(st. dev.)	(11.6)	(10.0)	(35.7)	(26.2)	(7.2)	(22.9)

Table 4 : Overview of the main quantities and the ratio between upward and downward flow during winter and summer measurements.

Table 4 gives an overview of the following average quantities for the winter and summer situations : Δp is the pressure difference, ΔT is the temperature difference between the cavity and the external air, θ_e the external temperature, w the wind speed and G_a the airflow rate through the cavity (per metre width).
Distinction is made between upward and downward flow, the number of opened grids and the measuring period.
During summer and winter, the main direction of the airflow is upward. We find an upward flow during 90% of the time in summer (1 opened grid) versus 73% (1 opened grid) of the time in winter.
The average pressure difference as well as the temperature difference for upward flow with one opened grid are approximately the same in winter and in summer. The airflow rate reaches about 19 m³/h.m, which corresponds to an air-change rate of 27 h^{-1}.
For low wind speeds and one opened ventilation grid, the linear relationship between the pressure difference and the temperature difference is very good in summer and relatively good in winter. Figure 5 shows, during summer and with low wind speed, that the upward airflow rate is proportional to the square root of the temperature difference.
The opening of 2 ventilation grids has a high impact on the airflow rate compared to the situation where only one grid is open (60 m³/h.m in place of 19 m³/h.m for an upward flow).

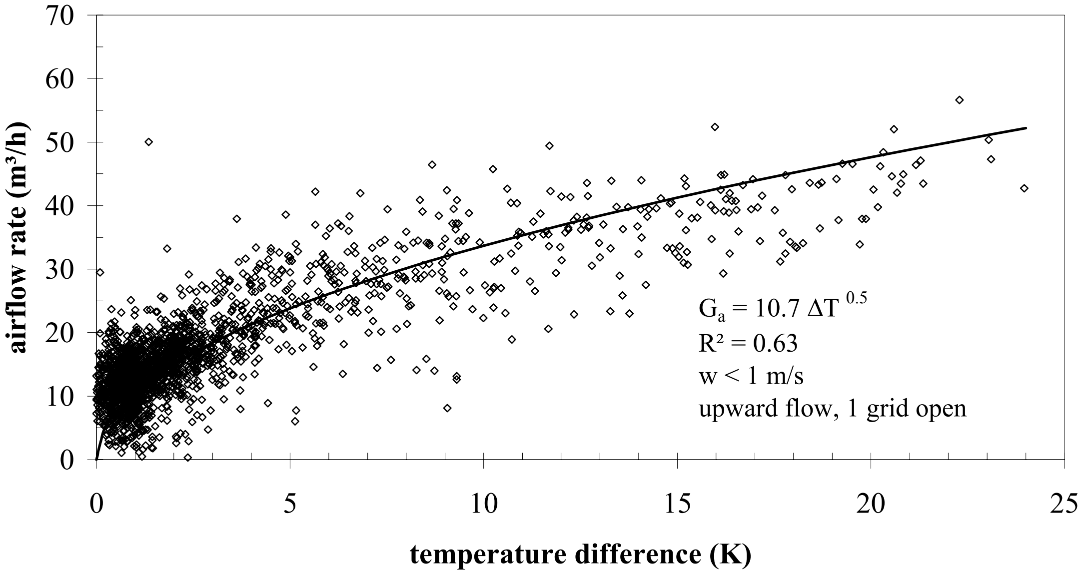


Figure 5 : Airflow rate as a function of temperature difference during summer measurements and upward flow conditions, 1 opened grid, wind speed < 1 m/s.

References

D. Saelens, Energy performance assessment of single storey multiple-skin facades, PhD, 2002, Katholieke Universiteit Leuven, Belgium

3.5 The Aula Magna Building in Belgium (Prieus, Flamant)

Introduction

In this chapter monitoring results of a naturally ventilated multi storey double skin façade installed in the AULA MAGNA building in Belgium are analysed. The analysis gives information concerning the airflow rate and temperatures in the façade cavity for summer and winter periods. It is based on thesis work performed by V. De Meulenaer for the winter measurements in 2002-2003 and S. Prieus for the summer measurements in 2003.

Geometry and characteristics of the facade

Geometrics of the building: 72 m x 31.5 m x 19 m(height)
Horizontal division: transparant metal frame every 2.7 m in height
Geometrics of the glass planes: 2.7 m x 1.35 m (see Figure 1)
Composition of the facade: the DSF is composed for some parts of the façade by a combination "glass-opaque panel" (see grey parts in Figure 1) and for other parts by a combination "glass-glass" (see blank parts in Figure 1):

1) glass-opaque panel: external skin double glazing, cavity 65 cm, cement bound fibre panel of 1,4 cm, 10 cm insulation and 20 cm concrete.
2) glass-glass: external skin double glazing, cavity 65 cm, sunscreen (10 cm away from the internal glazing) (reflection 35 % + transmission 11 %) , internal skin double glazing

Windows (=openings) for ventilation of the cavity are positioned at the bottom and at the top of the DSF (see Fig 1) and are 1.33 m wide, 0.66 m high and can be opened 0.25 m.

	Type	Construction	U-value	Reflection	Transmission
Outer glass	Thermoplus Clearlite	8-15-6 mm	1,8 W/m²K	13 %	79 %
Inner glass	Thermobel	8-15-6 mm	2,9 W/m²K	14 %	78 %

Measurements

Positioning:
Studied zone:
Height 19 m (7 modules of 2.7 m)
Width: 10 m in the SE facade

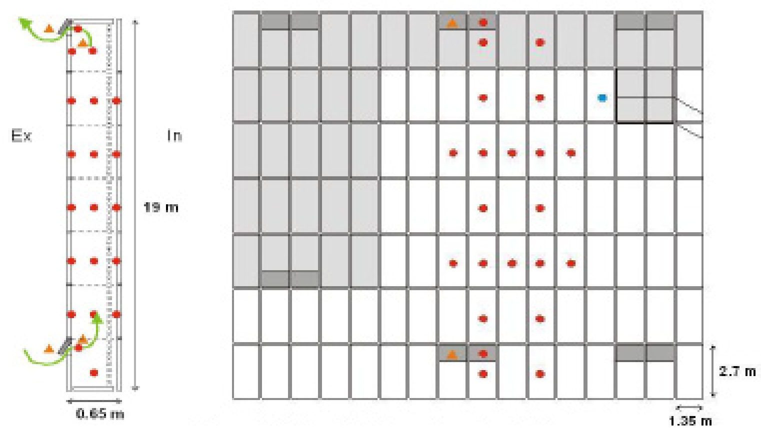


Figure 1: Positioning of the measurement equipment

The analysis has taken into account the following:

- The mean cavity temperature is the averaging of the 7 measured air temperatures (without the in- outlet temperatures on level 1 and 8)
- The inside temperature is 20°C / 21°C (because to the HVAC system)
- Time shift of 1.5 to 2 hours between the maximum value of the sun radiation and the cavity temperature.
- Solar radiation is measured on a vertical plane.
- Measurements were done every 15 minutes
- The Building Management System (BMS):
  - o Manages the opening of the windows (dampers)
  - o Based on temperature and relative humidity, measured by sensors in the 3 facades
  - o Opening of the dampers when
    - the cavity temperature > 30° C (measured at the 4th level of the façade) and when the outside temperature is lower then the cavity temperature
  - o No opening of the dampers when
    - the minimal temperature of the glass pane is lower than the dew point of the air in the foyer AND in case the outside temperature is lower than the dew point of the cavity air (to avoid condensation).
  - o Closing when the temperature drops 10°C

Temperature measurements

Measuring campaign:

1) Winter measurements: 3/12/2002 till 31/03/2003 (Fig 3, Fig 4)
2) Summer measurements: 1/07/2003 till 31/08/2003 (Fig 5, Tab 1)

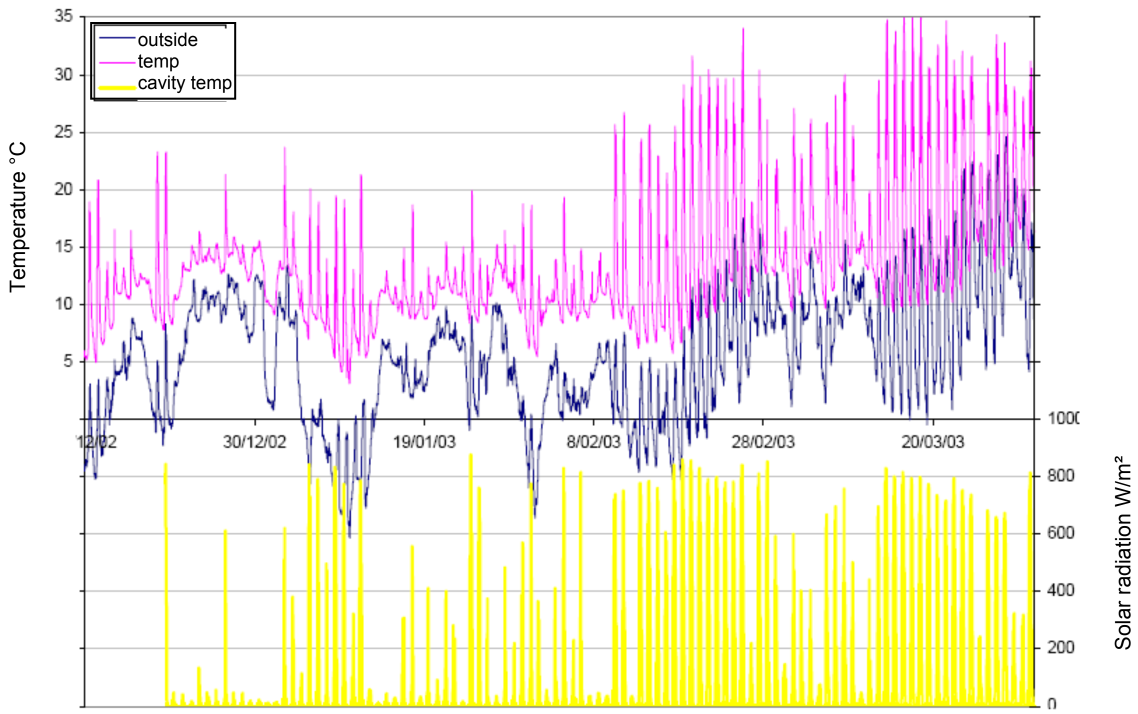


Figure 3: Measurements in WINTER (from 3/12/2002-31/03/2003) (outside temperature, mean cavity temperature, solar radiation)

The difference between the outside temperature and the cavity temperature during the winter months is approximately between 5 and 15°C.

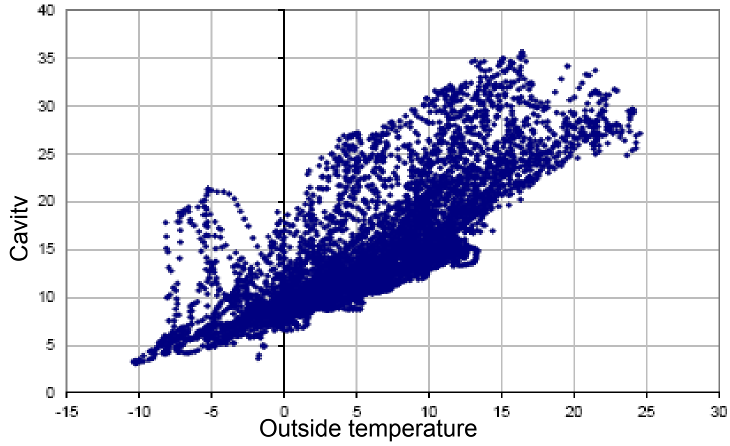


Figure 4: Mean cavity temperature in relation to the outside temperature (quarterly values)

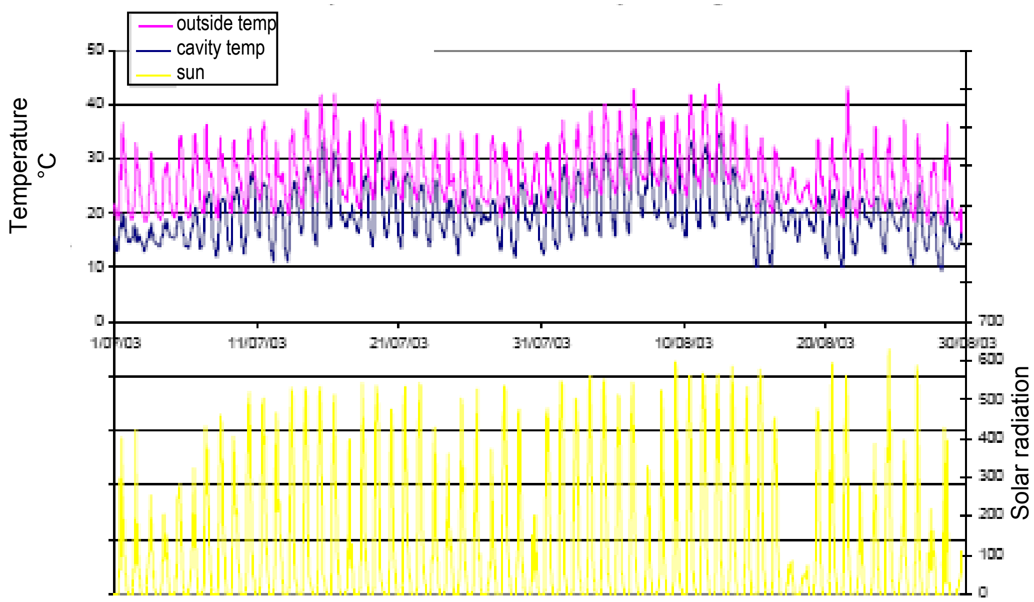


Figure 5: Measurements in SUMMER (from 1/07/2003-31/08/2003) (outside temperature, mean cavity temperature, solar radiation)

	Outside temp (°C)	Mean cavity temp (°C)	Solar radiation (W/m²)
		July	
average	19,4	26,6	109
min	11,0	18,4	0
max	33,2	41,8	542
		August	
average	20,6	27,6	114
min	9,4	16,5	0
max	35,5	43,8	629

Table 1: Mean temperatures and solar radiation for July and August

The difference between the outside temperature and the cavity temperature during the summer months is approximately 7 K.

Additionally temperature profiles have been analysed for a few type days.

- Winter period: the windows are typically closed.

Closed windows	13/01/03 Cloudy winter day	11/01/03 Sunny winter day

- Interstitial period: the windows are open during a relative short period usually during midday (between 10:30 am and 3:30 pm).

Open windows for a short period	16/03/03	18/03/03	27/03/03

- Summer period: the windows are typically opened.

Open windows for a long period	18/08/03 Cloudy summer day	24/08/03 Sunny summer day	12/08/03 Sunny summer day High outside temp.

The different type days and their characteristics are summarized in Table 2.

Measured day	Outside temp (°C)	Inside temp (°C)	Solar radiation (W/m²)	Mean cavity temp (°C)
13/01/03	Max: 6,5 Average: 2,2 Min: -1	20,7	Max: 10	Max: 11,5 Average: 9,2 Min: 7
11/01/03	Max: 1,5 Average: -3,1 Min: -5	21,7	Max: 785	Max: 21,5 Average: 10,3 Min: 5,5
16/03/03	Max: 16 Average: 8,3 Min: 0,5	19,9	Max: 816	Strong variation maximum values along the height: 26,5 to 55
18/03/03	Max: 15 Average: 7,5 Min: 0,5	19,9	Max: 798	Strong variation maximum values along the height: 26 to 55
27/03/03	Max: 23 Min: 5	21	Max: 680	Strong variation maximum values along the height: 26 to 53
18/08/03	18,5	21	Average: 38 Max: 83	Average: 23 Max: 26,3
24/08/03	Max: 22,9 Average: 21,8 Min: 12,7	21	Average: 264 Max: 664	Average: 26 Strong variation maximum values along the height: 28,4 to 43,5
12/08/03	Max: 35,1 Average: 26,4 Min: 17,2	21	Average: 234 Max: 578	Average: 33 Strong variation maximum values along the height: 40,1 to 51,9

Table 2: Characteristics of the type days

Conclusions:
In winter the buffer function of the double skin façade can be illustrated and a solar heat gain diminishes interior heating needs and compensates transmission losses. In summer there is an unwanted heat gain, although heat gains would be even greater without the natural ventilation of the DSF.

- Winter period => closed windows (dampers)
  11/01/03 (sunny): Solar heat gains towards the interior; transmission losses are compensated with the heated cavity air. The daily averaged difference between outside and cavity temperature is $\Delta T=13$ K (Tab 2). At the moment of the day when the incident solar radiation is maximum (midday), this temperature difference is about 25 K. The daily highest temperature obtained at the top of the façade cavity reaches 45°C.
  This day really illustrates the positive buffer functionality of the DSF.

  13/01/03 (cloudy): the buffer space is 7 K higher than the outside temperature. This temperature difference is relatively constant during the whole day.

  In general during the winter season: the averaged difference between the outside temperature and the cavity temperature during the winter days is approximately between 5 and 15 K (see Fig 3).

- Interstitial period: the windows are open during a relative short period
  16/03/03 & 18/03/03: One can see that there is a temperature drop of 10 K and more, when the ventilation windows (=openings) situated in the external glass skin of the DSF are opened. When the openings are closed, the DSF acts as a buffer. In function of the type of energy demand of the building (heating or cooling), a good control of the ventilation openings of the DSF can contribute to reduce the energy demand of the building.

- Summer period => open windows
  18/08/03 (cloudy): the buffer space is 5 to 7 K higher than the outside temperature

  24/08/03 & 12/08/03 (sunny): There is a temperature drop in of several degrees when the ventilation windows (=openings) are opened. Solar heat gains nonetheless contribute to increase the cooling demand of the buidling. At the moment of the day when the incident solar radiation is maximum (midday), the temperature difference between cavity and exterior is about 10 K and the cavity temperature can rise up to 50°C in the top level of the façade.

  In general during the summer season: the monthly averaged difference between the outside temperature and the cavity temperature is approximately 7 K(see Tab 1). During sunny days, the cavity temperature leads to unwanted solar heat gains towards the building.

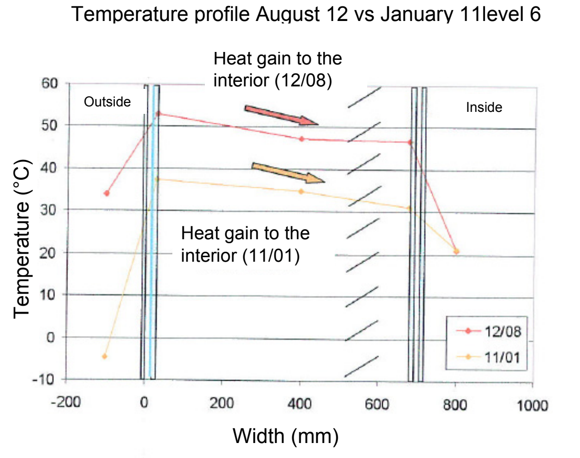


Figure 1: Level 6 → heat gain in winter and summer

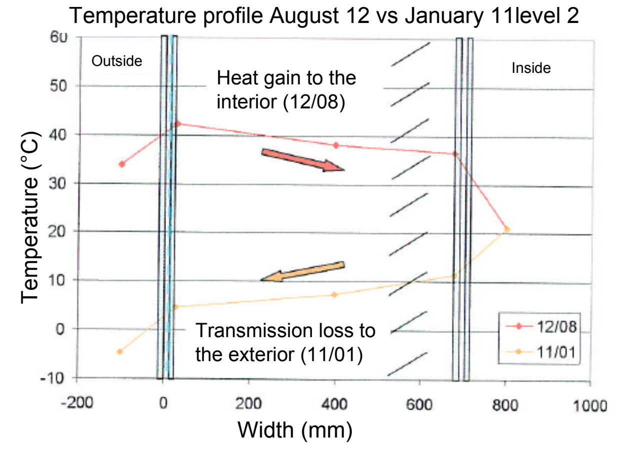


Figure 2: Level 2 → heat loss in winter, heat gain in summer

Airflow rate:
The air speed in the cavity is determined by the speed of the rising smoke though video registrations.

	Average air speed in the cavity (cm/s)	Air rate per hour (h^{-1})	
Closed windows	2 to 5	-	The lower values are on cloudy days, the upper values for sunny days.
Open windows	8 to 50	15 to 95	The lower values are on windless days, the upper values for windy days.

Table 5: Average air speed in the cavity

Air speed at the entrance of the windows (cm/s)	25 - 150
Airflow (m^3/h)	700 - 4500

Table 6: Air speed at the entrance of the windows

References

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2. Zomermetingen op de dubbele gevel van de Aula Magna te Louvain-La-Neuve, Vrije Universiteit Brussel, Sabrina Prieus, 2004

3.6 Siemens Building, RWE Tower, Victoria Insurance Building in Germany (Müller/Platzer)

A measurement of the facade temperature of three buildings with different facades is presented in [Müller, et alli.]. This work describes the buildings of Siemens in Dortmund, the RWE tower in Essen as well as the Vicoria Insurance in Düsseldorf. Unfortunately there is no detailed description of façade components and their characteristics. The solar radiation data and the ventilation rates are missing as well. Therefore Platzer tried to follow-up the measured temperature development at certain days in order to make a comparison with his own guideline approach.

Case 1: Victoria Insurance Building in Düsseldorf, East facade
The measurement data is based on the temperature data of August 8, 1998, a day in the hottest week of the measurements and were taken from a graphic. Presented are the temperatures of the room behind the double skin façade, the outside air and the facade gap in the middle of the element.
The weather data is comprised of the solar radiation of an average sunny day in August. (Orientation East façade -90°).
The facade consists of an inner tilt and turn window with an approximated low-e coated glazing (chosen characteristics: g=62 %, Uw=1.4 W/m²K, frame factor 70 %), a 350 mm deep facade gap with an external single glazed skin (8 mm; chosen characteristics g=75%, τe=70 %, Ug=5.7 W/m²K). The opening area is 6,3 % of the facade area, the window area about 61 %. The sill is insulated. The transparent part of the external skin was estimated to be about 85 %.
Additional used values for the model were for the sill (Up=0.8 W/m²K, ap=30 %). By using a standard air change rate of 2 h^{-1} temperature values have been calculated that represented very well the temperature line in the East façade (morning sunny, afternoon cloudy).

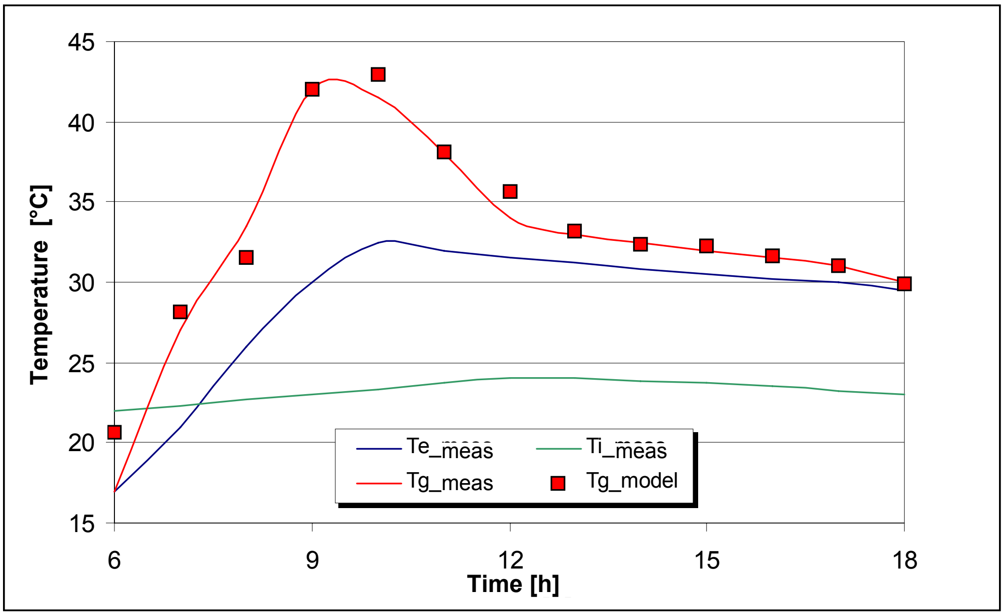

Figure 1: Temperature lines of the room, the exterior and the facade (measured on August 8, 1998 at the Victoria Building in Düsseldorf at the East facade compared to calculated temperatures Tg_model of the façade gap (chosen air change rate 2 h^{-1}).

Case 2: Siemens Building in Dortmund, SouthEast facade

The measurement data is based on the temperature data of August 8, 1998, a day in the hottest week of the measurements and were taken from a graphic. Presented are the temperatures of the room behind the double skin façade, the outside air and the facade gap in the middle of the element.
The weather data is comprised of the solar radiation of an average sunny day in August. (Orientation SouthEast façade -45°).
The facade consists of an inner standard wall with windows with approximated low-e coated glazing (chosen characteristics: g=62 %, Uw=1.4 W/m²K, frame factor 70 %), a 350 mm deep facade gap with an external single glazed skin (8 mm; chosen characteristics g=75%, τe=70 %, Ug=5.7 W/m²K). The opening area is 6,4 % of the facade area, the window area about 47 %. The sill is not extremely insulated. The transparent part of the external skin was estimated to be about 75 %.
Additional used values for the model were for the sill (Up=0.8 W/m²K, ap=30 %). By using a standard air change rate of 2 h^{-1} temperature values have been calculated that represented very well the temperature line in the SouthEast façade (maximum sun at noon).

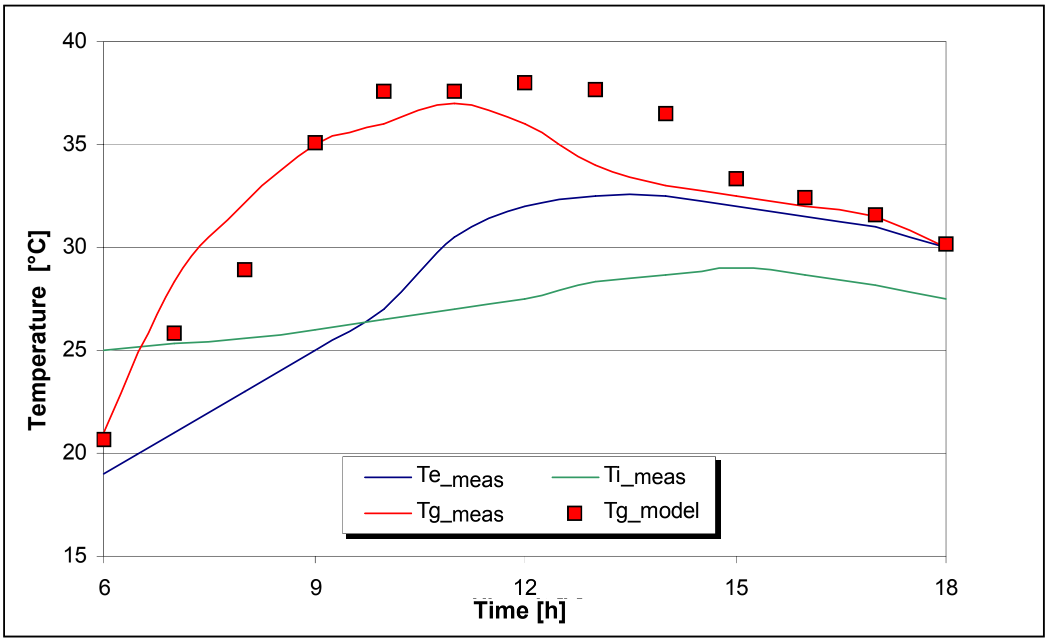

Figure 1: Temperature lines of the room, the exterior and the facade (measured on August 8, 1998 at the Siemens Building in Dortmund at the SouthEast facade compared to calculated temperatures Tg_model of the façade gap (chosen air change rate 2 h^{-1}).

Case 3: RWE Tower in Essen, South facade

The measurement data is based on the temperature data of May 5, 1998, and were taken from a graphic. Presented are the temperatures of the room behind the double skin façade, the outside air and the facade gap in the middle of the element.
The weather data is comprised of the solar radiation of a day in May. (Orientation South façade 0°).
The 50 cm deep double skin facade is totally glazed up to the ventilation openings. The façade was realised by using the principle of double windows (box windows). The section of

the façade shows tiltable windows on the inner side with the following approximated low-e coated glazing (chosen characteristics: g=62 %, Uw=1.4 W/m²K, frame factor 70 %), a 500 mm deep facade gap with an external single glazed skin (8 mm; chosen characteristics g=75%, τe=70 %, Ug=5.7 W/m²K). The opening area is 2,9 % of the facade area, the window area about 83 %. There is no sill. The opaque area consists only of ceilings and ventilation dampers. The transparent part of the external skin was estimated to be about 85 %. Additional used values for the model were for the sill (Up=0.8 W/m²K, ap=30 %). By using a standard air change rate of 2 h^{-1} temperature values have been calculated that represented very well the temperature line in the South façade (maximum sun in the morning and afternoon).

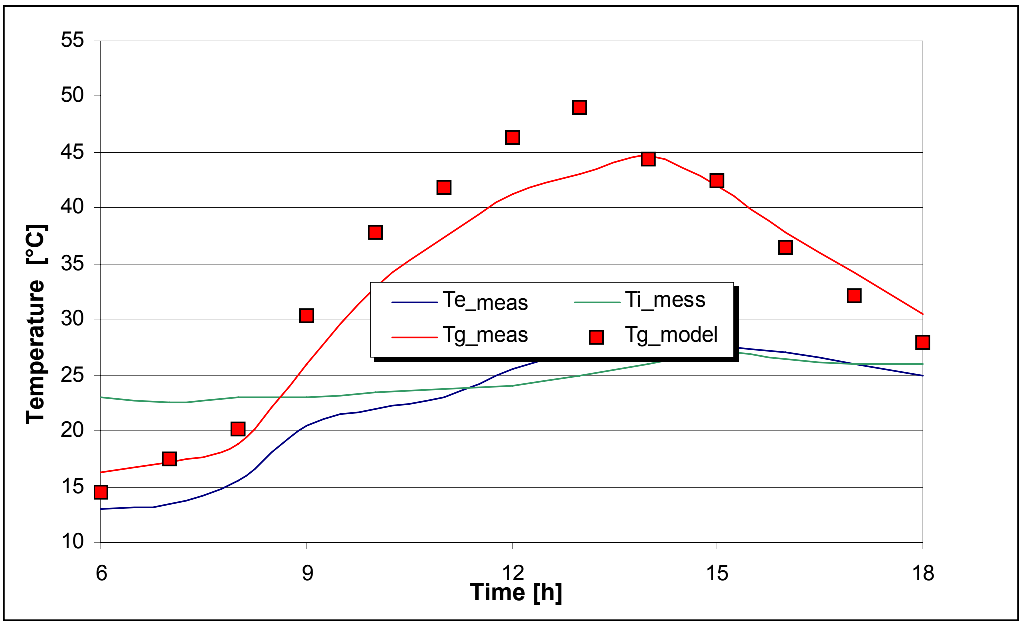

Figure 2: Temperature lines of the room, the exterior and the facade (measured on May 5, 1998 at the RWE Tower in Essen at the South facade compared to calculated temperatures Tg_model of the façade gap (chosen air change rate 2 h^{-1}).

The comparison of Platzer shows, that the calculated temperature with a chosen air change rate of 2 h^{-1} fits well to the measured gap temperature during the exemplary days. But as described in the text, most of the boundary conditions are only estimated, therefore the error in the calculation may influence the results more than a different air change rate. As the results are not very reliable for an overall approximation, they are not used furthermore.

References

1. Platzer, W.: Vorschlag für ein Bewertungsverfahren für Doppelfassaden, DIN working paper, 2004, Fraunhofer ISE, Germany

2. Müller, H. et alli: Experimentelle Untersuchungen an Doppelfassaden. Working paper, 2003, University Dortmund, Germany

3.7 Dissertation Ziller

In this PhD thesis a method is developed to estimate the air change rate in rooms or zones behind DSFs. The developed engineering model is based on model tests in a certain geometric scale by simulating the thermal forces governing the phenomenon of natural ventilation.

As the main goal of the work was the estimation of the air change rate in the room and not in the façade gap, there are only some results, which are useful for the simple calculation model of BESTFACADE. In general the calculations and several validation measurements at double skin facades confirm the estimations of the preceding measurements.

The figure below shows the dependency of the gap temperature from the solar radiation at the investigated façade. As the mean monthly solar radiation in middle Europe differs between 15 and 150 W/m² for different vertical orientations and seasons, the mean excess temperature in the façade gap is not higher than 2 K. Under higher solar radiation the temperature may rise up to 5 K. As described before, this study was done under model scale in wind tunnel conditions for the impact of the DSF to the adjacent zone. Therefore the results can not be used directly for an approximation of the gap conditions. But they can be used as indicator for the expected temperature level. Compared to the previously described measurements of DSF projects, the determined temperatures with this approach seem to be lower.

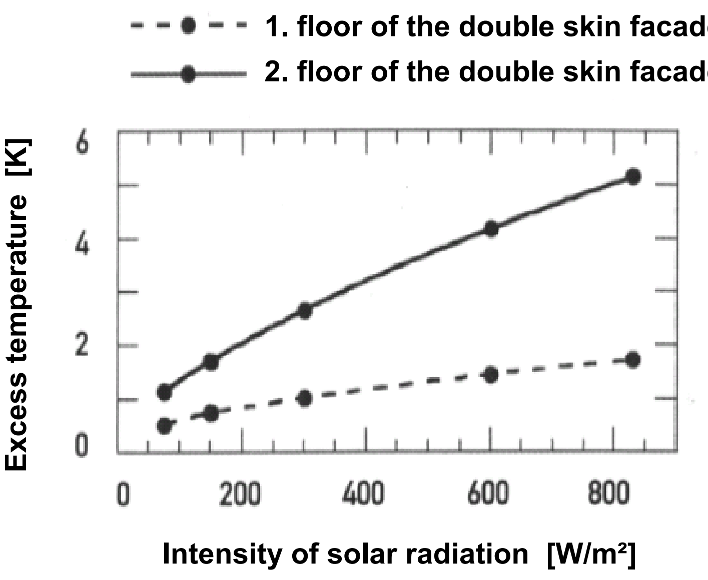

Figure 1: Calculated average excess temperature in a double skin façade dependent on the intensity of solar radiation with an absorption rate at the façade surface of 0.5.

References

Ziller, C.: Modellversuche und Berechnungen zur Optimierung der natürlichen Berechnung durch Doppelfassaden. Dissertation, 1999, RWTH Aachen, Germany

3.8 Summary of the measurement analysis (Erhorn)

The existing experimental studies on DSF are rather limted and concentrated on natural ventilated constructions under middle European climate conditions. In most of the studies typical climate situations in different seasons have been analysed. Only some studies include full year measurement periods. The available information has been analysed in the previous chapter. The focus of the analyses was on the mean monthly temperatures and air change rates in the gap of existing DSF, and not on the minimum or maximum values under extreme conditions or on dimensioning issues like different inlet and outlet areas.

In the table below the condensed mean monthly results are presented. The compiled excess temperatures and air change rates represent the mean conditions in the gap during the analysed periods; the value in brackets give the deviations of the mean values in the analysed seasons/months.

The analyses show that there is a huge difference if the dampers of the DSF are open or closed. The monthly mean excess temperature in the open gap is around 4 K with a deviation of 2 K during the year. In the case of closed dampers in the DSF the values are approximately double as high. Note, the mean excess temperature is not the temperature difference between the outlet temperature of the DSF and the outside temperature, but the mean temperature difference between the gap and the outside air. As simplified approach the outlet temperature can be estimated as the inlet temperature plus 2 times the excess temperature.

The differences at the air change rates are much higher. With closed gaps the mean air change rate was estimated to be 4 h^{-1} with a deviation of 4 h^{-1}. These mean values rise up to 25 h^{-1} when the gap is open.

Project	Country	Excess temperature		Air change rates or air velocity	
		Open gap (damper)	Closed gap	Open gap (damper)	Closed gap
BiSop	Austria	4 K (± 1 K)	3 K (± 1 K)	0,28 m/s (± 0,05 m/s)	0,13 m/s
VERU	Germany	4 K (± 1 K)	10 K (± 2 K)	20 h^{-1} (± 5 h^{-1})	1 h^{-1} (± 1 h^{-1})
Postcheque	Belgium	3 K (± 1 K)	-	8 h^{-1}	-
Vliet Test	Belgium	3 K (± 2 K)	7 K (± 2 K)	1,8 m/s	-
Aula Magna	Belgium	7 K (± 3 K)	10 K (± 5 K)	25 h^{-1}(± 10 h^{-1})$^{\#}$	7 h^{-1}(± 3 h^{-1})$^{\#}$
Estimated average and typical ranges		4 K (± 2 K)	8 K (± 4 K)	25 h^{-1}(± 10 h^{-1})	4 h^{-1}(± 4 h^{-1})

Table 1: Measured mean monthly excess temperatures and air change rates and their estimated deviation during the seasons for natural ventilated DSF constructions under middle European climate conditions. ($^{\#}$ this values are estimated by the author from measured air velocities in the case study)

The results are reflecting well the findings in the study VERU. The proposed procedure from the DIN V 18599 can be used in general, but the chosen default values have to be adapted.

4 Simplified approaches for the estimation of ventilation rates in double skin façade constructions

The analysis in chapter 2 has shown that the BESTFACADE approach should be applied in EN/ISO 13790 in the way as done in DIN V 18599, but extended to different kinds of DSF systems. The unknown influence factor in this approach is the ventilation rate in the façade construction, therefore a constant default value was implemented in DIN V 18599. The analysis in chapter 3 has shown, that the chosen value for naturally ventilated constructions of 10 h^{-1} produces (under middle European climate) results of the safe side, but with a high excess rate. Therefore the value has to be adjusted to make the calculation more precise and reliable.

Within the BESTFACADE project two different ways for the estimation of ventilation rates have been deeper analysed. The first approach, developed at the Fraunhofer Institute for Building Physics, is following the philosophy of the German standard and defining a mean ventilation rate in the DSF depending on the façade control strategy. The analysis of measurements in chapter 3 allows to summarise the values in a band of practical accuracy. The second approach predicts the ventilation heat transfer coefficient of a naturally ventilated DSF construction and was developed at the University of Lund. For this approach more detailed information on the façade construction, like inlet and outlet characteristics and obstacles in the cavity, are necessary.

4.1 Rules of thumbs - Estimated default values for air change rates and excess temperatures in the façade gaps based on measurement results (Erhorn)

The analysis in chapter 3 allows to estimate default values for the air change rates and excess temperatures in naturally ventilated DSF constructions under middle European climate conditions. The values are applicable for DSF constructions, which have inlets and outlets at every storey. For multistorey facades (the distance between inlet and outlet is 2 or more stories) the values has to be adjusted to a higher range.

Façade control strategy	(Estimated) air change rate (n_{gap}) [h^{-1}]		Excess temperature in the gap (ϑ_{excess}) [K]	
	Summer (April–October)	Winter (November–March)	Summer	Winter
Open at all times	25	25	6	4
Adjustable dampers	25	4	6	8

Table 1: Estimated default values for the mean air change rate and the mean excess temperature in a naturally ventilated façade gap for the calculation of the energy performance with the simple calculation method of BESTFACADE. (Note: the estimated air change rate in the cavity based on measurements from few monitored projects).

The excess temperature represents the mean air temperature in the façade construction. The outlet temperature is higher than this mean temperature. It can be approximatively estimated as

$$\vartheta_{out} = \vartheta_e + 2 \text{ x } \vartheta_{excess}$$

where ϑ_{out}, ϑ_e and ϑ_{excess} are the outlet, exterior and excess temperatures.

4.2 Detailed approach – Approximated ventilation heat transfer coefficient of a double skin façade (Hellström)

The mean temperature ϑ_u in the (unheated) gap of a double skin façade can be calculated by using the DIN V 18599 approach, as described in chapter 2.3 according to EN ISO 13789 (using equation 8 of chapter 2.3):

$$\vartheta_u = \frac{\Phi_u + \vartheta_i(H_{T,iu} + H_{V,iu}) + \vartheta_e(H_{T,ue} + H_{V,ue})}{H_{T,iu} + H_{V,iu} + H_{T,ue} + H_{V,ue}} \quad (1)$$

where ϑ_i and ϑ_e are the monthly average inside and outside temperatures, $H_{T,iu}$ and $H_{T,ue}$ are the transmission heat transfer coefficients between the cavity and the inside and the outside, Φ_u is the useful gained energy (solar and internal) in the cavity and $H_{V,ue}$ is the ventilation heat transfer coefficient.

The objective of this chapter of the report is to give an approximate expression for $H_{V,ue}$, which could be used to solve Eq. 1 for ϑ_u. In the following approximation it is assumed that the ventilation heat transfer coefficient between inside and façade, $H_{V,iu}$, is zero, which means that no heat transfer between the room and the façade via ventilation is foreseen.

The ventilation heat transfer coefficient, $H_{V,ue}$, can for steady state conditions be expressed as:

$$H_{V,ue} = h_v * (abs(\vartheta_u - \vartheta_e))^{0.5} \quad (2a)$$

where

$$h_v = (2 * g * H_{cav} / (T_e * \xi_{tot}))^{0.5} * \rho_u * C_p * \Delta\vartheta_{rel} * A_{cav} \quad (2b)$$

and

$$\Delta\vartheta_{rel} = (\vartheta_{out} - \vartheta_e) / (\vartheta_u - \vartheta_e) \quad (2c)$$

This relation is derived in Appendix I at the end of this chapter. The total pressure loss coefficient, ξ_{tot}, is calculated according to ISO 15099, which is shown in Appendix II at the end of this chapter.

On the assumption that $\vartheta_u - \vartheta_e > 0$, (which occurs for $H_{T,iu} * (\vartheta_i - \vartheta_e) + \Phi_u > 0$), Eq. 1 and 2 give for steady state conditions:

$$h_v * (\vartheta_u - \vartheta_e)^{1.5} + (H_{T,iu} + H_{T,ue}) * (\vartheta_u - \vartheta_e) - (H_{T,iu} * (\vartheta_i - \vartheta_e) + \Phi_u) = 0 \quad (3)$$

Relations for steady state conditions, which are approximately valid for hourly values, cannot be directly applied for monthly average values. This is because $\frac{1}{N}\sum_{n=1}^{N}(X_n)^m$ does not equal

$(\frac{1}{N}\sum_{n=1}^{N} X_n)^m$, where N is the number of hours in a month, unless X is a constant or m = 1.

Neither does $\frac{1}{N}\sum_{n=1}^{N}(A_n B_n)$ equal $(\frac{1}{N}\sum_{n=1}^{N} A_n)(\frac{1}{N}\sum_{n=1}^{N} B_n)$, unless A or B is a constant.

The relative variation of the variables in the expression for h_v in Eq. 2b is small during a month and a monthly average of h_v could therefore be calculated from the monthly average variable values. On the other hand, $\frac{1}{N}\sum_{n=1}^{N}(T_g - T_a)_n^{1.5}$ does not equal $(\frac{1}{N}\sum_{n=1}^{N}(T_g - T_a)_n)^{1.5}$, which would be required for directly using Eq. 3 with monthly average values. However, if a correlation of the ratio between the two monthly quantities could be found, h_v could be multiplied by this expression and Eq. 3 could be used.

To obtain values for the relation between the two variables, ParaSol simulations were performed for different kind of double skin façades and different climates. To allow also for negative numbers of $(\vartheta_u - \vartheta_e)$, $(\vartheta_u - \vartheta_e)^{1.5}$ was replaced by $(\vartheta_u - \vartheta_e) * (abs(\vartheta_u - \vartheta_e))^{0.5}$. Factors, f, between 1.0 and 1.9 were then obtained. A chosen value of f = 1.33 has a maximum relative error of approximately 21 % for $(\vartheta_u - \vartheta_e)$ from f.

Eq. 3 with monthly average values can then be expressed:

$$h_v * (\vartheta_u - \vartheta_e)^{1.5} + (H_{T,iu} + H_{T,ue}) * (\vartheta_u - \vartheta_e) - (H_{T,iu} * (\vartheta_i - \vartheta_e) + \Phi_u) = 0 \qquad (4a)$$

where

$$h_v = f * \rho_u * C_p * \Delta\vartheta_{rel} * A * (2 * g * H_{cav} / (\vartheta_e * \xi_{tot}))^{0.5} \qquad (4b)$$

The values of Φ and $\Delta\vartheta_{rel}$ are given according to the DIN approach. ρ_g can be approximated as ρ for ϑ_e, where ϑ_e is the monthly average ambient temperature.

Solving Eq. 4 for $(\vartheta_u - \vartheta_e)$ gives:

$$(\vartheta_u - \vartheta_e) = ((y + z)^{1/3} - (y - z)^{1/3} - b / (3*a))^2 \qquad (5)$$

where

$a = f * h_v$	$b = (H_{T,iu} + H_{T,ue})$	$c = (H_{T,iu} * (\vartheta_i - \vartheta_e) + \Phi_u)$
$x = b^2 / (9 * a^2)$	$y = c / (2 * a) - b^3 / (27 * a^3)$	$z = (y^2 - x^3)^{1/2}$

h_v is obtained from Eq. 4b, where f = 1.33 and $\Delta\vartheta_{rel} = (\vartheta_{out} - \vartheta_e) / (\vartheta_u - \vartheta_e)$ is given according to the DIN model.

Simplified solution for the ventilation heat transfer coefficient, the cavity temperature and the airflow.

Comparing two of the expression in Eq. 4, $h_v*(\vartheta_u - \vartheta_e)^{1.5}$ and $(H_{T,iu} + H_{T,ue})*(\vartheta_u - \vartheta_e)$, the former is much larger than the latter for normal operating conditions of a ventilated double skin façade. A simplification can therefore be made by exchanging $(H_{T,iu} + H_{T,ue})*(\vartheta_u - \vartheta_e)$ for $(H_{T,iu} + H_{T,ue})*(\vartheta_u - \vartheta_e)^{1.5}/ dT^{0.5}$, where dT = 2 K or a guessed value of $(\vartheta_u - \vartheta_e)$. The equation can then be written:

$$\vartheta_u - \vartheta_e = ((H_{T,iu} * (\vartheta_i - \vartheta_e) + \Phi_u) / (h_v + (H_{T,iu} + H_{T,ue}) / dT^{\,0.5}))^{(2/3)} \quad (6a)$$

where

$$h_v = f * \rho_u * C_p * \Delta\vartheta_{rel} * A_u * (2 * g * H_{cav} / (\vartheta_e * \xi_{tot}))^{0.5} \quad (6b)$$

The ventilation heat transfer coefficient, $H_{V,ue}$, is then:

$$H_{V,ue} = h_v * ((H_{T,iu} * (\vartheta_i - \vartheta_e) + \Phi_u) / (h_v + (H_{T,iu} + H_{T,ue}) / dT^{\,0.5}))^{(1/3)} \quad (6c)$$

The effective mean volume flow rate, V, and air velocity, w, in the cavity can be obtained from:

$$V = H_{V,ue} / (\rho_u * C_p * \Delta\vartheta_{rel}) \quad (6d)$$

$$w = V / A \quad (6e)$$

The following approximate values of some of the parameters can be used:

$f = 1.33$, $\rho_u = 1.2$ kg/m^3, $C_p = 1006$ J/kgK, $g = 9.81$ m/s^2, $T_e = 293$ K, $dT = 2$ K.

ξ_{tot} is calculated according to Appendix II at the end of this chapter. $\Delta\vartheta_{rel} = (\vartheta_{out} - \vartheta_e) / (\vartheta_u - \vartheta_e)$ can be given according to the DIN model, which means $\Delta\vartheta_{rel} = 2$. From simulations of some realistic cases, using models of ISO 15099, $\Delta\vartheta_{rel}$ values of around 1.8 were achieved. The values depend however on the flow conditions.

Conclusions

Simplified expressions for the monthly values of the average air temperature, ϑ_u, the ventilation heat transfer coefficient, $H_{V,ue}$, and the airflow rates in the double façade cavity are given by Eq. 6a-e. ϑ_u can also be obtained by inserting the value of $H_{V,ue}$ into Eq. 1. For poorly ventilated DSFs, ϑ_u has to be solved through an iteration process, using $dT = \vartheta_u - \vartheta_e$ in Eq. 6a, or by using Eq. 5.

Appendix I: Derivation of Equation 2

The driving pressure difference between the cavity and the outside air, caused by thermal forces, can for steady state conditions be expressed:

$$\Delta P_{drive} = abs(\rho_u - \rho_e) * g * H_{cav} \approx abs(\vartheta_u - \vartheta_e) / T_e * \rho_u * g * H_{cav} \quad (A1)$$

while the total pressure losses can be written:

$$\Delta P_{loss} = \xi_{tot} * \rho_u * w^2 / 2 \quad (A2)$$

Putting $\Delta P_{drive} = \Delta P_{loss}$ gives the absolute air speed in the cavity, w:

$$w = (2 * g * H_{cav} * abs(\vartheta_u - \vartheta_e) / (T_e * \xi_{tot}))^{1/2} \quad (A3)$$

The absolute volume flow rate of the cavity, V, is then:

$V = w * A_{cav} = (2 * g * H_{cav} * abs(\vartheta_u - \vartheta_e) / (T_e * \xi_{tot}))^{1/2} * A_{cav}$ (A4)

The absolute ventilation energy flow rate per unit length from the cavity, Q_v, can then be written:

$Q_v = V * \rho_u * C_p * abs(\vartheta_u - \vartheta_e) * (\vartheta_{out} - \vartheta_e) / (\vartheta_u - \vartheta_e)$ (A5)

which, as $Q_v = H_{V,ue} * (\vartheta_u - \vartheta_e)$, gives

$H_{V,ue} = h_v * (abs(\vartheta_u - \vartheta_e))^{0.5}$ (A6a)

where

$h_v = (2 * g * H_{cav} / (T_e * \xi_{tot}))^{0.5} * \rho_u * C_p * \Delta\vartheta_{rel} * A_{cav}$ (A6b)

and

$\Delta\vartheta_{rel} = (\vartheta_{out} - \vartheta_e) / (\vartheta_u - \vartheta_e)$ (A6c)

Eq. A6a-c equals Eq. 2a-c.

Appendix II: Calculation of the total pressure loss coefficient, ξ_{tot}

The total pressure loss coefficient can be calculated according to ISO 15099:

$\xi_{tot} = 1 + \xi_{in} + \xi_{out} + \xi_{extra}$ (A7a)

where

$\xi_{in} = (A_{cav} / (0.6 * A_{in}) - 1)^2$ (A7b)

$\xi_{out} = (A_{cav} / (0.6 * A_{out}) - 1)^2$ (A7c)

ξ_{extra} = pressure loss coefficient due to obstacles within the cavity (not included in ISO 15099)

and

A_{in} is the cross section area of the inlet opening

A_{out} is the cross section area of the outlet opening

A_{cav} is the cross section area of the cavity

This value of ξ_{tot} is approximately valid for all DSF cavities, except for those with a cavity width, W_{cav} < 0.1 m, for which also the pressure loss due to friction inside the cavity should be considered. A double skin façade with W_{cav} = 0.1 m, H_{cav} = 10 m and without a solar shading device in the cavity, was investigated with the software ParaSol. Neglecting friction losses was for this case giving an overestimation of $(\vartheta_u - \vartheta_e)$ of around 5 % in the summer and 7 % in the winter. The error drops rapidly with increasing values of W_{cav}.

If a solar shading device is used in the cavity, Eq. A7 should for similar reason not be used if W_{cav}< 0.2 m. For the case that the inlet and outlet opening widths are much smaller than the cavity width, $W_{in} << W_{cav}$ or $W_{out} << W_{cav}$, there are no restrictions for the use of Eq. A7. It is here assumed that $A_{cav}/A_{in} = W_{cav}/W_{in}$ and $A_{cav}/A_{out} = W_{cav}/W_{out}$.

The total pressure loss is obtained with Eq. A2.

Nomenclature:

A = area (m^2)
C_p = specific heat capacity ($Jkg^{-1}K^{-1}$)
f = factor (-)
g = acceleration of gravity (ms^{-2})
H = heat transfer coefficient (WK^{-1}), height (m)
h_v = coefficient ($WK^{-1.5}$)

P = pressure (Pa)
Q = heat flow rate (W)
T = temperature (K)
V = ventilation flow rate (m^3s^{-1})
w = air speed (ms^{-1})
W = width or depth (m)

Greek:
Φ = heat flow rate (W)
ξ = pressure loss coefficient (-)
ρ = density (kgm^{-3})
ϑ = temperature (°C)

Subscripts:
cav = cavity
e = external
i = internal
in = inlet
out = outlet
rel = relative
tot = total
T = transmission
u = cavity air (unheated space)
v, V = ventilation

5 The simple calculation method developed in the BESTFACADE project (Erhorn)

The BESTFACADE method is based on the CEN conform philosphy of the DIN V 18599. The herein developed holistic approach uses the monthly based balancing method according to EN/ISO 13790 for the calculation of the net energy demand for heating and cooling of a zone in combination with the method for lighting energy estimation according to EN 15193-1. In the method a continous procedure for calculating the impact of DSF constructions on the overall energy demand of buildings is applied. The method is based on the following main elements:

Energy need for heating (according to chapter 2.1.1)
For each building zone, the energy need for space heating for each calculation period (month or season) is calculated according to:

$$Q_{H,nd} = Q_{H,nd,cont} = Q_{H,ls} - \eta_{H,gn} \cdot Q_{H,gn} \tag{1}$$

Energy need for cooling (according to chapter 2.1.1)
For each building zone, the energy need for space cooling for each calculation period (month or season) is calculated according to:

$$Q_{C,nd} = Q_{C,nd,cont} = Q_{C,gn} - \eta_{C,ls} \cdot Q_{C,ls} \tag{2}$$

Energy need for lighting
For each building zone, the energy need for lighting for each calculation period (month or season) is calculated according to:

$$W_{L,t} = \Sigma\{ (P_n \times F_c) \times \{(t_D \times F_o \times F_D) + (t_n \times F_o)\} \tag{3}$$

Impact of the DSF construction
The DSF construction has influences on the terms $Q_{H,ls}$, $Q_{C,ls}$, $Q_{H,gn}$, $Q_{C,gn}$ and on the daylight supply factor F_D via the following indicators:

$Q_{H,ls}$, $Q_{C,ls}$: ϑ_u the temperature in the gap of the façade construction for calculating the transmission and ventilation losses, taking in consideration the buffer effect between the room and the external environment.

$Q_{H,gn}$, $Q_{C,gn}$: $Q_{S,tr}$ solar radiation entering through transparent surfaces, taking in consideration the additional glazing between the room and the external environment

F_D : $I_{O,GDF}$ the correction factor for glazed double skin facades in front of the considered space

The three indicators can be calculated as follows:

Temperature in the gap of the façade ϑ_u
The temperature in the unheated gap can be calculated according to EN ISO 13789, using equation:

$$\vartheta_{u} = \frac{\Phi_{u} + \vartheta_{i}(H_{T,iu} + H_{V,iu}) + \vartheta_{e}(H_{T,ue} + H_{V,ue})}{H_{T,iu} + H_{V,iu} + H_{T,ue} + H_{V,ue}} \qquad (4)$$

where the only unknown term is H_V. For solving this a simplified approach for the approximation of the ventilation rate in the gap was developed in chapter 4, either as default value for typical operating modes of the façade or as more advanced formular taking into account the caracteristic of the façade construction.

Solar gains $Q_{S,tr}$

The solar gains $Q_{S,tr}$ through the transparent components of the dividing surfaces are calculated by taking into consideration the additional glazing (between the inner façade and the external environment).

$$Q_{S,tr} = F_{F,iu} A_{iu} g_{eff,iu} F_{F,ue} \tau_{e,ue} I_{S} t \qquad (5)$$

which takes into account all the characteristics of the façade layers.

Correction factor for the daylight availabilty $I_{O,GDF}$

The correction factor for glazed double skin facades in front of the considered space can be obtained by:

$$I_{O,GDF} = \tau_{GDF} * k_{GDF,1} * k_{GDF,2} * k_{GDF,3} \qquad (6)$$

where:

τ_{GDF} is the transmission factor of glazed double skin façade
$k_{GDF,1}$ is the factor accounting for frames of glazed double skin façade
$k_{GDF,2}$ is the factor accounting for dirt of glazed double skin façade
$k_{GDF,3}$ is the factor accounting for not normal light incidence on facade
Vertical and horizontal barriers within the façade gap can be approximated by specific parameters. Only the part of the glazed double skin façade projected onto the transparent main (inner) façade plane is considered in the determination of $k_{GDF,1}$.

6 IEE BESTFACADE Information Tool (Erhorn, Wössner, Duarte, Matos, Farou)

The simple calculation method developed in the BESTFACADE project is the basis for the BESTFACADE tool for the energy need and lighting autonomy in office rooms with different façade types. The simple to use tool is not thought for in detail calculative assessment but for giving first indications on the impact of different façade types on the heating, cooling and lighting energy demand. It is based on a lighting information and decision tool developed at Fraunhofer Institute of Building Physics for assessing the daylight availability and the electrical lighting demand for different façade types and was extended to heating and cooling energy demands in the participating European regions within the BESTFACADE project.

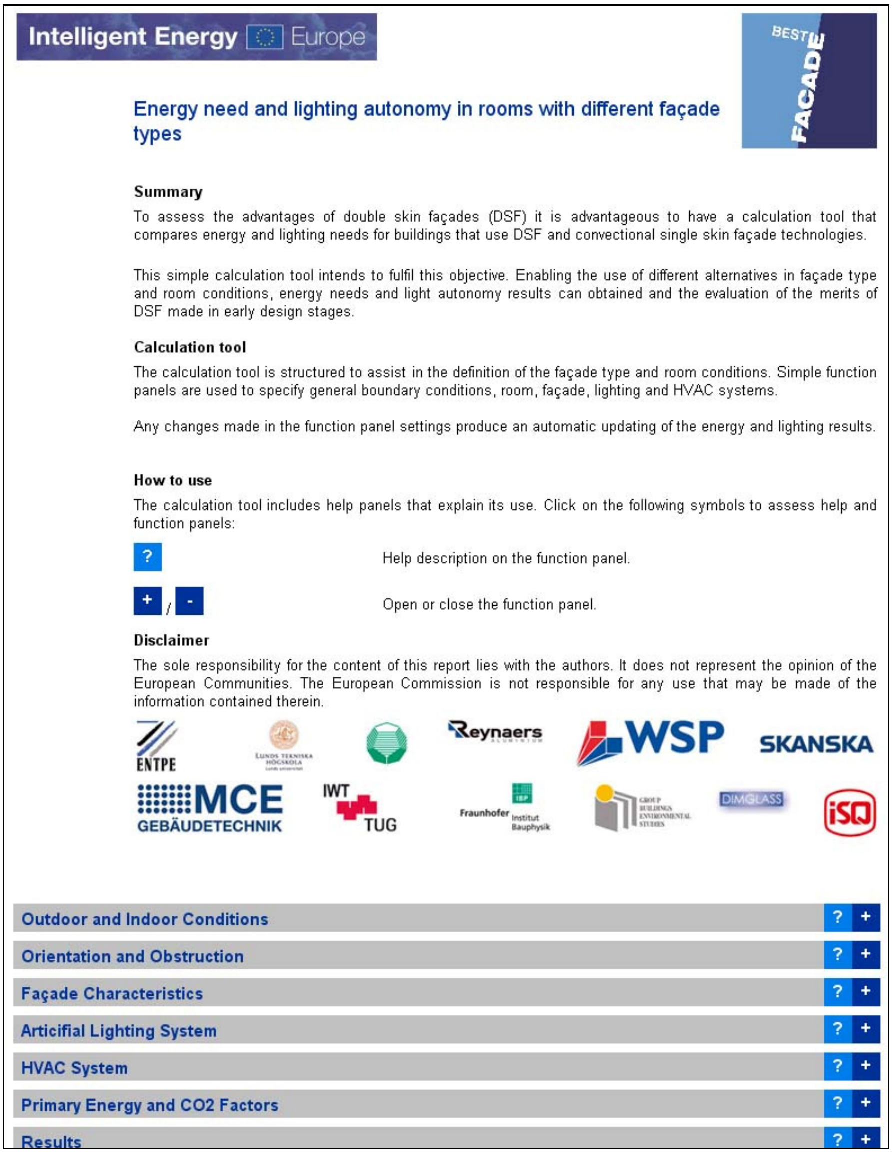

Figure 1: Screenshot of the start page of the BESTFACADE tool on the energy need and lighting autonomy in rooms with different façade types.

After choosing the European region (North, Central, South), the internal gains (standard, extended), the façade orientation and the possible linear obstruction, the user has to define the façade characteristics. This includes the façade types (single façade, double skin façade naturally ventilated and double skin façade mechanically ventilated), different types of glazings, different window wall ratios and various shading systems. The next step is the choice of the artificial lighting system (direct, indirect or direct/indirect, task lighting) and the lighting control (manual, daylight dependent, dimming, independent control near and far from the window). The offered HVAC systems include district heating with radiators or fan coils, mechanical or natural ventilation only and district cooling with fan coils or with cooling ceiling.

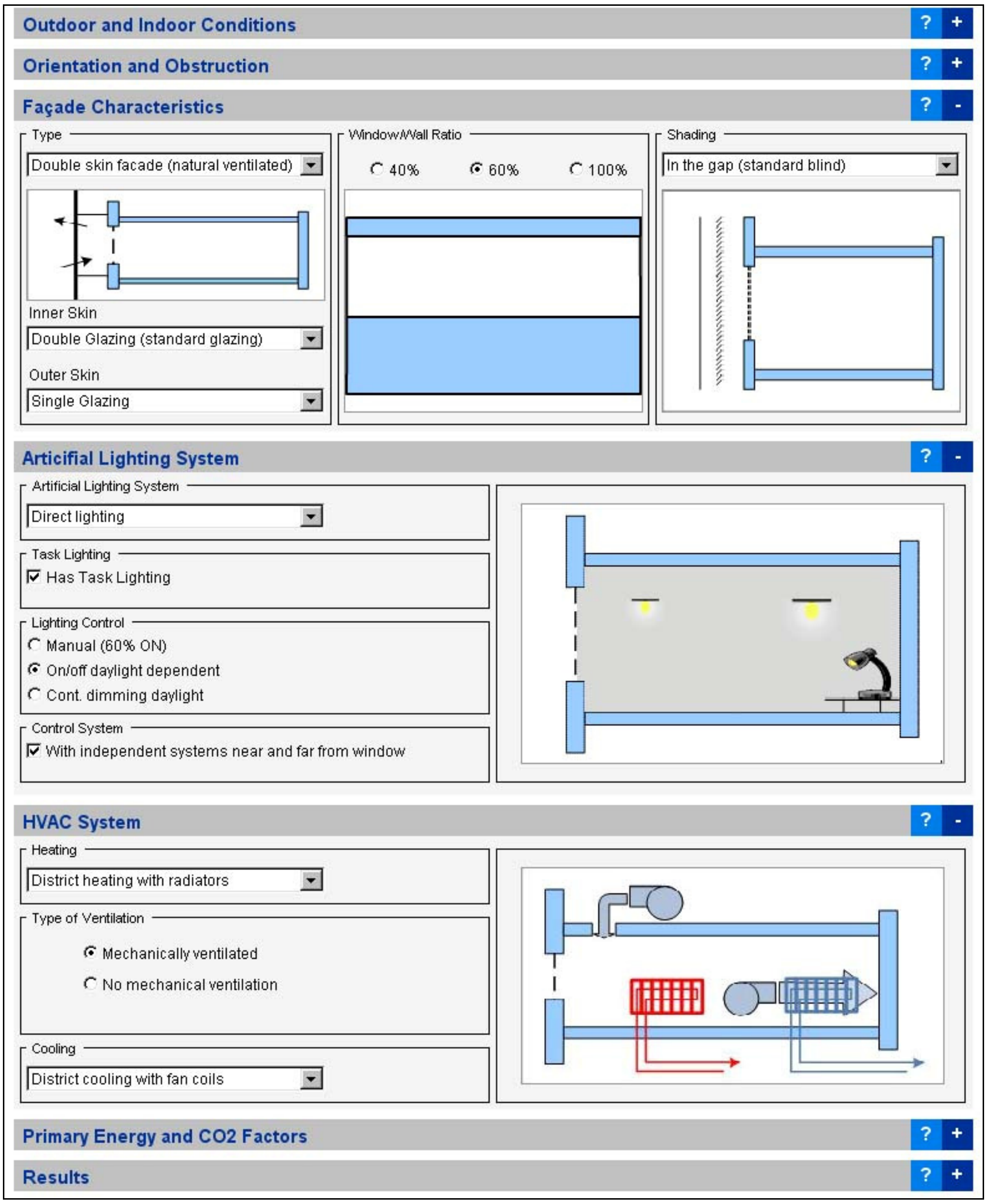

Figure 2: Screenshot of the BESTFACADE tool part definition of facades, lighting and HVAC systems.

The results given are based on the simple calculation method developed within the BESTFACADE project and include net energy, final energy and primary energy demands for heating, cooling, lighting, ventilation and appliances as well as the CO_2 emissions. The lighting results are further elaborated by giving the relative annual luminuous efficiency at each point of the room plus the minimum and the maximum and the daylight autonomy of the office.

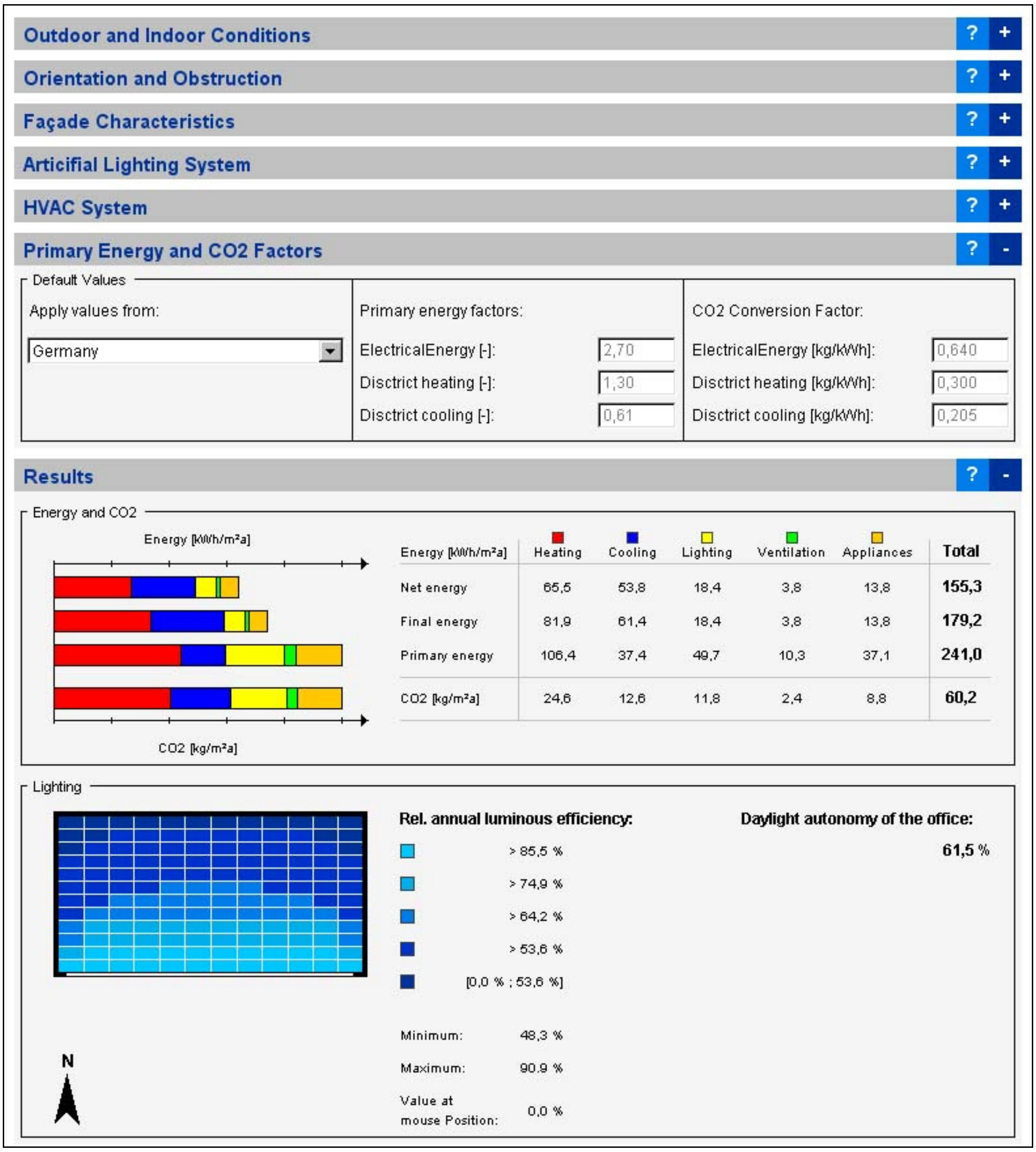

Figure 3: Screenshot of the BESTFACADE tool part definition of the primary energy and CO_2 factors and results for energy, CO_2 and luminous efficiency and daylight autonomy.

References

Duarte, R. et alii: BESTFACADE WP4 “Energy Design Guide” – Documentation. Internal working document.

7 Validation projects (Guarracino, Flamant, Hellström, Schiefer, Sinnesbichler)

Within the BESTFACADE project several validation calculations have been made. The results are collected in the BESTFACADE validation report (internal document). Besides the validation of the developed simple energy performance calculation method the work has been used to check the applicabilty of several commercial software products on the measured DSF constructions of several case studies.

References

Guarracino, G.: BESTFACADE WP4 "Validation Report". Internal working document.

8 Summary

The EU IEE BESTFACADE project has analysed various approaches for the energy performance assessment of double skin facades. The analysis made evident, that the BESTFACADE approach should be applied in EN ISO 13790 in the way as done in DIN V 18599, but extended to different kinds of DSF systems. The major influence factor, the air change rate, was approximated for different façade types and temperatures based on measured data. The simplified assessment method was validated with simulation tools and applied at an internet based simple to use energy design guide for buildings with different façade systems. This energy design guide is primarily intended to be used during the early planning stage of a building.

9 References

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