

CONDENSATION IN A CLOSED CAVITY DOUBLE SKIN FAÇADE: A MODEL FOR RISK ASSESSMENT

J. Laverge¹, S. Schouwenaars², M. Steeman³, A. Janssens⁴, N. Van Den Bossche⁵

- 1 Ghent University, Ghent, Belgium.
jelle.laverge@ugent.be *Corresponding author*
- 2 Scheldebouw, Middelburg, The Netherlands
sschouwenaars@scheldebouw.com
- 3 Ghent University, Ghent, Belgium
marijke.steeman@ugent.be
- 4 PhD, Ghent University, Ghent Belgium
arnold.janssens@ugent.be
- 5 Ghent University, Ghent, Belgium
nathan.vandenbossche@ugent.be

ABSTRACT

Double skin façades are a popular feature in office buildings worldwide, because of their aesthetic, thermal and acoustical properties. This paper discusses a dynamic model that allows the designer of such a façade to assess the risk for condensation in the enclosed cavity between the panes of the façade. Prediction of this risk is crucial because of the associated need for cleaning and accessibility of the cavity. First, the assumptions made for the thermal, airflow and hygric behaviour within the cavity are discussed. Next, the results rendered by the model are compared to those obtained in a full scale test setup. The good agreement demonstrated when hygroscopic behaviour is included yields the conclusion that this model is a powerful tool to describe the hygro-thermal behaviour of the cavity in a double skin façade and stresses the importance of including non-isothermal moisture buffering behaviour in the such a model.

1. INTRODUCTION

For highrise office buildings, double skin façades offer a attractive alternative in building envelope conception. In office building architecture, glass envelopes have gained popularity since the rise of modernism, even in cold climates. Traditional glass facades however, have a number of implicit disadvantages. The most relevant in this context include poor thermal insulation properties for winter conditions and high overheating risks, even in extremely cold climates, in sunny conditions. In noisy environments, poor acoustic insulation can

also be an important drawback. Double skin facades combine the aesthetic value of a fully glazed envelope with good thermal and acoustic performance. Furthermore, they protect shading devices, mounted in the cavity between exterior and interior glazing, from wind gusts. This allows to operate the shading even in windy conditions and thus protect the building better against overheating. Lots of possible configurations of doubles skin façades and their properties have been discussed in literature [1,2,3] along with models to simulate their behaviour. A distinction can be made according to the ventilation scheme of the cavity or according

to the placing of the insulating glass unit (IGU). Each of the configurations has its own specific (dis)advantages. To prevent excessive heat gains towards the interior of the building, for example, the IGU is often placed at the interior side of the facade element. A recurrent problem in these double skin facade concepts with single outdoor and double indoor glazing is condensation on the cavity side of the single glass pane. This phenomenon is caused by under cooling of the outer single glass pane due to long wave radiation or the leakage of humid air from the indoor environment into the cavity.

Permasteelisa Group developed an innovative concept, with a fully sealed cavity and a very modest dry air flow (“closed cavity facade”), aimed at preventing condensation within the cavity at all times. Because of this dirt offset on the window panes can be prevented and the need for cleaning inside the cavity can be eliminated over the lifetime of the facade. This reduces operational costs of such systems considerably. Additionally, since operable window parts are far more complex and expensive than closed elements, avoiding these can be economically interesting. Moreover, operable parts are far less airtight, thus increasing energy losses through the envelope, with obvious economical consequences. Results from a concept test performed by Ehrmann [4] have demonstrated that the proposed approach is effective to prevent condensation on the outer glazing. However, an appropriate tool is needed to assess the performance of such a facade element during the design process for a specific project and to determine the appropriate airtightness and dry air properties for the specific boundary conditions to which the facade element will be subjected.

In this paper, a model for condensation risk assessment in double skin facades is presented, along with the results from two measurement campaigns that were used to validate the model. Unlike most models (eg. Jiru [5] and Da Silva [6]) that focus on the energy balance, this model focuses on the

prediction of the hygro-thermal conditions in the double skin facade cavity. The model couples building energy simulation (BES), multizone airflow and heat-air-moisture (HAM) models to describe these conditions. The model is designed for use with different facade configurations and under any cold, moderate or warm climate condition. The model is implemented in a tool, used in the design of the pressurized curtain wall units for the quantification of the required element air tightness and optimal sizing of the compressed air system.

Special attention is given to the hygroscopic behaviour of materials enclosed in the cavity of a double skin facade element. Although virtually no hygroscopic material can be found in a cavity, the rather extreme conditions cause it to react in a rather counterintuitive manner. The validation of the model with measurements allow to demonstrate that non-isothermal hygroscopic behaviour will have a large influence on the hygro-thermal conditions in the cavity and stress the importance of including detailed HAM modelling to produce accurate results.

2. MODELING ASSUMPTIONS

The most fundamental assumption made in conceiving the model that is presented in this paper, is that the hygrothermal conditions inside the cavity of a double skin facade module can be modeled with sufficient accuracy with a multizone model. Although computational fluid dynamics (CFD) simulations will allow for the prediction of local effects, the calculation cost that is associated with this kind of simulation renders it impractical for the use in early stages of facade design.

When the multizone assumption is accepted, two balances have to be solved that will determine, on the one hand, the temperatures of the different elements of the facade and, on the other, the moisture content of the facade module. The latter will be influenced by infiltration due to leakage of the module, by

the supply of dry air to the module that is specific for the closed cavity façade concept, and by moisture buffering effects. Therefore, three different components have to be coupled to obtain a satisfactory model: a thermal model, an airflow model and a buffer model.

2.1 Thermal model

To model the behaviour that will govern the thermal conditions within the façade element, the multi zone building component of the commercial BES software package TRNsys [7] was used. This software package was chosen because of the easy integration it offers between different building services and building envelope components, allowing for the extension of the model to more integrated building service applications. As was explained in the introduction, the model presented is aimed at predicting the hygro-thermal conditions within the cavity and the risk for condensation on the outer single glass pane more specifically. Since the central pane

it is not relevant for the scope of the model presented here.

The temperature in the cavity will be governed to a large extent by the presence of the shading device or blind. To model the radiation exchange between the blind in the cavity and both glazing units as accurately as possible, the cavity was split in two separate zones. Because of the starttemperature[7] assumption within TRNsys, this will reduce the accuracy of the temperature prediction when the blind is up in sunny conditions, since radiation exchange between glass panes is underestimated. However, in practice, the blind is always radiation controlled. These conditions therefore fall outside the normal operational range of the cavity. In Figure 1., the differences between the heat transfer as it is implemented in the model (b) and a more accurate description of the heat transfer in the more detailed static model WINDOW [8] (a), developed by Lawrence Berkeley Laboratory in the US and the basis for the window module in TRNsys, are shown for both the

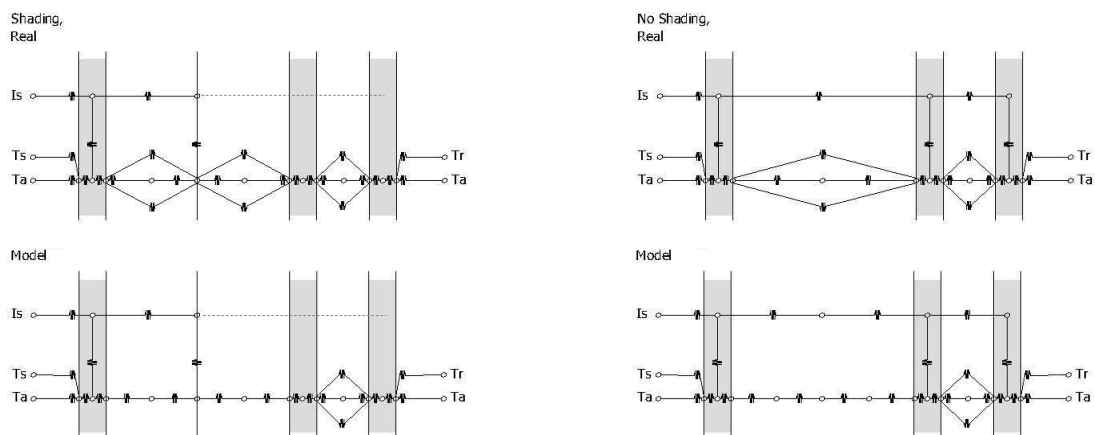


Figure 1. Schematic representation of the heat transfer in WINDOW (a, above) and in the presented model (b, below)

temperature of the outdoor glazing will, due to thermal bridge effects of the frames, be the coldest point of the cavity boundary and thus determine the condensation risk, only the glass panes of the cavity were modeled. The detailed simulation of the heat flux through the frames and the 2D effects associated with

situation where the blind is up and that where the blind is down.

2.2 Airflow model

The changes in moisture content of the cavity due to airflows are modeled with the

multizone airflow model COMIS [9]. A plug-in module for TRNsys is available to couple this model with the thermal model. The thermal and airflow model can also be integrated into a single TRNsys component, named TRNflow [7]. The two thermal zones that were used in the thermal model are replaced with one single zone node in the airflow model. The air temperature is therefore assumed to be the same in both halves of the cavity. This can be considered realistic due to air rotation effect around the blind in the cavity. This single cavity node has 2 connections to the outside environment and 2 to an internal zone node. Additionally, a fixed volume flow of dry air is introduced. Each connection is modelled as a crack, one at the bottom and one at the top of both the outer and inner glazing unit respectively. By introducing these cracks at different heights, air flows due to thermal buoyancy effects can be modeled. The value for the upper and lower crack of each of the glazing units is assumed to be equal. By situating these cracks at the top and bottom of the façade module, the thermal stack height, that is the driving force for buoyancy effects in the cavity, is at its maximum value. Since most leakage in window frames is situated at the corners of the frames, this is a rather realistic assumption. As was discussed above, temperatures in the cavity can be very high. This effect will influence the airflow in the cavity, especially because the pressurization flow is very small. The latter is very small indeed: the pressurization flow is, depending on the design parameters, from 1/3 up to one order of magnitude smaller than the leakage coefficient of the cavity. The pressurization introduced by this flow is therefore as small as 0.01 to 0.1 Pa. The time needed to reach a vapour pressure at 2/3 of the original difference between cavity and dry air vapour pressure, when no other flow pattern than pressurization with this flow interferes, (the cavity ‘time constant’) is larger than 20h.

Two different approaches to simulate the influence of wind were implemented. In the

first approach, only standard climatic data such as wind direction and wind velocity are available. In this case, the wind pressure on the facade element is calculated by using wind pressure coefficients (C_p). These coefficients describe the correlation between the local wind pressure, calculated from the meteorological wind pressure, and the pressure on the facade in a non-dimensional way. This approach will mostly be useful in rather simple geometries. For these cases, the wind pressure coefficients can easily be found in literature or calculated with CPCALC [10]. However, high frequency fluctuations that typically appear on building facades cannot be simulated this way. Therefore, a second approach was implemented where the absolute pressure difference over the facade element can be introduced directly in the model.

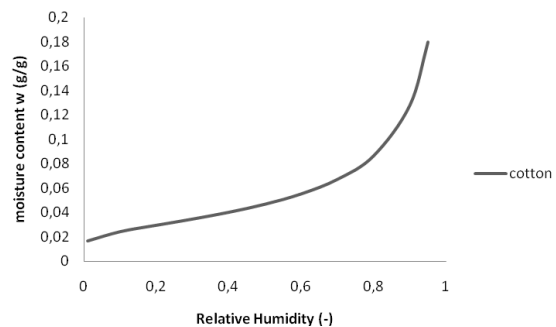


Figure 2. Sorption isotherm for cotton

2.3 Moisture model

Very little hygroscopic material can be found in the cavity of a double skin façade. Both frames and glass are non-hygroscopic and the blind is usually a woven metal and only a very thin layer. Therefore it would be a logical assumption that hygroscopic buffering can be neglected or at least be modeled with a simplified model such as a lumped capacitance or an effective moisture penetration depth (EMPD) model that are available in TRNsys. The lumped capacitance model magnifies the moisture content of the air volume of the cavity with an amount corresponding to the buffer capacity of the

available hygroscopic material, while the EMPD model concentrates all buffering capacity of the hygroscopic material in a single control node that is in equilibrium with the air node and a second ‘deep’ node that is in equilibrium with this buffer node. These models, however, all use linear isothermal material properties. As can be seen in figure 2., the sorption curve of hygroscopic material is more or less linear in the moderate relative humidity range. When the boundary conditions remain within this range, a linear approximation of the moisture content can be assumed. At the extremes, however, the curve deviates rather drastically from this linear approximation. The sorption curve shown in figure 2. was measured on a cotton textile sample by Derluyn [11]. The conditions in the cavity of the double skin façade are such that large variations in temperature and relative humidity occur over the course of a day. This renders the simple models inappropriate for this context. Therefore, for comparison, a proper 1D non-isothermal moisture buffering (or HAM) model was introduced in the model to predict the influence of sorption in the cavity. This model, developed by Steeman [12], was conceived as a TRNsys plug-in and can therefore easily be integrated in the total model for the double skin façade cavity. The HAM model assumes well mixed air and uniform surface coefficients at the boundaries of the hygroscopic material. All material properties are moisture dependent. This model was validated against an analytical problem solution and with climate chamber measurements [13]. Hysteresis and latent phase change energy are not taken into account. Because of the latter, the model is not valid for situations where liquid transport in the material is the dominant transport phenomenon due to capillary condensation. Although the aim of the model that is presented is to assess condensation risk at the outdoor glazing surface, the conditions around the hygroscopic material (which is in the middle of the cavity) are never outside the hygroscopic range ($RH < 98\%$) and thus

within the applicable range of the HAM model.

3. VALIDATION MEASUREMENTS

3.1 Test setup

To validate the results obtained with the presented model, measurement data from two measurement campaigns were used. Both of these campaigns are full scale in situ tests. The first test campaign was conducted in 2006 in Gundelfingen, Germany [4], the second in 2009 in Middelburg, The Netherlands [14]. For each of these tests, 2 façade elements were built into a insulated test room. The tested elements were 3100 mm high by 910 mm wide and with a cavity depth of 150 mm. The indoor temperature of the test room is kept at a constant level with heating and cooling equipment to simulate a standard office indoor environment. Outdoor temperature, relative humidity, direct incident solar radiation, wind speed, wind direction and absolute pressure difference over the facade element were measured, along with temperature at several places on each glass pane, relative humidity and dewpoint in the cavity and temperature and relative humidity in the test room. Each of these properties was recorded every 15 minutes. Both tests were ran over several weeks. A complete description of the measurement setups has been reported by Erhorn [4] and Sneyers [14] respectively.

3.2 Model parameters

The flow coefficients for the cracks in the model are determined by a pressurization and windpressure test on the studied façade element. The pressurization test, that is conducted according to the philosophy of the EN 13829 standard [15], is used to determine the total air leakage coefficient of the façade element. The tested elements have a leakage rate at 100 Pa of $0.3 \text{ m}^3/\text{hm}^2$, which is 10 times better than the best class for airtightness of window frames according to the EN 12207 standard [16]. In Europe, in contrast to the

united states, this kind of airtightness levels is not unusual for facade elements. By measuring the pressure inside the cavity compared to that at the leeward side of the element in a windpressure test [17], the ratio of leakage between the two panes can be determined. With this ratio, the total leakage and the assumption that lower and upper cracks have equal flow coefficients, all 4 flow coefficients can be determined.

4. RESULTS

4.1 Temperature

In a first stage, the influence of the modelling approach on the temperature predictions for the different glass panes was studied by comparing the temperature results from the model to those obtained in WINDOW.

Figure 3. demonstrates the difference between the predicted temperatures of the glass panes for a number of static boundary conditions with both the model that is used and WINDOW. As was expected, the agreement is very good with a closed blind and is gradually lost with higher solar radiation incidence when the blind is up. The deviations introduced by the modelling approach in TRNsys are thus small and the results are satisfactory.

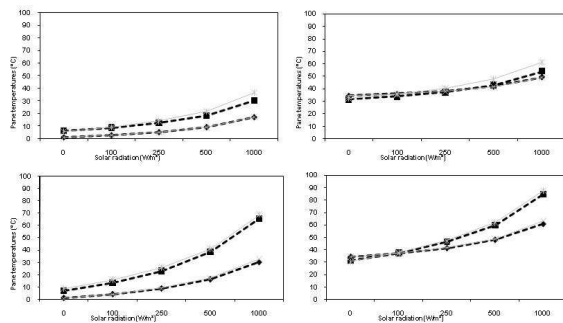


Figure 3. Temperature results from the presented model (black) and WINDOW (grey) under static boundary conditions.

Next, the measured boundary conditions from the tests were introduced in the model and the results were compared to those obtained in test

setup. In figure 3., the temperature predictions for the cavity side of both outer and inner glazing are compared with the measurement results for 5 days during the first measurement campaign. The graph shows good agreement, although the peak temperatures of the outer glazing are slightly underestimated. This is a deviation to the safe side, however, so this does not affect the applicability of the model. These deviations are most likely due to uncertainties about the radiation properties of the single glazing used in the test setup. Again, the agreement is satisfactory.

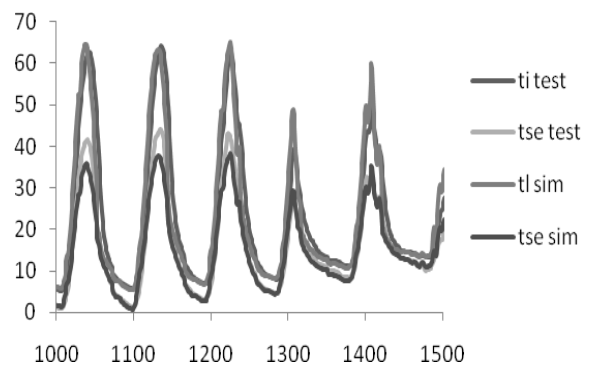


Figure 4. temperature predictions (°C) of the glass panes by the model and measured temperatures for 5 days

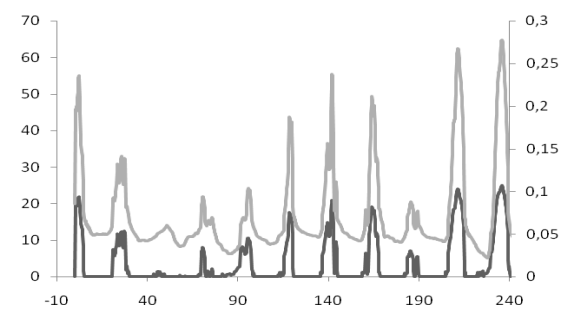


Figure 5. Airflow (dark, °C) and temperature (grey, ACH) in the cavity for 10 days of simulation

4.2 Airflow

No measurement results for the airflows between the cavity and its surroundings are available. Therefore, only modelling results can be shown in this section. Figure 4. demonstrates that with the heating of the cavity, a buoyancy effect exists that causes air

from the outdoor and indoor environment to enter the cavity, as was discussed in the modelling chapter. The cavity air temperature is also shown in the graph. The correlation between cavity overheating and outdoor air infiltration is obvious.

4.3 Moisture

The results for the relative humidity and the dewpoint temperature in the cavity for a model without buffering are shown in figure 6. In the dewpoint curve, the influence of the buoyancy flows discussed above can clearly be seen. The infiltration of outdoor air containing more moisture than the dry air in the cavity causes peaks in the dewpoint curve. Additionally, the large variations of the relative humidity, especially the very low RH values in the hot period of the day can be noticed. This confirms that the conditions in the cavity are such that the assumptions of the simplified buffer models are not valid. The detailed HAM model will be necessary to produce realistic results if any hygroscopic material is present in the cavity.

The importance of the use of an appropriate HAM model is demonstrated in figure 7., where the predicted dewpoint temperature in the cavity is displayed, as it is modelled both with the introduction of the HAM module in the model and without. When no buffering is assumed, the results display the anticipated behaviour caused by the buoyancy flow: a rise in dewpoint temperature in the cavity when the temperature in it is considerably higher than that of both inner and outdoor conditions, due to the buoyancy effect, and a slow decline back to the baseline due to the small pressurization flow. However, this does not correspond at all with the measured dewpoint, which is subject to a much more violent peak and decline. This behavior was confirmed in both of the measurement campaigns, conducted independently on different locations to exclude equipment based bias. Only with the introduction of very modest amount (saturation vapour content of 55 g/m³

of cavity) of hygroscopic material, similar results can be obtained with the simulations.

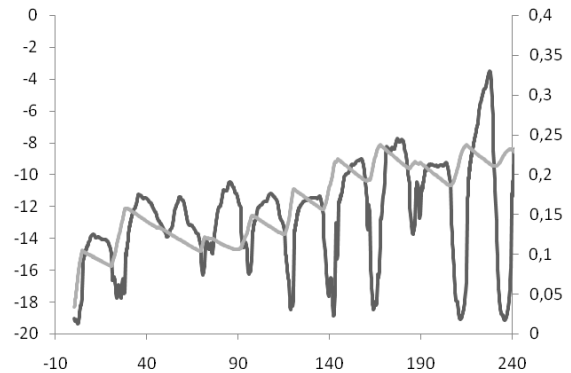


Figure 6. Relative humidity (-) and dewpoint temperature (°C) in the cavity, simulated for 10 days without buffering

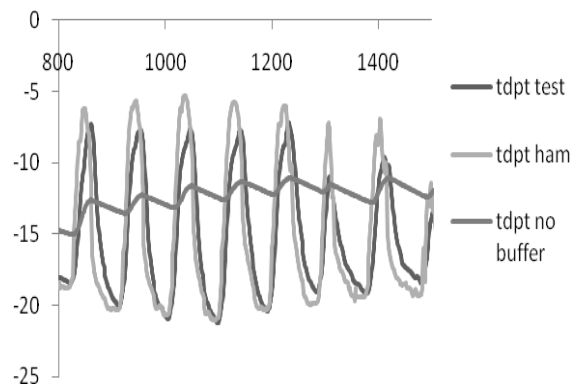


Figure 7. dewpoint temperature (°C) predictions of cavity air by the model with and without HAM module and measured dewpoint temperatures (°C) for 1 week

5 CONCLUSIONS

In this paper, a model for the prediction of the hydro-thermal conditions in a double skin façade cavity was proposed. The model is based on a multizone model and assumes well mixed air in each of the zones. A BES model is combined with an airflow model and a 1D non-isothermal HAM model. The results that are obtained with the model are compared to measurement data from two measurement campaigns and show satisfactory agreement. The presented model can be used for condensation risk assessment during the design process for double skin façade elements.

6 DISCUSSION

Although satisfactory agreement between the model results and measurement data can be found if the hygroscopic properties of the cavity are fitted – as was demonstrated in figure 7 – it is not yet clear what elements in the cavity are responsible for the observed behaviour. In a follow-up project, the hygroscopic properties of the textile of the blind will be measured, to determine whether this is the major contributor to the hygroscopic behavior of the cavity. Furthermore, the effect of the hygroscopic behavior should be studied more in detail in order to optimize the material properties of the different components enclosed in the cavity.

7 ACKNOWLEDGEMENTS

The development of the model presented in this paper was made possible by the support of Permasteelisa Group.

8 REFERENCES

- [1] Saelans, D.; Roels, S.; Hens H. (2008) "Strategies to improve the energy performance of multiple-skin facades" *Building and Environment*, vol 43 (4), pp. 638-650
- [2] Poizaris, H. (2004) *Double skin facades for office buildings: literature review* Report EBD-R—04/3, Lund University
- [3] Oesterle, E. et al. (2001) *Double skin facades: integrated planning*. ISBN 3-7913-2504-3, Germany
- [4] Ehrmann, H.; Briem, P. and Scholz, C. (2005). *Compact Wall, Conditioned Air Cavity Façade: measurement results*. R&D report, Josef Gartner GmbH, Gundelfingen, Germany.
- [5] Jiru, T.E.; Haghghat, F. (2008) "Modelling ventilated double skin facade – a zonal approach." *Energy and Buildings*, vol. 40 (8), pp. 1567-1576.
- [6] Da Silva, F.M.; Gomes, M.G. (2008) "Gap inner pressures in multi-storey double skin facades" *Energy and Buildings*, vol. 40 (8), pp. 1553-1559.
- [7] Transolar. TRNSYS software tool component, Stuttgart, Germany
- [8] Mitchell, R.; Kohler, C.; Arasteh, D. (2001) *WINDOW 5.0 users manual*, LBNL, Berkeley, US
- [9] Feustel, H. E. and Smith, B. V. (1997) *COMIS 3.0 users's guide* IEA annex 23 / LBNL, Berkeley, US.
- [9] Grosso, M. (1993) *Modelling Wind Pressure Distribution on Buildings for Passive Cooling, Proceedings of the International Conference Solar Energy in Architecture and Urban Planning*. Commission of the European Communities, pp. 17–21, Florence, Italy
- [11] Derluyn, H. (2006) *Role of Textiles and Paper for Stabilizing the Indoor Environment*, MSc thesis, Katholieke Universiteit Leuven, Leuven, Belgium
- [12] Steeman, M.; Janssens, A.; Steeman, HJ.; Van Belleghem, M.; De Paepe, M. (2010) "On coupling 1D non-isothermal heat and mass transfer in porous materials with a multizone building energy simulation model", *Building and Environment*, vol 45, pp. 865-877.
- [13] Steeman, M. (2009) *Hygrothermal Modelling for Building Energy Simulation Applications*, PhD-thesis, Ghent University, Ghent, Belgium
- [14] Sneyers, C. (2009) *Double Skin Condensation Assessment Tool: validatie aan de hand van metingen in een testbox*, masterspaper Ghent University, Ghent, Belgium. (in Dutch)
- [15] CEN. 2001. *Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method (ISO 9972:1996, modified)*, EN 13829, Brussel.
- [16] CEN. 2000. *Windows and doors. Air permeability. Classification*, EN 12207, Brussel.

- [16] CEN. 2000. *Windows and doors. Air permeability. Test method*, EN 1026, Brussel.