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[F02-03] Empirical Validation Data Sets for Double Skin Façade Models

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SUMMARY

During recent years application of double skin facades (DSF) has greatly increased. However, successful application depends heavily on reliable and validated models for simulation of the DSF performance and this in turn requires access to high quality experimental data.

Three sets of accurate empirical data for validation of DSF modeling with building simulation software were produced within the International Energy Agency (IEA) SHCTask 34 / ECBCS Annex 43. This paper describes the full-scale outdoor experimental test facility, the experimental set-up and the measurements procedure.

The empirical data is composed for key-operating modes, i.e. external air curtain mode (summer cooling), thermal insulation mode (all openings are closed) and air pre-heating mode (heating season) and consist of boundary conditions and DSF performance parameters. The DSF performance parameters discussed in the paper are the temperature gradients in the DSF cavity, the mass flow rate in the naturally ventilated cavity and the resulting heating and cooling load.

INTRODUCTION

The DSF concept carries the notion of transparency, openness and intelligence, which are highly appreciated together with the concept's advantages, if well designed, in improving the acoustics, providing daylight and being energy efficient. The design, dimensioning and application of DSF must be carried out meticulous, as insufficiencies will lead to an increased energy use (mainly for cooling) and inferior indoor climate. However, standard tools for designing conventional buildings are not sufficient for design of DSF, as this require detailed dynamic simulations.

In the literature one of the main problems reported regarding DSF modeling and simulations are the absence of experimental data (Gertis 1999, Saelens 2002). Most of the mathematical models have not been validated against empirical data and require an expert knowledge in the physics of DSF to perform the simulations. Consequently, the degree of confidence in the simulated results is rather poor. There is a lack of systematic guidelines on how to model DSF and on the most suitable tools. Most of this is caused by the lack of empirical validation.
Still, DSF solutions are being used in the building design often resulting in poor indoor climate and unnecessary energy use. It is therefore critical to expand the knowledge about dimensioning of DSF buildings and to develop and validate tools, which can assist in the optimization of the performance of DSF systems. To address the problem of lacking experimental data a series of measurements has been carried out in the outdoor, double-skin façade full-scale test facility 'the Cube'.

VENTILATION MODES

According to the literature, there exist many classification schemes for describing the DSF performance (Poirazis 2004, Loncour et al., 2004). However, focusing on the energy performance and the air flow path in the double skin façade, a DSF classification according to the ventilation principle is being used (Loncour et al., (2004):

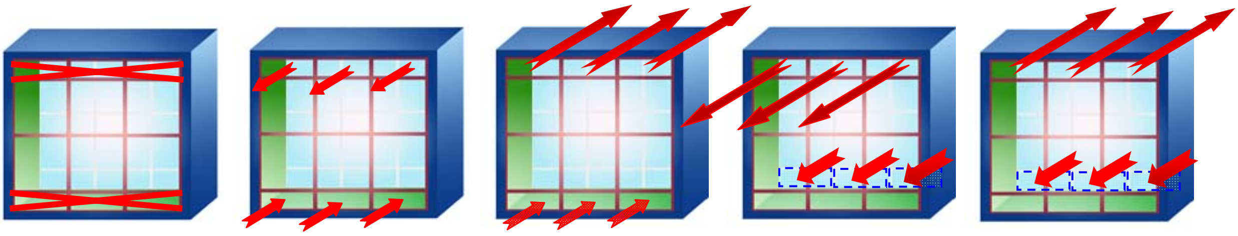


Figure 1. Classification of DSF according to ventilation principle. A- thermal insulation, B-external air curtain, C- preheating mode, D- exhaust mode, E-internal air curtain.

Due to the extremely time consuming and complex procedure involved in operating and data processing, only three ventilation modes were tested: A) Transparent insulation mode/thermal buffer, B) External air curtain mode and C) Preheating mode

MODE A: Transparent insulation mode. All the openings were closed. The principle of this mode is the same as of the conventional window. Air in the DSF cavity is heated to the temperature higher than the outside temperature, this decreases the radiant heat exchange between the internal window surface and the adjacent room.

MODE B: External air curtain mode. The external operable windows at the top and bottom of the cavity were open, the air entered the DSF at the bottom of the cavity, it was heated while passing through the DSF cavity and then, released to the external environment, carrying away some amount of the solar heat gains. The flow motion in the cavity was naturally driven.

MODE C: Preheating mode. The external operable windows at the bottom and the internal operable windows at the top of the cavity were open, the air entered the DSF at the bottom of the cavity, it was heated while passing through the DSF cavity and then, released to the internal environment, being preheated by some amount of the solar heat gains. The flow motion in the cavity was mechanically driven.

EXPERIMENTAL TEST FACILITY

'The Cube' is an outdoor test facility located at the main campus of Aalborg University. The test facility is designed to be flexible for different choice of DSF operational modes, natural or mechanical flow conditions, different types of shading devices etc. Moreover, the superior control of the thermal conditions in the room adjacent to the DSF and the opening control allow to investigate the DSF both as a part of a complete ventilation system and as a separate element of building construction. The accuracy of these measurements is justified by the quality of the facility construction: 'the Cube' is very well insulated and airtight.

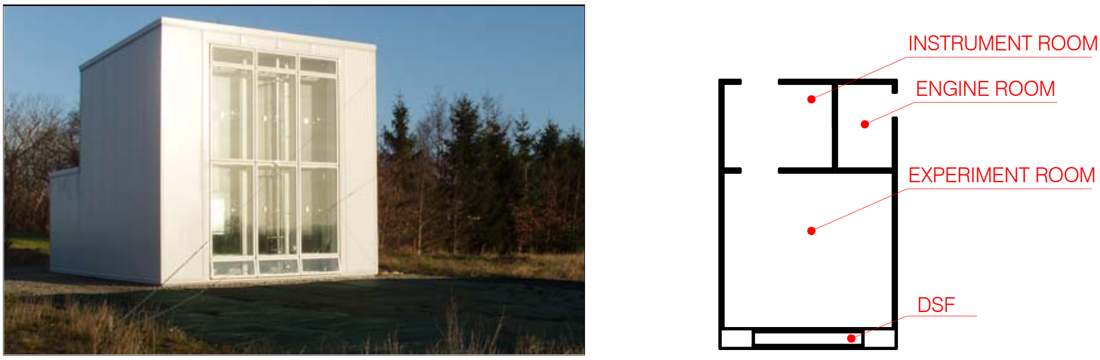


Figure 2. 'The Cube' (left). Plan of 'the Cube' (right).

‘The Cube’ consists of four domains, see Figure 2. All openings of the double skin façade are controlled and can be operated separately. The combination of openings open defines the operative strategy of the DSF, see Figure 1.

The temperature in the experiment room can be kept constant, as there is a ventilation system with heating and cooling units installed in the experiment room, see Figure 3. In order to avoid temperature gradients in the experiment room, a recirculating piston flow with an air speed of approximately 0.2 m/s is used. This resulted in typical temperature gradient of approximately 0.02°C/m and maximum of 0.1°C/m. The air intake for recirculation is at the top of the room and the air passes through the preconditioning units of the ventilation system before it is supplied at the bottom of the room through the fabric low impulse ducts. Maximum power on cooling and heating unit is 10 kW and 2 kW respectively.

Figure 3. KE-low impulse fabric ducts in the experiment room (left, centre), Ventilation system in the experiment room (right).

Knowledge of solar radiation is crucial for the task of these experiments. In non-laboratory conditions the ground reflected solar radiation depends on the surroundings and can vary a lot. For this reason, a large carpet was fixed on the ground from the side of the southern façade to achieve uniform reflection from the ground. The size of the carpet ensures a view factor between the DSF and the ground of approximately 0.5. Achieving of a reasonably higher view factor would require to double-up the carpet size. The fabric of the carpet was chosen so that it does not change reflectance property when it is wet due to its permeability and have reflectance property of apx. 0.1, close to the generally assumed reflectance property of the ground. The carpet is also seen in the Figure 2. Absorption, reflection and transmission properties of all the surfaces in the DSF, experiment room and windows were tested at the EMPA Materials Science & Technology Laboratory. This was also the case for the ground carpet. The information about the optical properties of the surfaces is available as a function of the wavelength, in the wave length interval 250-2500nm.

A number of preliminary experiments were completed for "calibration" of the test facility, improvements of measurement techniques and on best suitable positioning of equipment. The air tightness of 'the Cube' was 0.3 h^{-1} at 100 Pa. Transmission heat losses were estimated for two set points, for a temperature difference between air temperature in the test room and outdoors of 16°C and 21°C resulting in a heatloss of 0.26 W/(m^{2o}C).

EXPERIMENTAL DATA SETS

The duration of each experiment was approximately 2 weeks. Air temperature, air flow rate in the cavity and the amount of surplus heat gains removed from the cavity by the air are main performance parameters and can also be used as measures for validation of building simulation tools. The air temperature in the experiment room was kept uniform and constant at approximately 22°C to minimize the influence of the interior environment on DSF performance. Both, the interior and exterior environment define the boundary conditions for the DSF, and the detailed knowledge of those was essential for further application of the experimental results and evaluation of the DSF performance. The surplus solar gains into the experiment room were measured indirectly, by assessment of the total cooling power delivered to the experiment room in order to keep the air temperature constant. All of the equipment in the experiment room, which functions as heat sources, were connected to the wattmeter to keep track of all loads and losses in the room.

The natural wind speed varies in time and space in a highly random manner and it is highly turbulent. At the same time, the wind speed is one of the main contributors to the natural ventilation flow. Experimental data for the vertical wind speed profile covers a measurement period from 1st of June 2006 until 1st of January 2007. This period includes various wind directions and wind speeds. Wind velocity and wind direction was measured in six points above the ground in order to build a vertical wind profile. Both 2D and 3D ultrasonic anemometers were placed on the mast in the centre line of the building, 12m away from its South façade (Figure 4). The sampling rate was 5 Hz.

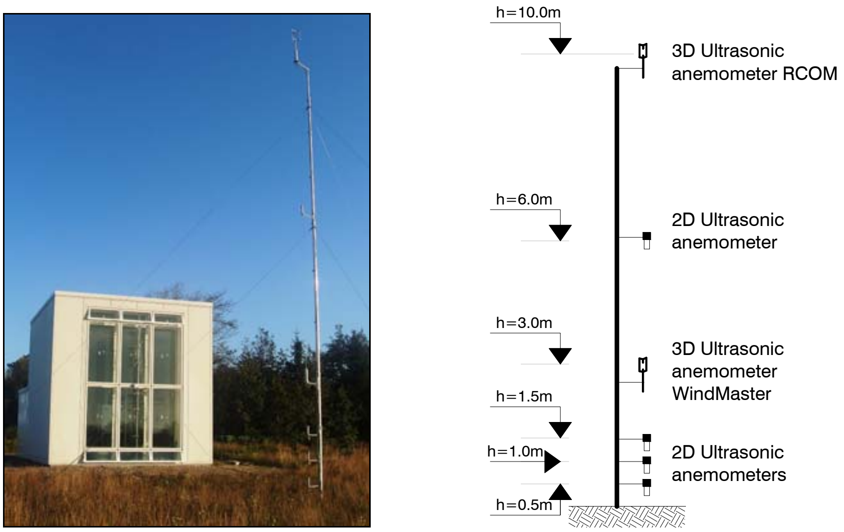


Figure 4. Wind mast in front of 'the Cube' (left). Positioning of equipment on the mast (right).

Outdoor air temperature was measured using two thermocouples type K at the height of 2 m above ground. Air humidity of the outside air was measured continuously for completing the list of required climate data parameters for building simulation tools. Outside air humidity was measured every 10 minutes. For purpose of weather data assembling two pyranometers were placed horizontally on the roof of 'the Cube'. BF3 pyranometer measures Global and Diffuse solar irradiation on the horizontal surface. Another pyranometer, Wilhelm Lambrecht, measures only Global solar irradiation on the horizontal surface and was placed on the roof for control of BF3-readings. In the Table 1, the weather boundary conditions are divided into two groups, corresponding to each test mode.

Table 1. Weather conditions during the experiments.

MODE	*Mean outdoor air temperature* ^oC	*Mean wind speed* m/s	*Mean diffuse solar irradiation on horizontal* W/m^2	*Mean total solar irradiation on horizontal* W/m^2
A	9.6	5.2	58*	89*
B	12.5	3.6	91*	175*
C				

** Mean for solar irradiation is given only for the periods with sun.*

Direct solar radiation is an essential element for the façade operation, but it can heavily affect measurements of air temperature and may lead to errors of high magnitude using bare thermocouples. A number of tests were carried out preliminary to the experiments, where various techniques were investigated on their ability to shield thermocouples from direct irradiance, in order to achieve an accurate and reliable way to measure the air temperature reducing the error caused by radiation (Kalyanova et al., 2007). As an outcome of these tests, all of the thermocouples placed free in the DSF cavity were protected: thermocouples were coated with silver, shielded from direct solar radiation by a silver-coated tube, which was continuously ventilated by a minifan, see Figure 5. The air temperature in the DSF cavity was measured at six different heights in the centre line of the cavity. The measurements were carried out with the sampling frequency 5Hz and averaged for every 10 minutes.

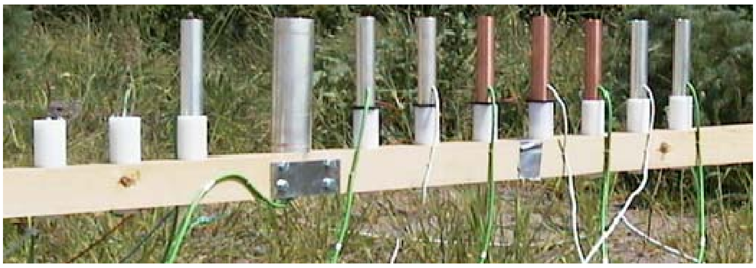
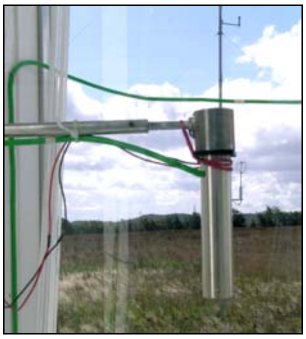


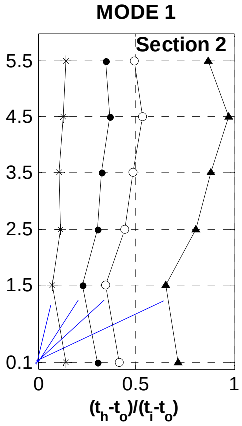
Figure 5. Experimental setup: testing of shielding techniques for air temperature measurements under direct solar access.

The dimensionless air temperature was used to investigate the vertical temperature gradients in the DSF cavity, the definition of it is given in equation:

$$t_{\dim} = \frac{t_h - t_o}{t_i - t_o} \tag{1}$$

t_h - temperature in the DSF cavity at the height h, ^oC
t_o - outdoor air temperature, ^oC
t_i - indoor air temperature (in the experiment room), ^oC





(•) all - *complete set of experimental data*
(o) $I_s>0$ - *corresponds to the period with solar radiation*
(*) $I_s=0$ - *corresponds to the period without solar radiation*
(▲) $I_s>I_{sm}$ - *corresponds to the period with solar radiation higher than mean*
- blue line illustrates the situation when the air temperature in the DSF at the height 0.2m assumed to be the same as inlet (outdoor) air temperature

Figure 6. Silver coated ventilated tube for shielding a thermocouple from solar radiation (left). Dimensionless temperature gradient in the DSF cavity in the MODE1 (right).

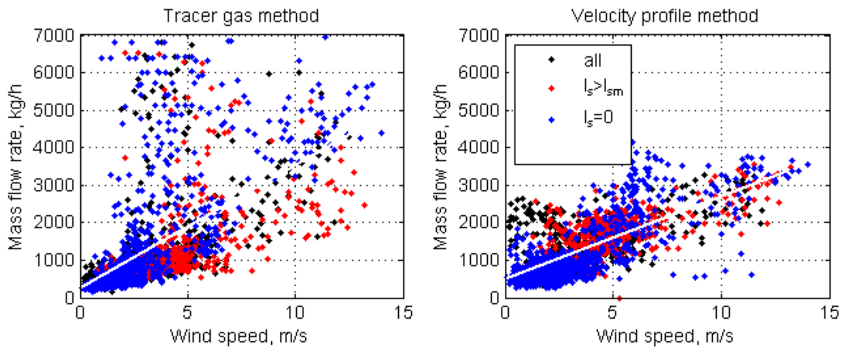
For all sections the measurements at the bottom of the cavity were at the height of 0.1m above the floor. Looking upon the dimensionless profiles (Figure 6) it is possible to observe that the air temperature measured at the bottom of the DSF is relatively high. This is likely to be an experimental error. If the inlet air temperature is assumed to be the same as the outdoor air temperature, then it is reasonable to approximate the dimensionless air temperature in the centre of the inlet opening to zero (at the height 0.2m), which is illustrated with a *blue line.*

Measurement of glazing surface temperature was performed in the centre of a glazing pane for each large window section. The temperature was measured at: the internal surface of the inner window (ii), the external surface of the inner window (ei), the internal surface of the outer windowpane (ie). This measurement was conducted with sensors shaded from direct solar access. Continuous shading of the thermocouple sensor at the inner pane (ie) was ensured by a thin aluminium foil fixed around the sensor at the external surface. As a result, the foil shaded both a sensor at the external (ie) and internal (ii) surfaces. The thermocouple at the internal surface of the outer pane (ei) was shaded in a similar way by a piece of aluminium sticky tape on the external surface of the outer pain.

Assessment of the air change rate is crucial for the evaluation of indoor climate and the performance of a double skin façade. As a result, the air change rate repeatedly becomes a target for measurement, prediction and simulation. In the meantime, the air flow occurred in the naturally ventilated spaces is very intricate and extremely difficult to measure. The stochastic nature of wind and as a consequence non-uniform and dynamic flow conditions in combination with the assisting or opposing buoyancy force cause the main difficulties. There were three techniques used for the air flow measurements, but only two of them were successful:

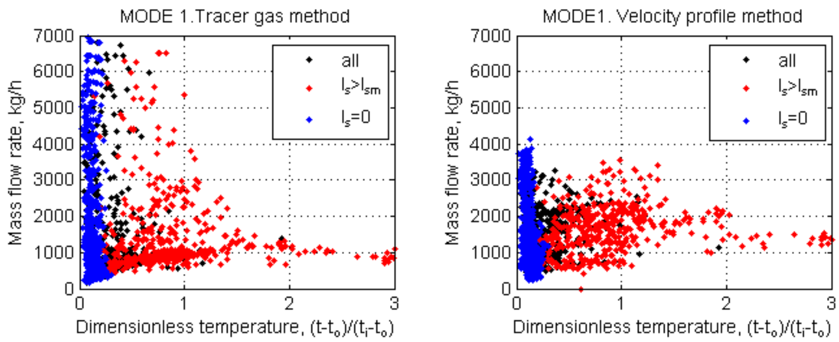
Velocity profile method. This method requires a set of anemometers to measure a velocity profile in the opening, and then the shape of the determined velocity profile depends on amount of anemometers installed. Instead of placing equipment directly in the opening in the case of the double skin façade, it can be placed in the DSF cavity, where the velocity profile can be measured in a few levels instead for one.

Tracer gas method. This method requires the minimum amount of measurements and equipment, but it is characterized with frequent difficulties to obtain uniform concentration of the tracer gas, disturbances from the wind washout effects and finally with the time delay of signal caused by the time constant of gas analyzer. The constant injection method (Etheridge, 1996) was used in the experiments.



all - complete set of experimental data
I_s>I_{sm} - corresponds to the period with strong solar radiation
I_s=0 - corresponds to the period without solar radiation

Figure 7. Mass flow rate measured in the DSF cavity with the tracer gas method (left), velocity profile method (right) and illustrated as a function of the wind speed. MODE 1.



all - complete set of experimental data
I_s>I_{sm} - corresponds to the period with strong solar radiation
I_s=0 - corresponds to the period without solar radiation
I_s>I_{sm}

Figure 8. Mass flow rate measured in the DSF cavity with the tracer gas method (left), velocity profile method (right) and illustrated as a function of dimensionless temperature in the cavity. MODE 1.

In the Figure 7 and Figure 8, it is illustrated that the major part of experimental data is available for the wind dominated driving forces, although it is common to assume that the mass flow rate in a double-skin façade cavity is buoyancy driven. The wind impact is present even for the periods with relatively strong solar radiation (I_s>I_{sm}). Both of the measurement methods have sources of errors and comparing their outputs have some level of disagreement. However, the natural air flow phenomena is very complex and this results is the best approximation to the long time monitoring of natural air flow phenomena and can be used for experimental validation of numerical models of natural ventilation air flow, for more information see Kalyanova (2007).

One of the main targets of this experimental work was to accurately estimate solar gains and heat losses by the room adjacent to the double skin façade, as these parameters independently reflect the performance of the DSF cavity. Their independence is assured by the minimized influence of the experiment room on the DSF performance, as the thermal conditions in the room were kept constant, no regulation of the window openings used and no shading devices installed, building is very well insulated and air tight, the air tightness of the building, the transmission heat losses are known and all influencing climate parameters were measured.

Water was used in the cooling unit of the ventilation system. With the purpose to avoid the condensation on the surface of the surface of the cooling unit, the minimum water temperature was set to 12^{o}C. The difference between the supply and return water temperature from the cooling unit in the experiment room was measured using one thermocouple type K with a maximum uncertainty of 0.1^{o}C. The mass flow of the water supplied to the cooling unit was measured with a water flow meter MULTICAL from Kamstrup, which measures in a range from 0 to 1 kg/s and calibrated to an uncertainty of ±0.1% of the reading. Both the temperature difference and the water mass flow were collected by Helios data logger at a frequency 0.1 Hz.

The heating unit in the ventilation system was rarely activated, as in most cases, the additional heating load from the fan of the ventilation system in the experiment room ensured a sufficient cooling load. To keep a track on all loads to the experiment room, including the heating unit, all equipment in the room was connected to a wattmeter. The accuracy of the device was 0.1% of the reading (2.6 kW). A data logger Helios assembled readings from the wattmeter at a frequency 0.1Hz.

CONCLUSION

The details about the experimental test facility and experimental set-up, described in this paper, provide a good foundation for empirical validation of thermal building simulation tools for modeling double-skin façade buildings. In this work, extensive studies of the mass flow rate and air temperatures in the cavity and adjacent zone are supported with detailed information on the input parameters for a building thermal simulation tool. The generally rare experimental data for the DSF-buildings, containing results of the mass flow rate measured in a naturally ventilated are especially unique.

ACKNOWLEDGEMENT

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REFERENCES

Gertis K. (1999). Sind neuere Fassadenentwickelungen bauphysikalisch sinnvoll? Teil 2: Glas-Doppelfassaden (GDF) (English translation), Bauphysik, vol. 21, pp. 54-66.

Kalyanova, O., Jensen, R. L. and Heiselberg, P. (2007). Measurement of air flow rate in a naturally ventilated double skin facade. Proceedings of Roomvent 2007: Helsinki 13-15 *June 2007* . Finland: FINVAC ry.

Kalyanova O., Zanghirella F., Heiselberg P, Perino M. and Jensen R. L. (2007). Measuring air temperature in glazed ventilated façades in the presence of direct solar radiation. Proceedings of Roomvent 2007. Finland : FINVAC ry.

Loncour X., Deneyer A., Blasco M., Flamant G. and Wouters P. (2004). Ventilated Double Facades. Classification & Illustration of façade concepts. Belgian Building Research Institute: Department of Building Physics, Indoor Climate & Building Services. October 2004.

Poirazis H. (2004). Double Skin Facades for office buildings—Literature review, Report EBD-R-04/3, Division of Energy and Building Design, Lund University (2004).

Saelens D. (2002). Energy performance assessments of single storey Multiple-Skin Facades. PhD thesis, Laboratory for Building Physics, Department of Civil Engineering, Catholic University of Leuven, Belgium.