Aalborg Universitet

Challenges in Performance Assessment of Responsive Building Elements

Heiselberg, Per Kvols

Published in:
e-nova Internationaler Kongress 2008

Publication date:
2008

Document Version
Publisher's PDF, also known as Version of record

Challenges in Performance Assessment of Responsive Building Elements

P. Heiselberg
Aalborg University, Aalborg, Denmark

ABSTRACT:
The challenges regarding simulation of the performance of responsive building elements and building integrated ventilation lie in the combined analysis of the heat transfer in the building element and of the air flow of the ventilation system. Typically, these analyses have been performed separately focusing on either the building physics or the fluid dynamics part of the problem and using simplified assumptions about the other part. This has traditionally been an acceptable approach, but for building integrated ventilation and application of responsive building elements this is not the case as the building physics and fluid dynamic behavior is interrelated and dependent on each other.

This paper highlights this issue on the basis of a selected example of performance prediction of a ventilated double skin façade.

1 INTRODUCTION

Research into building energy efficiency over the last decade has focused on efficiency improvements of specific building elements like the building envelope, including its walls, roofs and fenestration components, and building equipment such as heating, ventilation, air handling, cooling equipment and lighting. Significant improvement have been achieved, and whilst most building elements still offer opportunities for efficiency improvements, the greatest future potential lie with technologies that promote the integration of responsive building elements and communication among building services.

Responsive Building Elements are defined as building construction elements which are actively used for transfer of heat, light and air. This means that construction elements (like floors, walls, roofs, foundation etc.) are logically and rationally combined and integrated with building service functions such as heating, cooling, ventilation and energy storage. The development, application and implementation of responsive building elements are considered to be a necessary step towards further energy efficiency improvements in the built environment. With the integration of responsive building elements and building services, building design completely changes from design of individual systems to integrated design of “whole building concepts, augmented by “intelligent” systems and equipment.

Building integrated ventilation is an example of a technology that integrates responsive building elements with the ventilation system. The focus on the environmental impacts of energy production and consumption has provided an increased awareness of the energy used by fans, heating/cooling coils and other equipment in ventilation and air conditioning systems. An expectation of a reduction in annual energy costs has also been an important driving force for the development of natural and hybrid ventilation strategies.

Available data from case studies provided in the international project IEA ECBCS-Annex 35 show that a substantial energy saving has been achieved in a number of buildings, mainly because of a very substantial reduction in energy use for fans and a reduced energy use for cooling. This was achieved primarily by utilising the natural driving forces and the natural cooling potential of the outdoor air. Building elements like embedded ducts, multiple skin facades and exposed thermal mass was used to some extent to preheat and/or pre-cool ventilation air or to reduce the impact of high heat gains. But, due to limited knowledge on the integrated performance of these elements and the ventilation system as well as appropriate simulation methods the system designs were far from optimised.

Development, application and implementation of responsive building elements in building integrated ventilation systems are a possible next step towards further energy efficiency improvements in the built environment and will provide new opportunities for further improvement of environmental performance.

1.1 *Responsive Building Elements*

A *Responsive Building Element (RBE)* is a building component that assists to maintain an appropriate balance between optimum interior conditions and environmental performance by reacting in a controlled and holistic manner to changes in external or internal conditions and to occupant intervention. RBEs are, thus, elements that respond to outdoor and indoor environment changes and occupants requirements in a proper way so as to keep optimal and adaptive comfort conditions, simultaneously contributing to minimize the energy consumption for the control of the indoor environment.

From a practical point of view, examples of existing RBE include, among the others:

- *façades systems* (ventilated facades, double skin facades, adaptable facades, dynamic insulation,...),
- *foundations and other underground systems* (earth coupling systems, embedded ducts, ...),
- *energy storages* (active use of thermal mass, material - concrete, massive wood - core activation for cooling and heating, phase change materials, ...),
- *roof systems* (green roof systems, ...),
- *passive solar systems*,
- *daylighting technologies,*
- *evaporative cooling elements* (roof ponds, water walls, spray ponds, ...).

By using a responsive façade element, for example, it will be possible to change the thermal insulation properties of the building envelope in order to exploit the best opportunities offered by the indoor/outdoor environmental conditions. That means increasing the heat losses through the walls when an overheating of the indoor environment may occur or reducing the U-value when the building needs to be heated. Furthermore, the façade can be ventilated and integrated with an HVAC system in order to act, depending on the boundary conditions, either like a sort of an air solar collector (to pre-heat the ventilation air during winter time) or as an exhaust duct for the ventilation air (in order to mitigate the solar heat gain during the cooling season).

1.2 *Performance Assessment*

In the design and performance analysis of responsive building elements it is crucial to be able to predict the element as well as whole building performance with a satisfactory accuracy, especially, when selection between different alternative design solutions is needed or if the aim is to perform an optimization of the building performance.

The challenges regarding simulation of the performance of responsive building elements and building integrated ventilation lie in the combined analysis of the heat transfer in the building element and of the air flow of the ventilation system. Typically, these analyses have been performed separately focusing on either the building physics or the fluid dynamics part of the problem and using simplified assumptions about the other part. This has traditionally been an acceptable approach, but for building integrated ventilation and application of responsive building elements this is not the case as the building physics and fluid dynamic behavior is interrelated and dependent on each other.

This paper highlights this issue on the basis of a selected example of performance prediction of a ventilated double skin façade.

2 MODELLING OF VENTILATED DOUBLE SKIN FACADES

In modelling and performance assessment of Double Skin Facades (DSF) the network approach has proven to give the best results, as it is able to provide the necessary accuracy level within acceptable complexity levels. Besides it can solve the transient part of the assignment and is able to cover large design complexities. The developed network-models can be of varying level of complexity, depending on decisions made with reference to the influencing parameters. These parameters are: heat transfer, airflow in the cavity, solar radiation, longwave radiation exchange”.

“The main challenges that have to be solved for development of simulation model in elements are:

Heat transfer. The first dilemmas appear with the estimation of convective heat transfer coefficient, as this is a function of the flow regime in the DSF, which is depending on the geometry and the temperature in the cavity. Varying velocity profiles in the cavity adds an additional difficulty to the estimation of the heat transfer components. Another matter is related to the non-linear vertical temperature distribution in the cavity, which causes variable heat fluxes through the DSF with height.

Airflow. There are two components which determine airflow through the DSF in a case of natural ventilation; these are the buoyancy force and the driving pressure due to wind. Both of these components are problematic to model. The main difficulty with regard to the buoyancy force is related to the non-linear temperature distribution in the cavity. The main difficulty with regard to wind is related to estimation of local pressures on the façade as well as local wind velocity, wind direction and the turbulent characteristics of the wind. Moreover the flow resistance coefficients are complex to estimate for the naturally ventilated cavities, as the velocity profiles are different from mechanically ventilated cavities, thus new resistance coefficients have to be obtained.

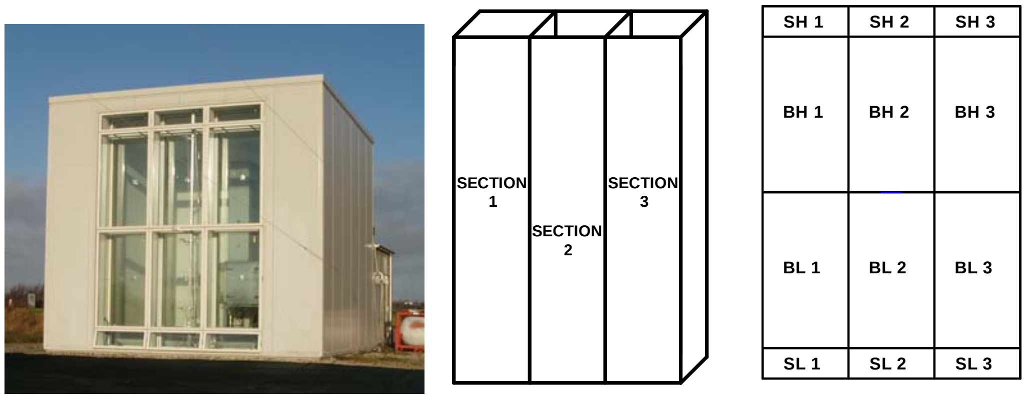
Solar radiation and long wave radiation. The main difficulty related to these elements is associated with the decision of choosing the best modeling method and number of reflections necessary to include in the model.

With regard to the overall modeling approach the complexity of the numerical model depend on the manner how the building and buildings systems are differentiated into nodes, i.e. whether the cavity temperature, the convective heat transfer, etc. are represented by one bulk-value or the façade is vertically/horizontally partitioned and a number of values are calculated. As the calculation time increases with complexity three different models has to be developed to give different choices with regard to time consumption and modeling accuracy. In the most simple model parameters will be represented by one bulk value. The second step will be a vertical partition and the final step both a vertical and a horizontal partition.

The following shows an example of what can be achieved by the state-of-the-art methods today by comparing assessment of temperature and air flow rate in a naturally ventilated double skin façade with measurements in a full scale test rig under real weather conditions.

3 EXPERIMENTAL SET-UP

The full-scale experiments are conducted in the experimental test facility the ‘Cube’, which is described in detail in (Kalyanova and Heiselberg 2006). The ‘Cube’ is located in an open flat country with the DSF openings facing south. There are two experimental zones: the double skin façade cavity and the test room behind the DSF. The building has a shape of a cube with the dimensions 6x6x6 m. Window partitions of the façade visually subdivide the DSF into three sections, see figure 1. Internal dimensions of the double façade cavity are following, height – 5.5 m, width - 3.6 m, depth – 0.58 m.



a) b) c)

Transcription: **1st letter stands for “B” – big and “S” – small; 2nd letter stands for “H” – high and “L” – low; Number stands for “1” ,”2”,”3” – number of DSF section.**

Figure 1. a) The 'Cube'. b) Section of the DSF cavity. c) DSF openings.

Experiments in the naturally ventilated cavity were completed for an external air curtain mode with openings in the external façade at both the bottom (SL1-3) and the top (SH1-3).

In this mode, the external operable windows at the top and bottom of the cavity are open to the outside, the air enters the DSF at the bottom of the cavity, heats up when passing through the DSF cavity and then released through the top openings to the external environment, carrying away some amount of the solar heat gains. The flow motion in the cavity is naturally driven. The air flow rate depends only on wind and buoyancy and is limited by the opening size. The external air curtain mode is a frequently used solution in summer to prevent surplus solar gains into the room and to improve the efficiency of the solar shading by limiting the air temperature in the cavity by external air flow to minimize/avoid increased heat transmission/radiation to the room. Thus the opening degree of the windows was adjusted to the mean air temperature in the double façade cavity was 5-10 degrees above the outdoor temperature, in order to avoid too high cavity temperatures in the external air curtain mode.

3.1 *The 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 wash-out 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. Carbon dioxide (CO_2) was used as tracer gas and was released in the lower part of the double skin façade cavity, just above the SL openings. Even distribution of the tracer gas along the DSF cavity was ensured by delivery through a perforated tube of internal diameter 3.5 mm, perforation distance 4mm and 0.5mm diameter of perforations. Samples of the tracer gas dilution were taken in 12 points (4 samples per section) at the top of the DSF cavity, but below the SH- openings. All the samples were mixed in a collector, b, and then the average concentration was measured by a gas analyzer BINOS. Outdoor CO_2 concentration was measured continuously by a gas analyzer URAS. Both devices were preliminary calibrated to an accuracy of 10ppm. A Helios data logger collected data from the gas analyzers with a frequency of 0.1 Hz.

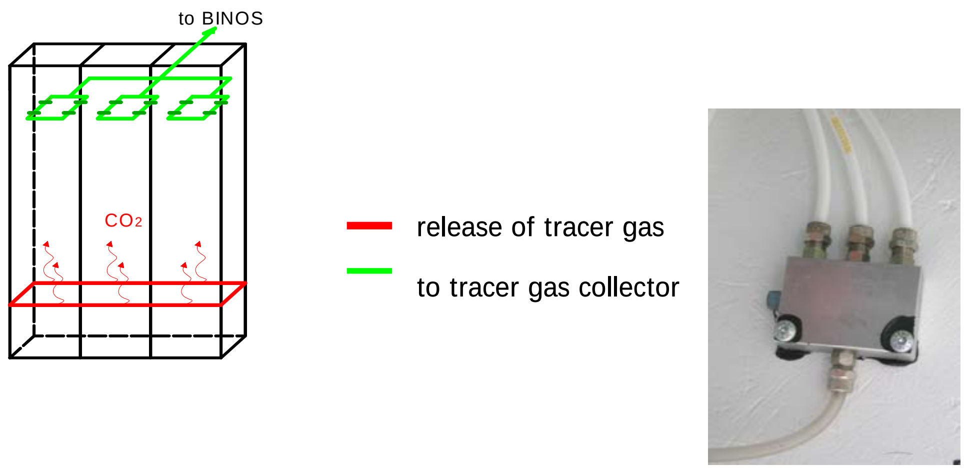


Figure 2. a) Experimental setup for the tracer gas method. b) Collector of the samples.

a) b)

Figure 3. a) and b) Positioning of anemometers in the DSF cavity.

3.2 *The velocity profile method*

This method requires anemometers to be placed in the DSF cavity to measure velocity profiles in the DSF cavity. The velocity profile was measured in a few different heights for better accuracy. During the experiments the velocity profiles were measured in section 2, see Figure 1, in 6 heights, see Figure 3, at a frequency of 10Hz for a 10 min averaging period. Hot sphere anemometers are temperature compensated and to ensure accurate measurements under the direct solar radiation they were preliminary tested and calibrated under artificial sun conditions, in the wind tunnel. The velocity profiles were measured only in the mid section of the cavity, and equal flow conditions was assumed in all three sections of the DSF cavity for the air flow estimation.

4 COMPARISON BETWEEN PREDICTIONS AND MEASUREMENT RESULTS

The measurement data set is available for a 2 weeks period, from 1st of October until 15th of October, and includes all necessary weather data, such as wind speed, wind direction, outdoor air temperature and humidity, total and diffuse solar irradiation on a horizontal surface, ground temperature under the foundation and atmospheric pressure. It includes a wide spectrum of various thermal conditions: periods with high direct solar radiation, with high diffuse solar radiation and of cool and warm outdoor air temperature. The air temperature in the DSF cavity, vertical temperature gradient in the cavity, surface temperatures of the glazing, mass flow rate in the DSF are available in the data set. During the experiments, the air temperature in the room adjacent to the DSF cavity was kept constant at 22°C. The cooling/heating power load to the room was measured and included into the data set as a parameter that reflects the performance of the DSF.

Only simulation results for the global parameters are reported here. These are the air temperature and the mass flow rate in the DSF cavity. The air flow rate in a double skin facade cavity is rather high compared to the temperature difference between the air in the cavity and outdoor therefore it is essential to perform the empirical validation of the air temperature predictions in the models via *'the temperature raise in the DSF '* to track the amount of energy transported by the air flow. Due to the magnitude of mass flow rate, an error in prediction of the air temperature in the range of 1°C can mean hundreds of watts of error in energy balance.

Figure 4 illustrates the temperature raise in the DSF cavity above the outdoor air temperature for two days with the principally different boundary conditions: 10th of October – a day with high direct solar radiation and 11th of October – a day with mainly diffuse solar radiation. It is obvious that the simulation results are also different for these two days: for days with a large amount of direct radiation, the air temperature in the DSF cavity is underestimated, while good agreement is achieved for a cloudy day. The same observations were valid for most of the simulated results (2 weeks period).

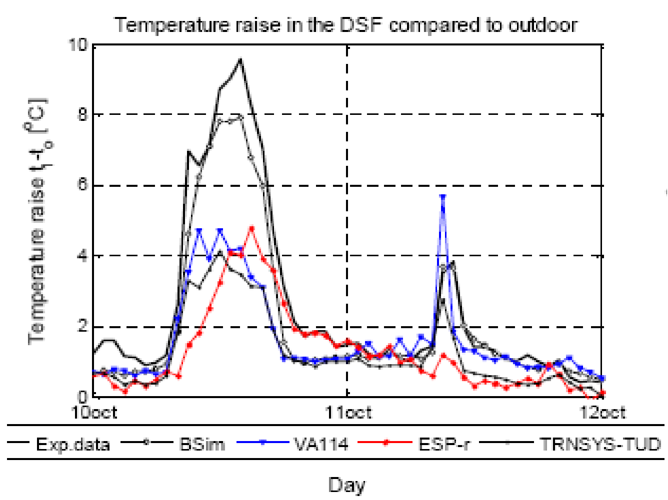


Figure 4. Temperature raise in the DSF cavity comoared to the outdoor air temperature. (Kalyanova and Heiselberg 2008).

Calculation of natural ventilation is particular interesting as the natural mass flow rate is exceptionally difficult to simulate, yet, it is one of the key actors in DSF performance. In Figure 5 it is shown that prediction of the mass flow rate in the DSF cavity is not very accurate.

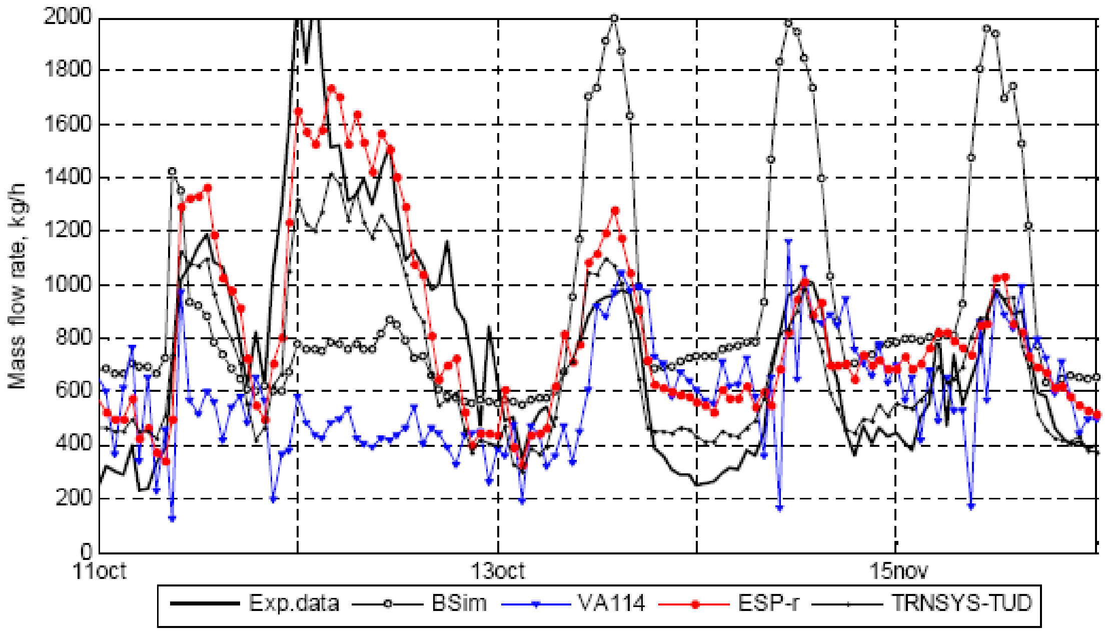


Figure 5. Hour averaged mass flow rate in the DSF cavity measured with the tracer gas method. (Kalyanova and Heiselberg 2008)

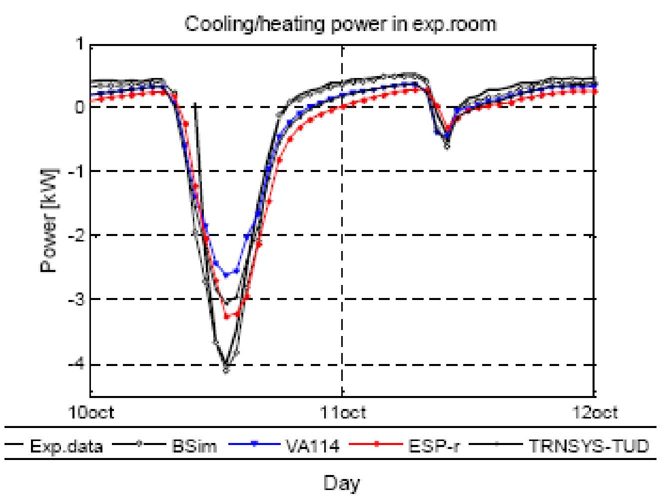


Figure 6. Cooling/heating power in the experiment room. (Kalyanova and Heiselberg 2008).

Figure 6 shows that the cooling power in the experiment room is mainly underestimated by all models. Moreover cooling power appears to be underestimated when the air temperature in cavity is underestimated too.

5 CONCLUSION

Air flow rate, flow regime, convective and radiative heat transfer have an impact on resulting air temperature in the cavity. To be successfully validated a model has to demonstrate consistency of predictions for all parameters. All of the parameters for one model should have certain agreement with the experimental data. For the moment, none of the models appeared to be consistent enough when compare results of simulations with the experimental data.

The difficulties with simulation of cooling power during day time are also a consequence of greater deviations in predicted air temperature in the cavity, which is interconnected with the natural driving forces and mass flow rate in the cavity and solar gains removed with the cavity air.

With regard to naturally induced air flow in the cavity, the similarities in the shapes between the measurements and simulations for TRNSYS-TUD and ESP-r model show a great potential. This is probably due to the fact that both of these programs take into the consideration the pressure difference coefficients for each opening. It is then reasonable to expect that prediction of mass flow rate in the cavity will certainly improve when thermal model works without the flaws: with appropriate calculations of the air temperature and vertical temperature gradient in the cavity under the strong solar radiation.

Improvement of thermal model requires more knowledge within the convective and flow regimes in the cavity. A dynamic model for estimation of convective heat transfer in DSF would be beneficial, as application of combined film coefficients appeared to be inappropriate and application of fixed film coefficients does not prove to be satisfactory.

Until now, none of the models account for recirculation flow in the cavity. Considering the consequences that recirculation flow in cavity may have on the temperature gradient in the cavity and also on the total mass flow rate, it is necessary to think of a mathematical model that is able to incorporate the effect from recirculation flow.

Although measurement results show reasonable agreements both the described measurement methods have sources of error and compared to laboratory conditions have relatively large uncertainties and there is a large potential for further research to improve accuracy when measuring air flow in naturally ventilated cavities

LITERATURE

Kalyanova ,O and Heiselberg, P. 2006. Empirical Test Case Specification: Test Case DSF200_e : IEA ECBCS Annex43/SHC Task 34 : Validation of Building Energy Simulation Tools. Aalborg: Aalborg University, Department of Civil Engineering.

Kalyanova, O., Heiselberg, P. Empirical Validation of Building Simulation Software: Modelling of Double Facades. Final Technical Report, Subtask E. *Report for IEA ECBCS Annex 43/SHC Task 34 Validation of Building Energy Simulation* Tools, ISSN 1901-726X, DCE Technical Report No. 027, Aalborg University, June 2008, Denmark