Comparative Validation of Building Simulation Software

Modeling of Double Facades : Final Report

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Comparative Validation of Building Simulation Software: Modeling of Double Facades

FINAL REPORT

Technical Report

IEA ECBCS Annex43 / SHC Task 34
Validation of Building Energy Simulation Tools

Subtask E

O. Kalyanova
P. Heiselberg

SOLAR HEATING & COOLING PROGRAMME
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Preface

This report is a product of a joint effort between International Energy Agency Solar Heating and Cooling (IEA SHC) Task 34 and Energy Conservation in Buildings and Community Systems (ECBCS) Annex 43. Ron Judkoff of the National Renewable Energy Laboratory (NREL) was the Operating Agent for IEA 34/43 on behalf of the United States Department of Energy.

International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster co-operation among the twenty-four IEA participating countries and to increase energy security through energy conservation, development of alternative energy sources and energy research, development and demonstration (RD&D).

Solar Heating and Cooling Programme

The Solar Heating and Cooling Programme was one of the first IEA Implementing Agreements to be established. Since 1977, its members have been collaborating to advance active solar, passive solar and photovoltaic technologies and their application in buildings and other areas, such as agriculture and industry. Current members are:

Australia	Finland	Portugal
Austria	France	Spain
Belgium	Italy	Sweden
Canada	Mexico	Switzerland
Denmark	Netherlands	United States
European Commission	New Zealand	
Germany	Norway	

A total of 37 Tasks have been initiated, 26 of which have been completed. Each Task is managed by an Operating Agent from one of the participating countries. Overall control of the program rests with an Executive Committee comprised of one representative from each contracting party to the Implementing Agreement. In addition to the Task work, a number of special activities—Memorandum of Understanding with solar thermal trade organizations, statistics collection and analysis, conferences and workshops—have been undertaken.

The Tasks of the IEA Solar Heating and Cooling Programme, both underway and completed are as follows:

1. Current Tasks:

Task 27	*Performance of Solar Facade Components*
Task 29	*Solar Crop Drying*
Task 31	*Daylighting Buildings in the 21st Century*
Task 32	*Advanced Storage Concepts for Solar and Low Energy Buildings*
Task 33	*Solar Heat for Industrial Processes*
Task 34	*Testing and Validation of Building Energy Simulation Tools*
Task 35	*PV/Thermal Solar Systems*
Task 36	*Solar Resource Knowledge Management*
Task 37	*Advanced Housing Renovation with Solar & Conservation*

Completed Tasks:

Task 1	*Investigation of the Performance of Solar Heating and Cooling Systems*
Task 2	*Coordination of Solar Heating and Cooling R&D*
Task 3	*Performance Testing of Solar Collectors*
Task 4	*Development of an Insolation Handbook and Instrument Package*
Task 5	*Use of Existing Meteorological Information for Solar Energy Application*

Task 6	*Performance of Solar Systems Using Evacuated Collectors*
Task 7	*Central Solar Heating Plants with Seasonal Storage*
Task 8	*Passive and Hybrid Solar Low Energy Buildings*
Task 9	*Solar Radiation and Pyranometry Studies*
Task 10	*Solar Materials R&D*
Task 11	*Passive and Hybrid Solar Commercial Buildings*
Task 12	*Building Energy Analysis and Design Tools for Solar Applications*
Task 13	*Advance Solar Low Energy Buildings*
Task 14	*Advance Active Solar Energy Systems*
Task 16	*Photovoltaics in Buildings*
Task 17	*Measuring and Modeling Spectral Radiation*
Task 18	*Advanced Glazing and Associated Materials for Solar and Building Applications*
Task 19	*Solar Air Systems*
Task 20	*Solar Energy in Building Renovation*
Task 21	*Daylight in Buildings*
Task 22	*Building Energy Analysis Tools*
Task 23	*Optimization of Solar Energy Use in Large Buildings*
Task 24	*Solar Procurement*
Task 25	*Solar Assisted Air Conditioning of Buildings*
Task 26	*Solar Combisystems*
Task 28	*Solar Sustainable Housing*

Completed Working Groups:
CSHPSS, ISOLDE, Materials in Solar Thermal Collectors, and the Evaluation of Task 13 Houses

To find more IEA Solar Heating and Cooling Programme publications or learn about the Programme visit our Internet site at www.iea-shc.org or contact the SHC Executive Secretary, Pamela Murphy, e-mail: pmurphy@MorseAssociatesInc.com.

Energy Conservation in Buildings and Community Systems

The IEA sponsors research and development in a number of areas related to energy. The mission of one of those areas, the ECBCS - Energy Conservation for Building and Community Systems Programme, is to facilitate and accelerate the introduction of energy conservation, and environmentally sustainable technologies into healthy buildings and community systems, through innovation and research in decision-making, building assemblies and systems, and commercialisation. The objectives of collaborative work within the ECBCS R&D program are directly derived from the on-going energy and environmental challenges facing IEA countries in the area of construction, energy market and research. ECBCS addresses major challenges and takes advantage of opportunities in the following areas:

- exploitation of innovation and information technology;
- impact of energy measures on indoor health and usability;
- integration of building energy measures and tools to changes in lifestyles, work environment alternatives, and business environment.

The Executive Committee

Overall control of the program is maintained by an Executive Committee, which not only monitors existing projects but also identifies new areas where collaborative effort may be beneficial. To date the following projects have been initiated by the executive committee on Energy Conservation in Buildings and Community Systems (completed projects are identified by (*)):

Annex 1:	Load Energy Determination of Buildings (*)
Annex 2:	Ekistics and Advanced Community Energy Systems (*)
Annex 3:	Energy Conservation in Residential Buildings (*)
Annex 4:	Glasgow Commercial Building Monitoring (*)
Annex 5:	Air Infiltration and Ventilation Centre
Annex 6:	Energy Systems and Design of Communities (*)
Annex 7:	Local Government Energy Planning (*)
Annex 8:	Inhabitants Behaviour with Regard to Ventilation (*)

Annex 9: Minimum Ventilation Rates (*)
Annex 10: Building HVAC System Simulation (*)
Annex 11: Energy Auditing (*)
Annex 12: Windows and Fenestration (*)
Annex 13: Energy Management in Hospitals (*)
Annex 14: Condensation and Energy (*)
Annex 15: Energy Efficiency in Schools (*)
Annex 16: BEMS 1- User Interfaces and System Integration (*)
Annex 17: BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18: Demand Controlled Ventilation Systems (*)
Annex 19: Low Slope Roof Systems (*)
Annex 20: Air Flow Patterns within Buildings (*)
Annex 21: Thermal Modelling (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25: Real time HEVAC Simulation (*)
Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28: Low Energy Cooling Systems (*)
Annex 29: Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy-Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)
Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM)
Annex 43: Testing and Validation of Building Energy Simulation Tools
Annex 44: Integrating Environmentally Responsive Elements in Buildings
Annex 45: Energy Efficient Electric Lighting for Buildings
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo)
Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings
Annex 48: Heat Pumping and Reversible Air Conditioning
Annex 49: Low Exergy Systems for High Performance Built Environments and Communities
Annex 50: Prefabricated Systems for Low Energy / High Comfort Building Renewal

Working Group - Energy Efficiency in Educational Buildings (*)
Working Group - Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group - Annex 36 Extension: The Energy Concept Adviser (*)
(*) – Completed

Participating countries in ECBCS:
Australia, Belgium, CEC, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Israel, Italy, Japan, the Netherlands, New Zealand, Norway, Poland, Portugal, Sweden, Switzerland, Turkey, United Kingdom and the United States of America.

SHC Task 34 / ECBCS Annex 43: Testing and Validation of Building Energy Simulation Tools

Goal and Objectives

The goal of this Task/Annex is to undertake pre-normative research to develop a comprehensive and integrated suite of building energy analysis tool tests involving analytical, comparative, and empirical methods. These methods will provide for quality assurance of software, and some of the methods will be enacted by codes and standards bodies to certify software used for showing compliance to building energy standards. This goal will be pursued by accomplishing the following objectives:

- Create and make widely available a comprehensive and integrated suite of IEA Building Energy Simulation Test (BESTEST) cases for evaluating, diagnosing, and correcting building energy simulation software. Tests will address modeling of the building thermal fabric and building mechanical equipment systems in the context of innovative low energy buildings.
- Maintain and expand as appropriate analytical solutions for building energy analysis tool evaluation.
- Create and make widely available high quality empirical validation data sets, including detailed and unambiguous documentation of the input data required for validating software, for a selected number of representative design conditions.

Scope

This Task/Annex investigates the availability and accuracy of building energy analysis tools and engineering models to evaluate the performance of innovative low-energy buildings. Innovative low-energy buildings attempt to be highly energy efficient through use of advanced energy-efficiency technologies or a combination of energy efficiency and solar energy technologies. To be useful in a practical sense such tools must also be capable of modeling conventional buildings. The scope of the Task is limited to building energy simulation tools, including emerging modular type tools, and to widely used innovative low-energy design concepts. Activities will include development of analytical, comparative and empirical methods for evaluating, diagnosing, and correcting errors in building energy simulation software.

The audience for the results of the Task/Annex is building energy simulation tool developers, and codes and standards (normes) organizations that need methods for certifying software. However, tool users, such as architects, engineers, energy consultants, product manufacturers, and building owners and managers, are the ultimate beneficiaries of the research, and will be informed through targeted reports and articles.

Means

The objectives are to be achieved by the Participants in the following Projects.

Comparative and Analytical Verification Tests:
- Project A: Ground-Coupled Heat Transfer with respect to Floor Slab and Basement Constructions
- Project B: Multi-Zone Buildings and Air Flow

Empirical Validation and Comparative Tests:
- Project C: Shading/Daylighting/Load Interaction
- Project D: Mechanical Equipment and Controls
- Project E: Buildings with Double-Skin Facades

Other:
- Project G: Web Site for Consolidation of Tool Evaluation Tests

Participants

The participants in the task are Australia, Belgium, Canada, Czech Republic, Denmark, France, Germany, Japan, the Netherlands, Spain, Sweden, Switzerland, the United Kingdom, and the United States. The United States served as the Operating Agent for this Task, with Ron Judkoff of the National Renewable Energy Laboratory providing Operating Agent services on behalf of the U.S. Department of Energy.

This report documents work carried out under Project E: Buildings with Double-Skin Facades.

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1. INTRODUCTION

1.1 Foreword

The main objective of the Subtask E is for buildings with Double Skin Facades (DSF) to assess suitability and awareness of building energy analysis tools for predicting energy consumption, heat transfer, ventilation flow rates, cavity air and surface temperatures and solar protection effect and interaction with building services systems.

The starting point of this subtask was to develop a set of empirical test cases for the experimental validation of building simulation software tools. From the literature review [1], it is clear that an identification of a double skin facade with a typical performance is not easy, as every double skin facade building is almost unique. Thus, considering the empirical validation of the double skin facade modeling, a number of questions appeared:

- What is the DSF construction to choose for the empirical validation (positioning of openings, type of glazing, dimension of the DSF cavity, application of shading device, partitioning of the cavity etc.)
- What is the operational principle for the DSF to choose for the empirical validation (naturally/mechanically ventilated, flow direction and origin of air flow)

In order to answer some of the questions, first, a set of comparative test cases was defined, simulated and analyzed in the period of construction of the experimental test facility. Completion of the comparative test cases helped to point out the areas of modeling difficulties, the necessary empirical test cases for completing the subtask assignment and the important parameters to measure during the empirical test cases. Moreover useful feedback was obtained from the participants with comments on the test case specification and the review of the comparative/experimental results. Finally, the close collaboration made the authors familiar with the tools and approaches used in the software tools participating in the subtask exercises.

The comparative test cases do not include an analytical solution; thus the results are compared only between the research groups performing the modeling. Completed comparative exercises demonstrate some severe disagreements between the simulation tools when predicting the air flow rate in a naturally ventilated cavity, and thus demonstrate the necessity for the empirical exercises to complete the validation procedure. Only a limited number of comparative test cases were defined, but these were sufficient to inform the experimental design and to appreciate the magnitude of differences between different simulation programs. The main emphasis of Subtask E was on the empirical tests to provide the reference against which modeling predictions could be compared.

1.2 Facts about the comparative test case specification

1.2.1 Comparative test case specification. General

An outdoor test facility at Aalborg University, the 'Cube', became a model for definition of the comparative test cases [2]. For that reason the constructional parts of the comparative and empirical specifications are alike. In the comparative specification, such parameters as wind pressure coefficients, air tightness, optical properties of the constructions etc. are defined on a literature basis or left up to the modeler decision.

A number of comparative tests were considered. These are subdivided by operational strategy of the DSF into five groups [2]. In addition, each group of tests includes a variation of such parameters as solar shading device, driving force, boundary conditions, opening area etc. Combining all these parameters will result in a large number of test cases.

As a result of discussion and evaluation of the results after each modeling iteration, the comparative test case specification was changed a number of times by including additional output parameters, information, clarification and improvements to the defined test cases.

Since the first draft of the comparative test case specification, there were a number of improvements made according to a few iterations of discussions and extensive feedback from the experts during the project stages. The main improvements to the first drafts of the specification included the following:

- Elevation above sea level
- Geographical site location
- Detailed information about the opening design, free opening area and direction of opening
- More detailed definition of the ground thermal resistance
- Definition of glazing ID according to IGDB
- Use of air temperature instead of operative temperature
- Solar altitude as an output parameter

1.2.2 Test cases in the comparative test case specification

Case DSF100. All the openings are closed. There is no exchange of the zone air with the external or internal environment. The zone air temperature results from the conduction, convection and radiation heat exchange. The movement of the air in the DSF appears due to convective flows in the DSF. The test case is focused on assessment of the resulting cavity temperature in DSF and solar radiation transmitted through the DSF into adjacent zone.

Case DSF200. Openings are open to the outside. The DSF function is to remove the surplus solar heat gains by means of natural cooling. Temperature conditions and air flow conditions in the DSF are to be examined together with the magnitude of natural driving forces.

Case DSF300. Openings are open to the inside. This is similar to the Test Case DSF200, but the external environment (wind and temperature) does not have as strong an influence on the cavity temperature as in the above case. The internal environment of the room behind the DSF is more important now. This test case has not been specified for the modeling.

Case DSF400. The bottom opening is open to the outside and the top opening is open to the inside. Such configuration of openings considers the DSF in an air supply (preheating) configuration. The influence of the processes in the DSF on thermal conditions in the room is to be revealed.

Case DSF500. The top opening is open to the outside and the bottom opening is open to the inside. This configuration of openings considers the DSF in an exhaust configuration.

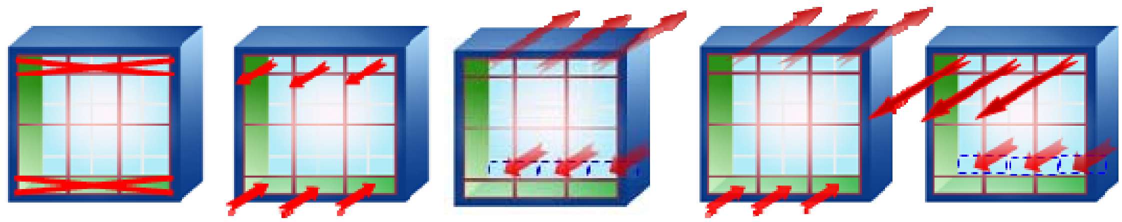


Figure **1**. Comparative test cases.

Test case	Solar shading	Driving force			Boundary conditions		Control of opening	Corresponding empirical test case
		Buoyancy	Wind	Mechanical	Internal	External		
DSF100_2	No	-	-	-	constant	variable	-	DSF100_e
DSF200_3	No	YES	NO	-	constant	variable	-	-
DSF200_4	No	YES	YES	-	constant	variable	-	DSF200_e
DSF400_3	No	-	-	YES	constant	variable	-	DSF400_e

Table **1**. Comparative test cases completed.

1.2.3 Weather data

The weather data used for the comparative test cases is based on the Danish Design Reference Year, which is valid for the geographical site location in Værløse, Copenhagen, Denmark. All of the comparative test cases were defined for the period from 17.04 until 30.04. In the test case DSF200_3, modifications were necessary in the weather data file, as the test case is specified for natural ventilation flow in the double facade cavity, which is driven due to pure buoyancy force. In order to ensure the condition of pure buoyancy, the wind speed in the weather file was set to zero.

It is necessary to point out, that due to the same internal and external boundary conditions for all test cases (except the absence of wind influence in the test case DSF200_3), it is possible to make a comparison of simulation programs' performance for different ventilation strategies.

1.2.4 Test case objective

The test cases completed during the comparative validation are defined according to their operation strategy. Since only a limited number of comparative exercises were defined, each test case represents a separate double facade operation strategy. Moreover each test case includes a number of constant and variable parameters and by the completion of the exercise it provides information on a limited aspect of the DSF modeling, while completion of all comparative exercises provides an overall picture of the suitability of various building simulation programs for simulation of buildings with a double skin facade.

The test case DSF100_2 is twofold from the complexity point of view. In truth, the convective flows in the DSF cavity with the all openings closed can become very complex and very difficult to model, however, the building simulation tools aren't always able to model the intricate convective flows. In many occasions the convective models are simplified and the test case becomes relatively easy to model. An application of the advanced convection modeling for this case may involve coupling of building simulation tool with CFD or involve superior models for evaluation of flow regime and convective heat transfer coefficients and, as a result, the modeling become more complex and time consuming. Despite the complexity of the convective flows modeling, this test case together with test case DSF400_3 is mainly used for validation of the test case specification and the model itself.

The simplest case of the DSF modeling is represented by the test case DSF400_3. This time the mechanical driving force ensures a constant airflow in the double facade cavity. The air is heated up in the cavity and supplied in to the adjacent room; as a result, this case represents the dynamic interaction between the DSF performance and the building's systems.

The overall building thermal performance has changed in the test case DSF400_3 compared to DSF100_2, however, both of these test cases were used for validation of the test case specification and then to test the building simulation software on its general ability to model transmission of solar radiation, long wave radiation exchange and overall building thermal performance.

The other two cases (DSF200_3 ad DSF200_4) are identical, except for the fact that there is no influence from wind in the test case DSF200_3. These are the most complex cases and involve predictions of the natural driving forces for calculation of the air flow rate. According to [2] prediction of the energy consumption in a DSF is not easy, modeling of the DSF cavity involves heat transfer, optical and air flow elements. The air flow element, especially in naturally ventilated spaces, is the most difficult to deal with and as a consequence it is very difficult to predict the energy consumption in buildings with naturally ventilated DSF. Evaluation of models for calculation of the natural ventilation phenomenon became a part of the current subtask exercise.

On the whole, every test case covers a separate area of DSF modeling and as a result gives an idea about software application and performance for modeling DSF in one or another operational mode, requirements for the model complexity etc.

1.2.5 Definition of zones

There are two main zones defined in the comparative test cases. Experts were asked to model a double skin facade as a separate zone – zone 1. The zone adjacent to the double skin facade is defined as zone 2, the experiment room. The heating and cooling system in zone 2 keeps the air temperature in the zone constant at 20ºC. The ability of building simulation tools to simulate the necessary energy consumption in zone 2, and the air temperature and airflow in zone 1 are the main quantitative measures of the building simulation tool performance and its validation.

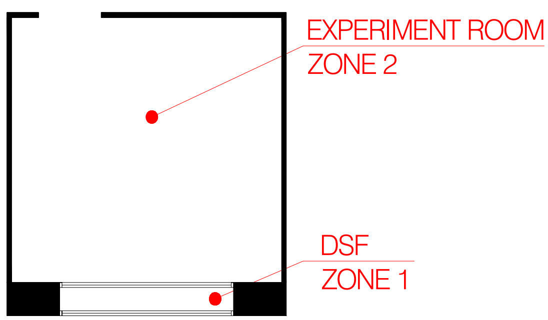


Figure 2. Definition of zones in the comparative test case specification.

1.2.6 Modeling requirements

Various building simulation software includes different approaches and applications for modeling of the physical processes involved. Initially, it was desired that all case-models involve the same applications for the same parameters in every model and use the most detailed level of modeling allowed by simulation program being tested.

Cases specified for the modeling involve interaction of various processes; thus modeling may require different combinations of software applications and their options. For this reason the building and its systems were specified in detail, but the way in which they were modeled was not prescribed. The design of the model had to be completed depending on the capability of the simulating software and the user's decision, but as close as possible to the specification.

In addition, it was requested that participants perform consistent modeling of the test cases. Modelers were asked to include in the modeling report detailed documentation of any discrepancy between the test case specification and the model.

1.2.7 Output parameters

The output parameters are defined in the specification. The following are the output parameters shared for all test cases:

N	Output	Unit	Description
1	Direct solar irradiation on the window surface	W/m²	Mean hourly value
2	Diffuse solar irradiation on the window surface	W/m²	Mean hourly value
3	Total solar irradiation on the window surface	W/m²	Mean hourly value
4	Total solar radiation received on the external window glass surface	kW	Mean hourly value
5	Solar radiation transmitted from the outside into zone1	kW	Mean hourly value
6	Solar radiation transmitted from zone 1 into zone2 (first order of solar transmission)	kW	Mean hourly value
7	Energy used for cooling/heating in the zone 2	kW	Mean hourly value (with the '+'sign for heating and '-'sign for cooling)
8	Hour averaged surface temperature of external window surface facing external	°C	Mean hourly value
9	Hour averaged surface temperature of external window surface facing zone1	°C	Mean hourly value
10	Hour averaged surface temperature of internal window surface facing zone1,	°C	Mean hourly value
11	Hour averaged surface temperature of internal window surface facing zone2	°C	Mean hourly value
12	Hour averaged floor surface temperature in the zone 1	°C	Mean hourly value
13	Hour averaged ceiling surface temperature in the zone 1	°C	Mean hourly value
14	Hour averaged floor surface temperature in the zone 2	°C	Mean hourly value
15	Hour averaged ceiling surface temperature in the zone 2	°C	Mean hourly value
16	Hour averaged air temperature in the zone 1	°C	Mean hourly value

Table 2. Output parameters shared for the all test cases.

In the test cases DSF100_2 and DSF400_ 3 the solar altitude is included as a separate output parameter. In the test case DSF200_3 and DSF200_4 the air flow rate is included as a separate output parameter.

1.3 Participants in the comparative validation

Results of the comparative exercise are compared between several building energy simulation programs. The following is the list of organizations who participated in the exercises and the simulation programs they used to perform the simulations.

Organization		Program
VABI	VABI Software BV Netherlands	VA114
ESRU	Dept. of Mechanical Eng. University of Strathclyde Glasgow Scotland	ESP-r
TUD	Technical University of Dresden (TUD) Germany	TRNSYS-TUD
LTH	Division of Energy and Building Design Department of Architecture and Built Environment Lund Institute of Technology (LTH) Sweden	IDA
AAU	Dept. of Civil Engineering Aalborg University Denmark	BSim

Table 3. Organizations who performed the simulations and the simulation programs used.

2. THE DOUBLE SKIN FAÇADE THEORY AND MODELING OF THE COMPARATIVE TEST CASES

2.1 Modeling of the double skin façade

This chapter of the report is aimed to summarize the main issues when modeling a DSF performance. The complexity of the DSF modeling is well known and there are no doubts about the necessity for the comparative and empirical exercises completed during the IEA Annex 34/43 activity. On the contrary, a general concern is expressed in the literature about the lack of the experimental data and validated software tools for the DSF buildings [1]. Moreover, there is a literature available with the clarification *why* it is difficult to perform the modeling of the DSF performance. Looking upon these arguments it is easy to understand why there is still an active hunt for a better model for the DSF modeling.

From another point of view, there are number of well developed building simulation tools, able to perform calculations necessary for the DSF modeling. Then appear a question:

- Does the claim that none of the simulation tools are able to perform an accurate modeling of a building with the DSF express a general fear for DSF modeling?
- Or does this a call for a new DSF model appear due to the lack of experience and knowledge about the DSF physics, when applying already existing building simulation tools or lack of knowledge about the suitable tool to use?
- Or is this just a call for a model that would simplify the modeling of the DSF?

In the literature review [1] it is explained why it is difficult to model the double skin façade. There is also made a classification of the main elements in the DSF physics, these are the optical, heat transfer and air flow element. Earlier, the participants of the comparative and empirical exercises have agreed that the optics and heat transfer elements are the common issues for the whole field of building simulations, then this report and whole activity of the subtask is focused on the investigations of the air flow element in modeling of the DSF performance, as it's assessment is crucial for the indoor climate and evaluation of the performance of the double skin façade.

However, the convective flows in the DSF cavity can be very strong and can have a serious impact on a final result of simulation. At the same time the different building simulation software uses different models in calculation of surface heat transfer coefficients. In order to help reader in evaluation of performance of different simulation tools, this chapter includes a section with a short summary over the surface heat transfer coefficients used in different models, while even more details can be found in the modeler reports, see in appendix.

2.2 Surface heat transfer coefficients. Convection

All of the models in the comparative validation exercises make a split between the convective and radiative surface heat transfer coefficients. As it can be seen from the table below, all of the models use longwave radiation exchange with the sky and the ground, the details about it can be found in the modeler reports. When looking upon the level of detail in modeling of external longwave radiation exchange all of the models include almost the same level of detail and therefore this will not be discussed further. However, it is not possible to do the same conclusion on the subject of convection heat transfer, as it will be demonstrated in this section. But first, the role of convective heat transfer in the specified comparative test cases is discussed.

The operational mode of the DSF can vary according to its function in one or another building, but the design of the DSF cavity is more or less the same: two layers of fenestration, subdivided by an air gap, which, in most of the cases, includes shading devices. No matter the operational strategy of the DSF, the air temperature in the gap is the result of the solar radiation absorbed by glazing and/or shading device. As a result, the air temperature in the DSF cavity is mainly the result of the convective heat transfer between the heated surfaces of glass and air. The floor or ceiling and side walls of the DSF rarely have any importance, as the weight of their areas is very small compared to the area of fenestration and shading.

The convective heat transfer is relatively easier to estimate for the mechanically induced flow motion compared to the naturally driven flow, where the convection heat transfer depends on size, shape, orientation, flow regime, temperature etc. At the same time the results of simulations can be very sensitive to the convective heat transfer coefficient in the models.

There are four cases defined in the comparative test case specification, only one of the cases involve air flow induced by mechanical driving forces, all the others are the cases where the flow motion is caused by the natural forces and the differences between the convection heat transfer coefficients in the models are important. Below is the table of summary of the convection heat transfer coefficients used in models in the comparative exercises.

Software	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
External heat transfer coefficient					
Convection, function of	if $v_{wind} \leq 5$ $h = 5.82 + 3.96 v_{wind}$ else $h = \frac{7.68 \cdot v_{wind}}{\sqrt{v_{wind}}}$	18 W/(m^2°C)	wind vel., wind dir.	25 W/(m^2°C)	$V_{loc}^{windward} = \max(0.25 v_{wind}; 0.5)$ $V_{loc}^{leeward} = 0.3 + 0.05\ v_{wind}$ $h = 5.678 \cdot \left(a + b \cdot \left(\frac{V_{loc}}{0.3048}\right)^n\right)$ if $v_{wind} \leq 4.88$ $a = 1.09,\ b = 0.23,\ n = 1$ else $a = 0,\ b = 0.53,\ n = 0.78$
Radiation (components)	sky, ground	sky, ground	sky, ground	sky, ground	sky, ground
Internal heat transfer coefficient					
Convection, function of	for vertical surfaces: *if* $\Delta T \leq 9.5/L^3$ $h = 1.42\left(\frac{\Delta T}{L}\right)^{0.25}$ *if* $\Delta T > 9.5/L^3$ $h = 1.31(\Delta T)^{0.33}$	3 W/(m^2°C)	Δ t, surface inclination - buoyancy flow- for all cases except DSF400_3 - channel flow include functions	4.4W/(m^2°C), except 3W/(m^2°C) for ceiling and floor	Δ t, surface inclination include functions
Radiation	Linearized coefficients based on surface emissivity and view factors	Linearized coefficients based on surface emissivity and view factors	Linearized coefficients based on surface emissivity and view factors	Nonlinear treatment of radiation heat exchange	Linearized coefficients based on surface emissivity and view factors

2.3 Air (mass) flow models

This section deals with the models for calculation of the air flow rate in a naturally ventilated DSF cavity applied in the comparative validation exercise. The air flow in naturally ventilated spaces is induced by the pressure differences, which evoke from the wind pressure, wind fluctuations and buoyancy forces (the mechanical force is not discussed in this section). The determination of the buoyancy force is straight forward, while the main difficulties in the theory of the natural ventilation exist due to highly transient wind phenomenon.

There is a number of approaches used for calculations of air flow in a naturally ventilated (multizone) buildings, however, all of them have most of the following issues in common:

- Challenge to represent the wind speed reduction from the meteorological data to the local microclimate near the building

- Challenge in determination of the wind pressure coefficients
- Challenge to decide on appropriate discharge coefficients and pressure loss coefficients in general
- Challenge to agree on an appropriate relation between pressure loss and air flow rate through the opening (determination of coefficients in the relationships), etc.

Depending on external conditions and the double skin façade running mode the air flow rate in a ventilated cavity can have significant variation in order of magnitude and in occurrence of a reverse flow. Contradictory, in a traditionally ventilated domain the minimum air change rate is specified in requirements for the indoor air quality, while maximum is normally restricted by the energy savings considerations. In view of that, the great variations in the magnitude of the airflow rate are identified as the distinctive element of the cavity flow. The variation of the flow magnitude may result in variation of the flow regimes and will further intricate the situation.

The commonly used models for calculation of the natural air flow rates are:

- The network pressure model – is based on continuity equations to determine pressures in different zones of the network and then the air flow rates are determined on the basis of different relationships (orifice, power-law etc.)
- The loop pressure equation model – is method where the pressure loop equations are written for the whole air path loop, and the air flow rate is determined on the basis of those equations.
- The experimental method is using empirical relationships for the determination of the air flow rates depending on temperature, wind speed, pressure difference coefficients and the discharge coefficient.

The pressure network and the pressure loop method are very similar. Moreover, both of these methods can apply the orifice and the power-law relationships for determination of the air flow rate on the basis of pressure difference. However, an application of one or another relationship is a sensitive matter, as the classic orifice equation is more suitable for the large openings and fully developed turbulent flow. Meanwhile the power-law equation is more flexible and can be adjusted to different conditions and opening sizes via the exponent *n* and coefficient *C*.

Equation 2-1

$$\Delta P = \frac{\rho \dot{V}^2}{2 \cdot C_D \cdot A^2}$$ Orifice equation

Equation 2-2

$$\Delta P = \left(\frac{\dot{V}}{C}\right)^{\frac{1}{n}}$$ Power-law equation

ΔP	- pressure difference across the opening
ρ	- air density
$\dot{V}$	- volume flow
C_D	- discharge coefficient
A	- opening area
n, C	- exponent and flow coefficient

The experimental method is the simplified one, where the transient character of the wind is simplified and a relationship as shown below used for the calculation of air flow rates.

Equation 2-3

$$\dot{V} = \left| \frac{c_v}{|c_v|} \cdot (c_v \cdot V_{10})^2 + \frac{\Delta T}{|\Delta T|} \cdot (c_t \cdot |\Delta T|)^2 \right|^{1/2}$$

Equation 2-4

$$c_t = \sum_{j=1}^{n} c_{D,j} \cdot A_j \cdot \left(\frac{2 \cdot (H_o - H_j) \cdot g}{T_i} \right)^{1/2}$$

Equation 2-5

$$c_v = 0.03 \cdot A$$

$\dot{V}$	- volume flow
c_v, c_t	- coefficient for the wind force and buoyancy correspondingly
V_{10}	- the reference wind velocity at the height 10m
ΔT	- temperature difference between two environments
n	- number of openings
j	- opening number
C_D	- the discharge coefficient
A_j	- area of the opening 'j'
H_o	- height of the neutral plan
H_j	- height of the opening 'j'
g	- gravity force

The summary of the model used for the comparative exercises is done in the table below:

Software		BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Influencing parameters in the flow model	wind force	x	x	x	x	x
	wind fluctuations	-	x	-	-	-
	buoyancy	x	x	x	x	x
Air flow model*		experimental	network	network	network	network
Pressure-Airflow relationship used			power-law	orifice	???	orifice
Coefficients in the power-law equation	exponent n		?		?	
	coefficient C		?		?	
Discharge coefficient for openings		0.65	0.61	0.65	0.65	0.65
Pressure difference coefficicents		different from spec, ΔCp=0, but wind impact is included by application C_v-coefficent	different from spec, ΔCp=0	as in spec	as in spec	interpolated from spec. ?
Model for wind fluctuations		-	[7], [8]	-	-	-

* None uses the loop equations

Openings in the comparative exercises were specified, all of them have the same orientation and therefore the wind pressure component can become less influencing or even assumed to be zero (in VA114). In such situation the wind turbulence can generate a substantial flow rate. However, only VA114 consider the wind fluctuations.

The pressure coefficients given in the comparative test case specification are given for the wind velocity at the building height (6m), however the wind velocity in the climate data file is given for the wind velocity at the 10m height. Besides the parameters included into the table above the reduction of the wind speed to the local terrain next to the building can have some degree of influence on the calculations of the wind pressure magnitude and influence of the wind turbulence for the air flow calculations. Below is given the comparison of the wind speed reduction relationships used in different models and it demonstrates that the models use almost the same wind reduction relationship in the simulations.

Software	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Reduction factor to the reference wind velocity at the height of 10m	0.922	0.922	0.922	1 (?)	ASHRAE ?

3. RESULTS FROM THE COMPARATIVE TEST CASES

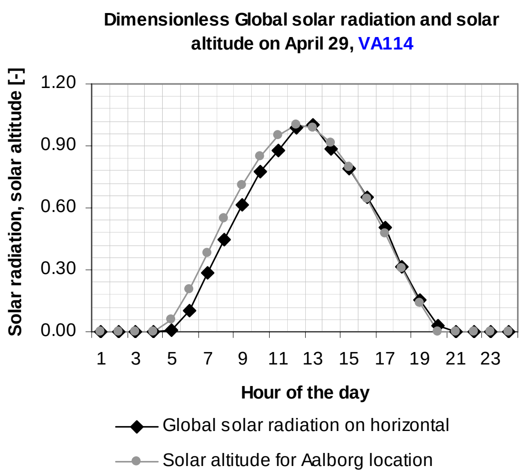
3.1 Foreword

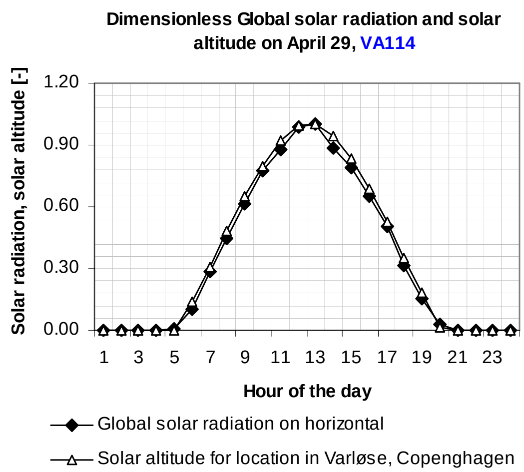
The identification of iterations in the sets of comparative exercises is difficult, in the first place because of a large number of the test cases defined, and secondly because the test cases were introduced to the participants stepwise with increasing complexity, where the trivial errors were identified and corrected at the first stages of comparative validation. As a consequence further simulations and results were obtained with better correspondence. Finally, due to the continuous feedback from the experts and adjustments made along with the comments it is best to describe only final results of the comparative validation.

The identification of the errors in the first stages of comparative validation was mainly related to the model design and definition of boundary conditions. At this stage the solar altitude was included as an output parameter to validate calculations of solar irradiation.

Originally the geographical site location for the comparative test cases was set the same as for the empirical ones (Aalborg), however the climate data in the comparative test cases provided to the participants was prepared on the basis of the Danish Design Reference Year with the solar irradiation measured in Værløse.

Comparison of maximum of the solar altitude and maximum of solar irradiation on the horizontal surface on a clear day showed a time shift of approximately 10 min, because of differences in site location for Aalborg and Værløse. In view of that the geographical site location in the comparative specification was changed to Værløse. Comparison of Værløse and Aalborg location is given in the figures below.





The evaluation of the results from the comparative test cases will be performed in the following sections, separated for each test case, with application of three types of plots:

1. Profiles with the results from the whole period of simulation
2. Profiles for a day with the high and low solar irradiation
3. Figure of the average, min and max values over the whole period of simulation

The first method of evaluation is very easy and visual: it gives an overview of the whole situation, and allows the identification of conditions when the model experiences difficulties etc. More details can be seen in the plots made for a day with the high and day low solar radiation. The days number 5 and 6, were used for all test cases in the comparative specification for closer comparison of the results. The day number 5 is the day with the relatively low solar intensity and the day number 6 is characterized with relatively high solar intensity. The final evaluation is supported with some statistical data and bar-plots for min, average and max values.

There is no detailed statistical analysis performed for the comparative test cases, as it requires a reference value to compare with the obtained results of simulations and no analytical solution exists.

3.2 Investigation of boundary conditions

The comparative test case specification includes weather data files used for the simulations. As mentioned before, the boundary conditions described by the weather data were the same for all test cases except the test case DSF200_3 (pure buoyancy case: wind velocity was set to zero). Starting with the same climate data, the different building simulation tools use different models for calculation of solar irradiation on the surface and solar radiation transmitted into a zone through a fenestration.

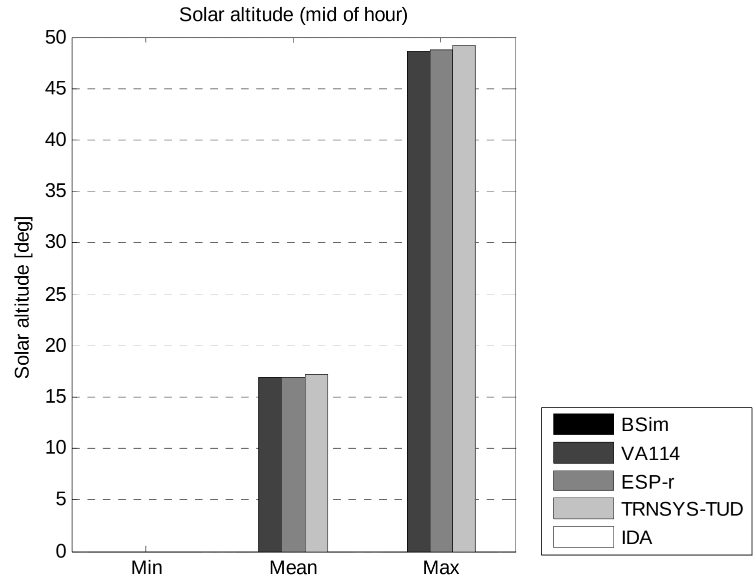
In order to be able to compare results from the comparative test cases, first, it is necessary to look at the boundary conditions which are *calculated* by various programs on the basis of defined weather conditions. These are the solar altitude, solar irradiation on the double skin facade surface (direct, diffuse and total), solar radiation transmitted into the DSF and into the adjacent experiment room. The experts were asked to include the solar altitude as an output parameter. There are three programs able to give an access to this data. Their results are compared in the following sections.

During the first iterations, various solar models were used in calculations of incident solar radiation, these are the Petersen model [3], the Perez model (1990) [4], the ASHRAE 1997 model [5], the Perez model(1987) [6]. In the VA114 model the circumsolar radiation was treated as direct, while in the other models, the circum solar radiation was treated as diffuse. The diversity of the solar models used in the first iterations of the comparative test case resulted in certain disagreements. Later on, the disagreements were minimized, as all modelers completed their simulations with the Perez model (1990 or 1987) and the circum solar radiation treated as diffuse. The choice of the Perez model was partly made on the basis of preliminary empirical results and previous experience from the other IEA tasks.

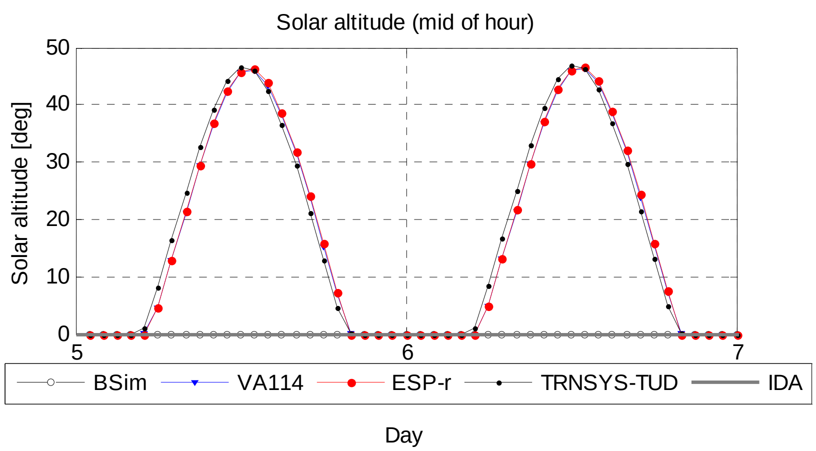
Calculation of the solar irradiation on a surface mainly depends on the solar model used in calculations. The differences between models are often expressed in different treatment of circum solar radiation and in calculations of the diffuse solar radiation, in general. Transmission of solar radiation depends on such factors in the model as:

- Calculation of solar path and path of solar radiation through the building (calculation of sunlit surfaces and surfaces in the shadow)
- Various treatment of diffuse and direct solar radiation (when calculating transmission of solar radiation)
- Level of detail in the window model
- Model for calculation of ground reflected solar radiation
- Incidence angle dependency
- etc.

3.2.1 Solar altitude



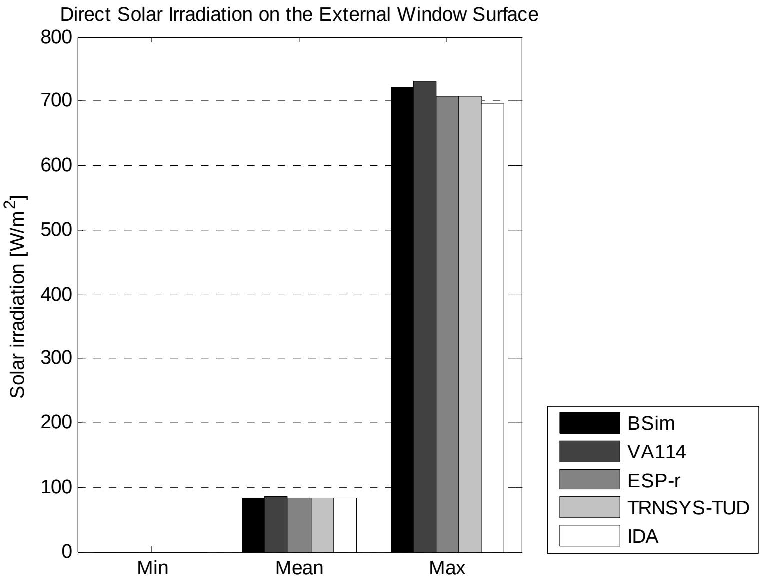
Solar altitude	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, deg	-	0	0	0	-
Max, deg	-	48.6	48.8	49.2	-
Average, deg	-	16.8	16.9	17.2	-



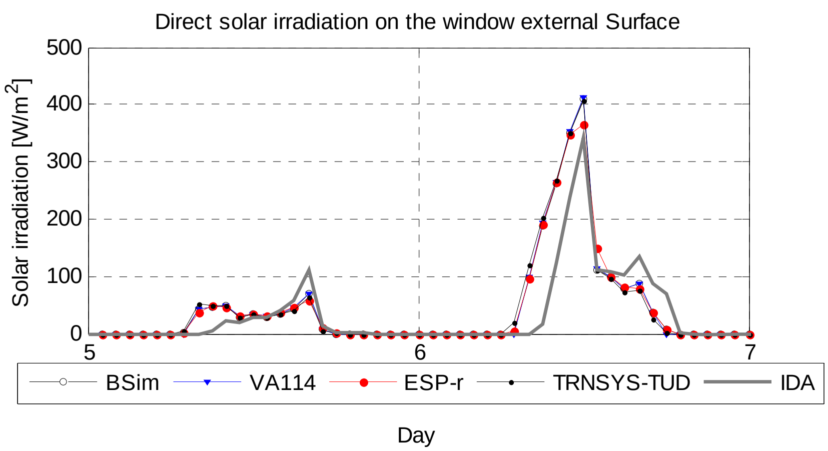
Unfortunately, the solar height is available only for three programs: VA114, TRNSYS-TUD and ESP-r. From the above plots and the table, it is noticeable that there is a slight difference in calculation of the solar height, TRNSYS-TUD seems to be 1 hourahead of ESP-r and VA114 When calculate the sunrise, while the sunset is calculated the same as the others.

Next, the solar irradiation on the external double facade surface is investigated via diffuse and direct component of global solar flux.

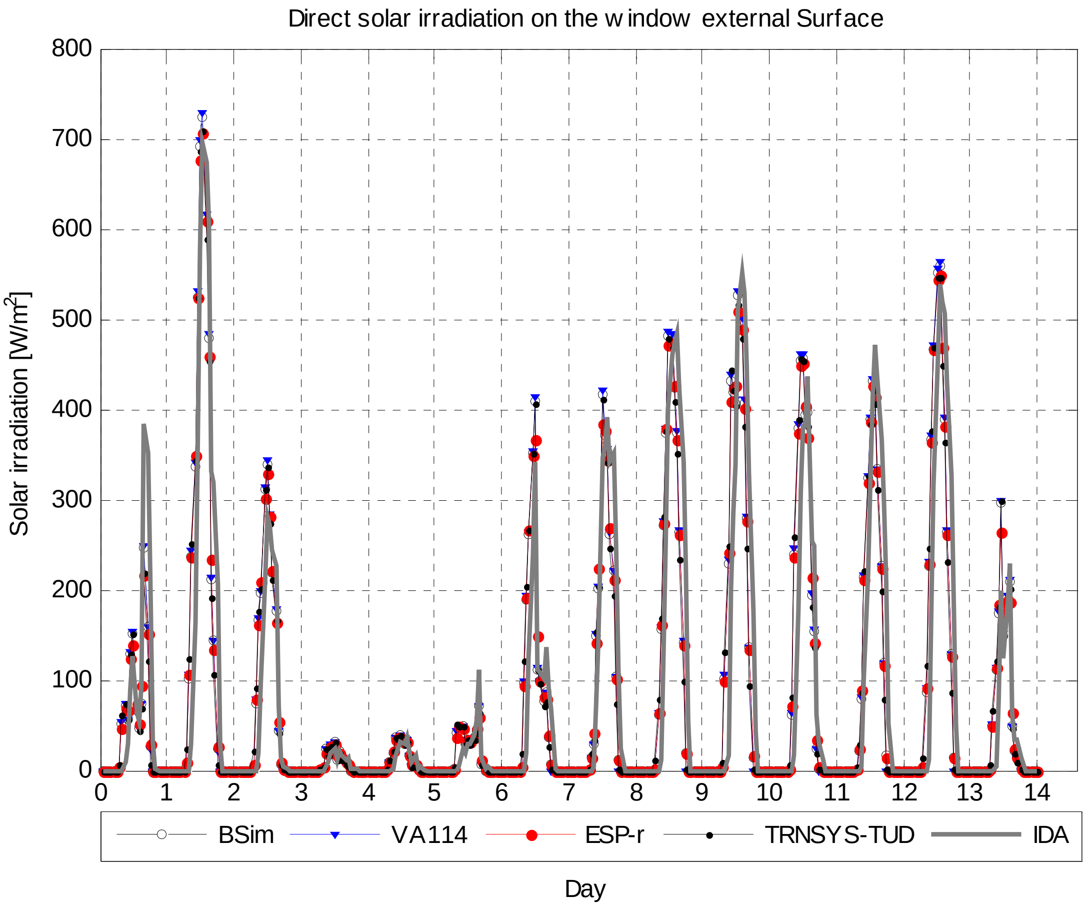
3.2.2 Direct solar irradiation



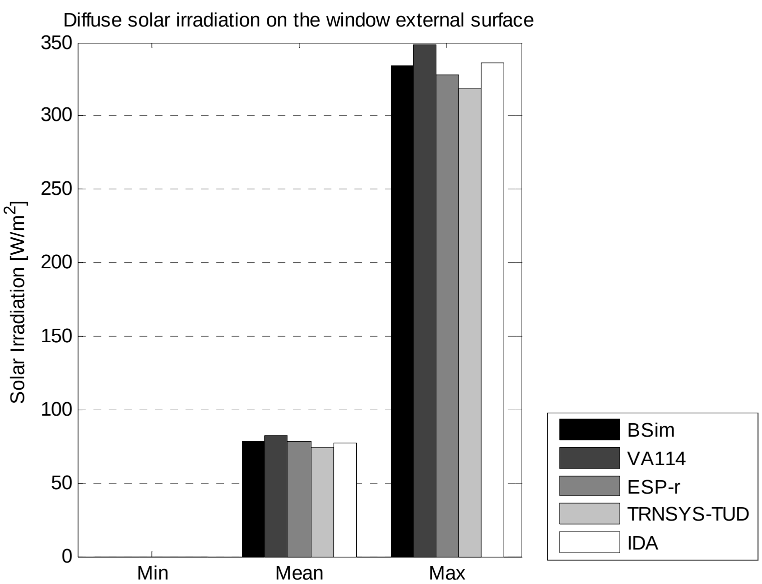
Direct solar rad. on ext window surface	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, W/m^2	0	0	0	0	0
Max, W/m^2	723	730	707	708	697
Average, W/m^2	84	85	84	82	82



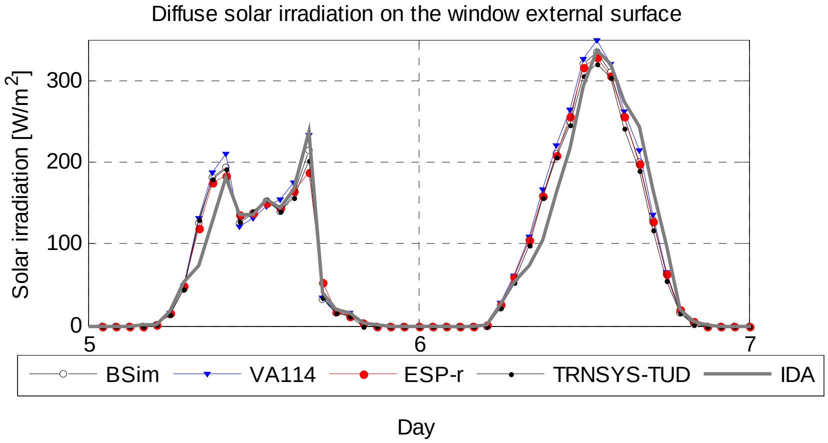
There are two groups of results for direct solar irradiation when compare the maximum values: the higher values belong to BSim and VA114 and the lower values belong to ESP-r, TRNSYS-TUD and IDA. Good correspondence of the results can be seen for the average values and especially for the days with the low solar intensity (see figure below). The 2-day plot of the results demonstrates a time-shift in IDA results, from evaluation of the time scale one can approximate this time shift to 1 hour, unfortunately the solar altitude hasn't been reported by IDA to perform further analysis.

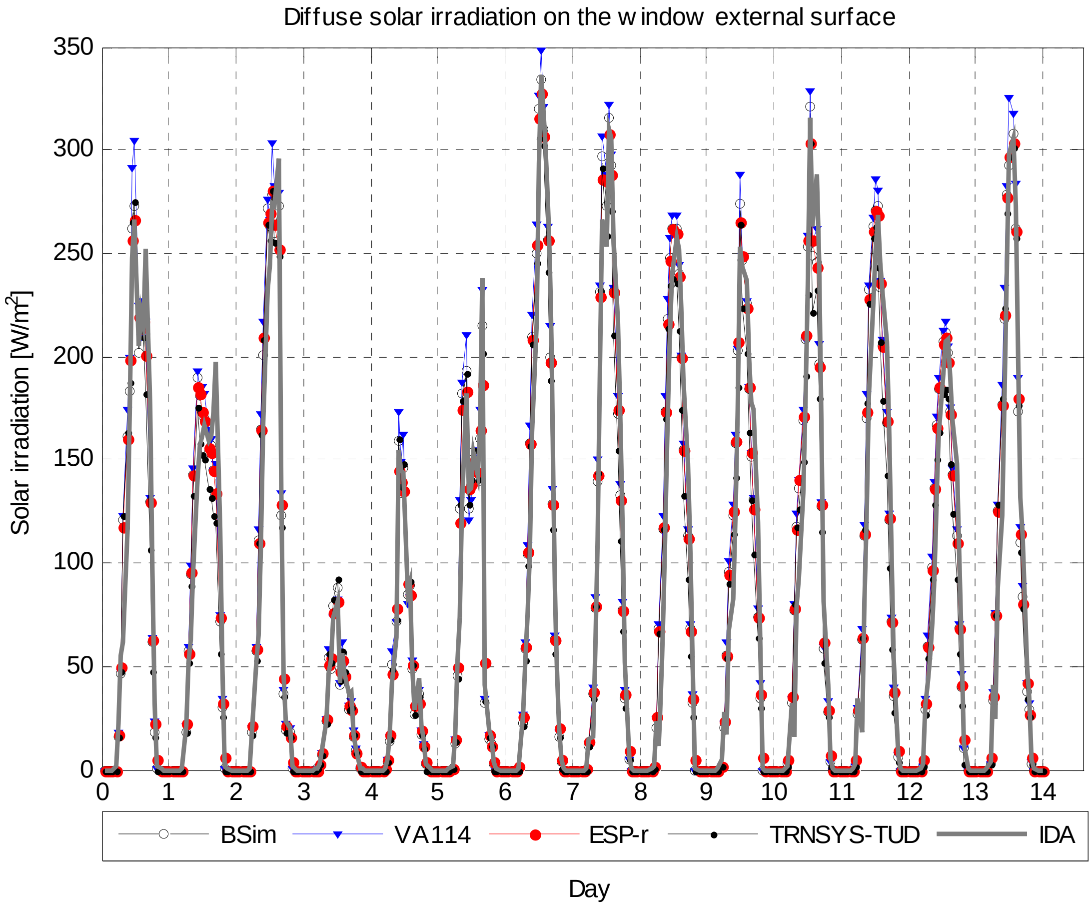


3.2.3 Diffuse solar irradiation



Diffuse solar rad. on the window ext. surface	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, W/m^2	0	0	0	0	0
Max, W/m^2	334	348	328	319	336
Average, W/m^2	79	82	79	74	77

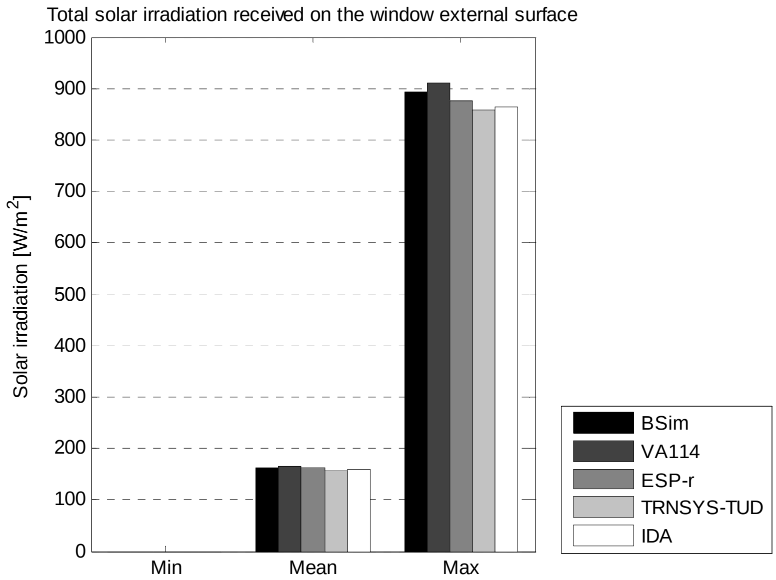




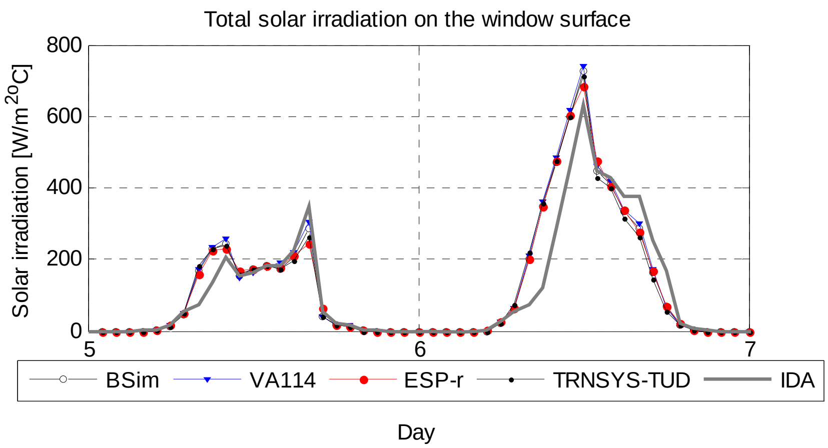
Prediction of the diffuse solar radiation shows relatively good correspondence between the mean values, while the maximal differ: highest values belong to VA114 and the lowest to IDA. Similar to the direct solar radiation, IDA results demonstrate some time shift, which is seen in 2-days plot.

The above plots of diffuse solar radiation depict the final results of simulations which are in good correspondence (all of the models have used Perez solar model). In the preliminary results the deviations in calculated diffuse solar radiation were more significant. The main cause of deviations was application of different solar models and different treatment of circum solar radiation.

3.2.4 Total solar irradiation

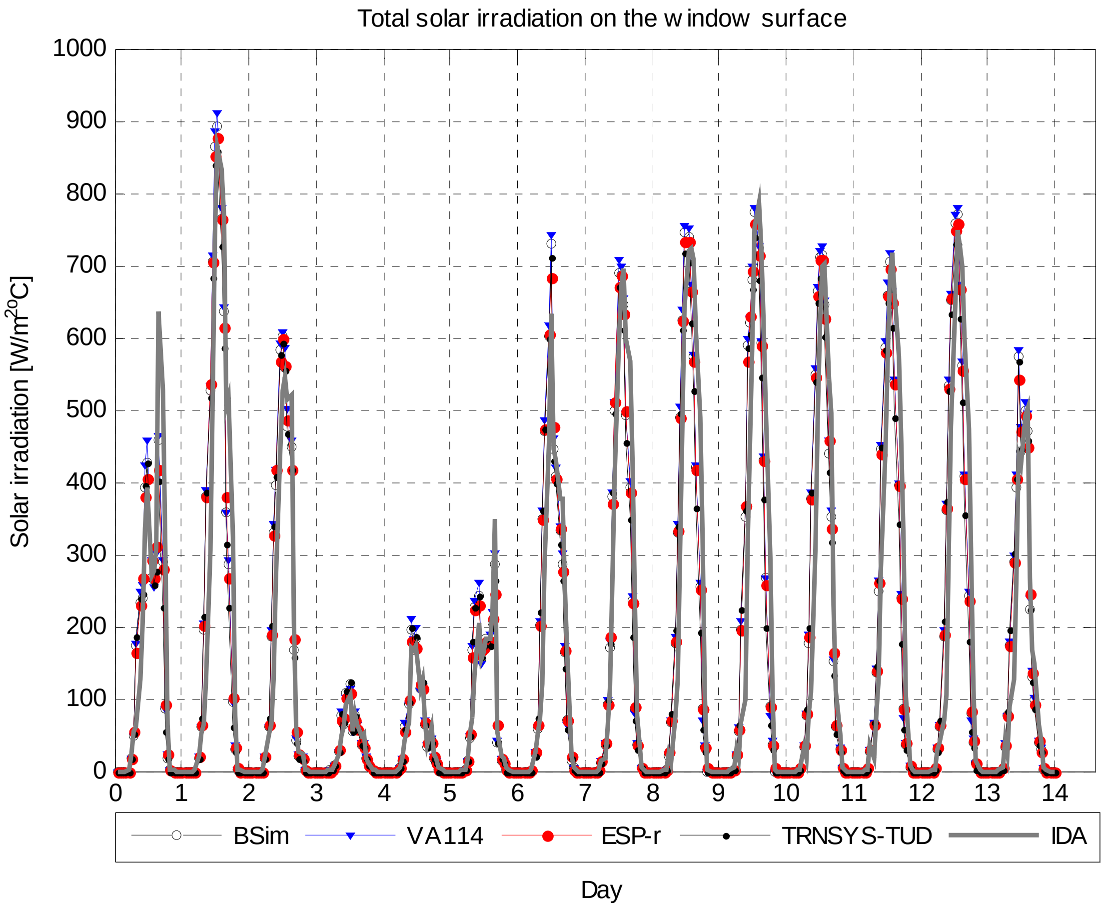


Total solar irradiation	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, W/m^2	0	0	0	0	0
Max, W/m^2	893	912	875	859	864
Average, W/m^2	162	167	162	156	159



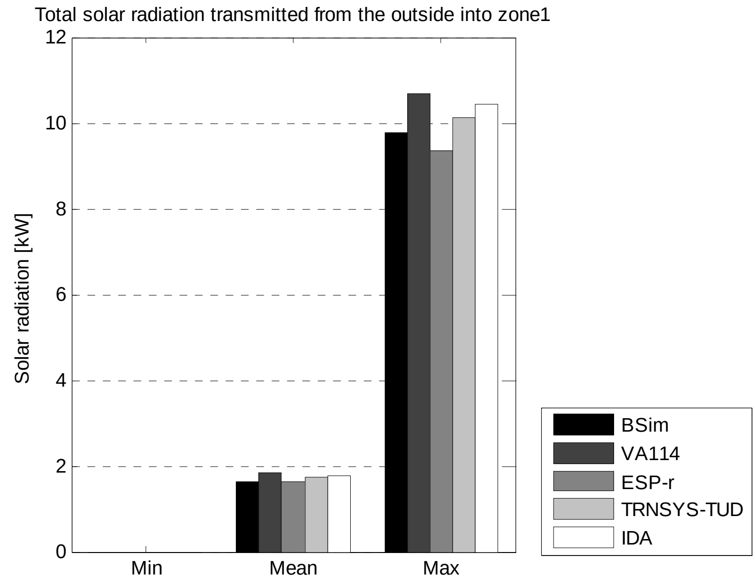
Good correspondence of the results when calculate the diffuse and direct solar radiation result in a total solar radiation with the final deviations, which are relatively small (±5W/m^2 of mean values). Still, the maximum values are characteristic for VA114.

With regard to IDA, the time shift can be seen. Since these are the initial conditions, which are characterized with the time shift, this will have an impact on the result and all of the parameters in the output log will have a touch of it.

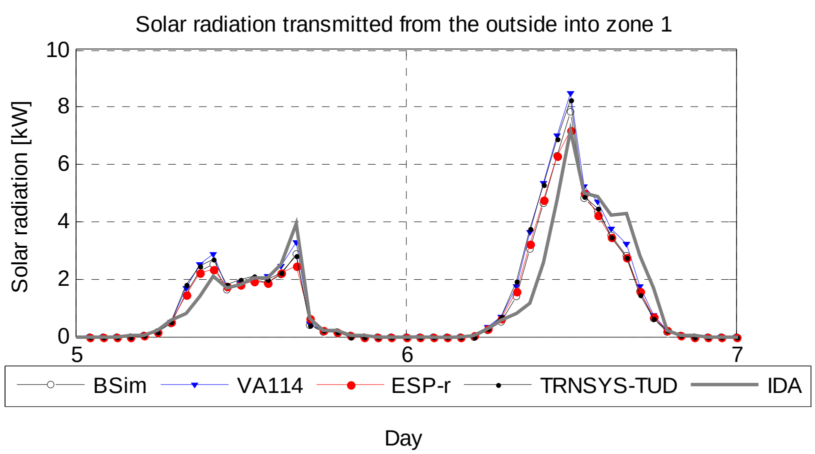


Total solar irradiation on the w indow surface
Solar irradiation [W/m2oC]
1000
900
800
700
600
500
400
300
200
100
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day

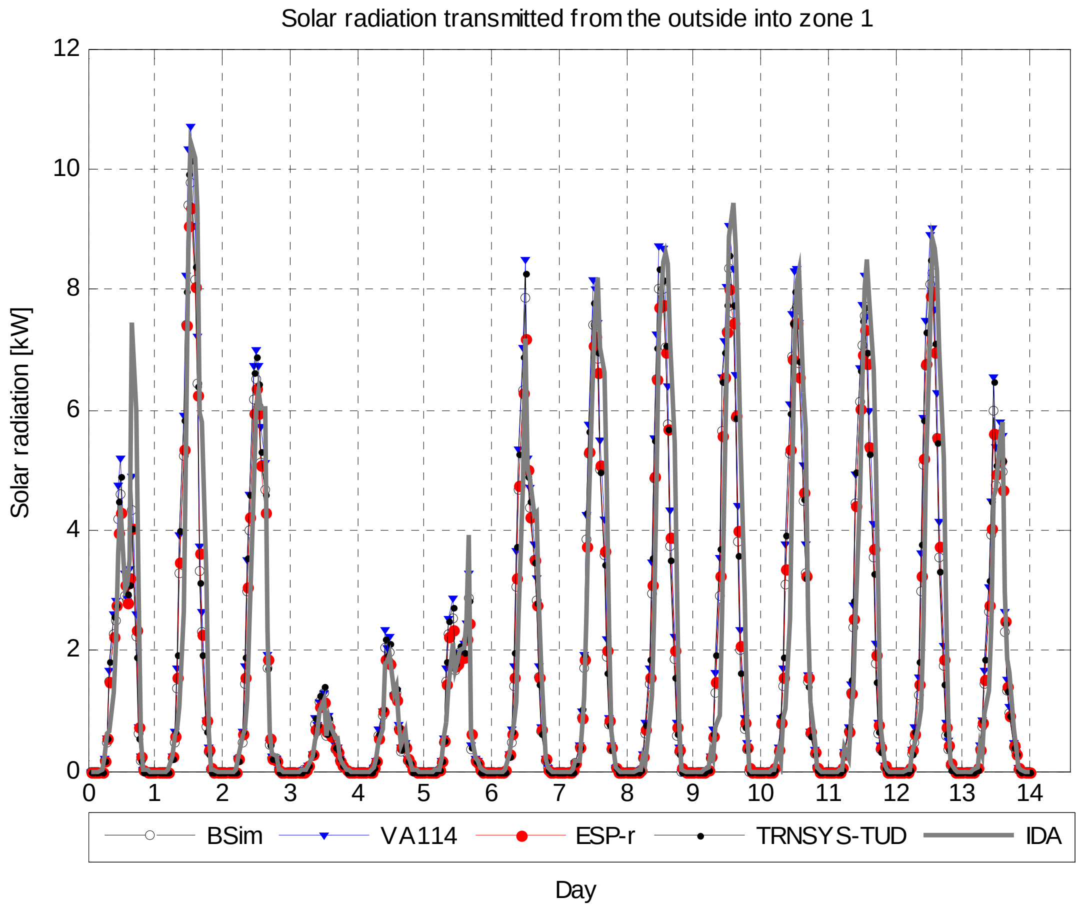
3.2.5 Solar radiation transmitted into the zone1 (first order of solar transmission)



Solar rad. transmitted into the zone 1	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, kW	0	0	0	0	0
Max, kW	9.8	10.7	9.4	10.1	10.4
Average, kW	1.6	1.8	1.6	1.7	1.8

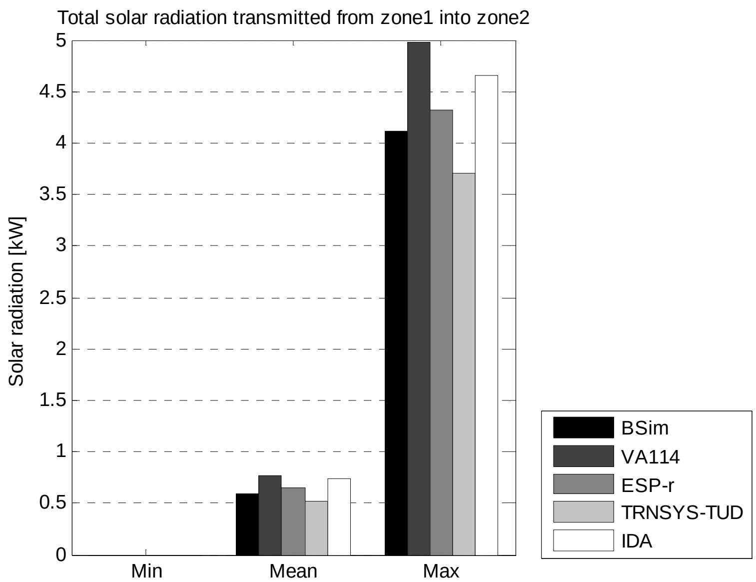


Transmission of solar radiation into the DSF (zone 1) shows good correspondence of the mean values. Again, there are two groups of the results: a group with the higher values (VA114, TRNSYS-TUD and IDA) and a group with the lower values (BSim and ESP-r).

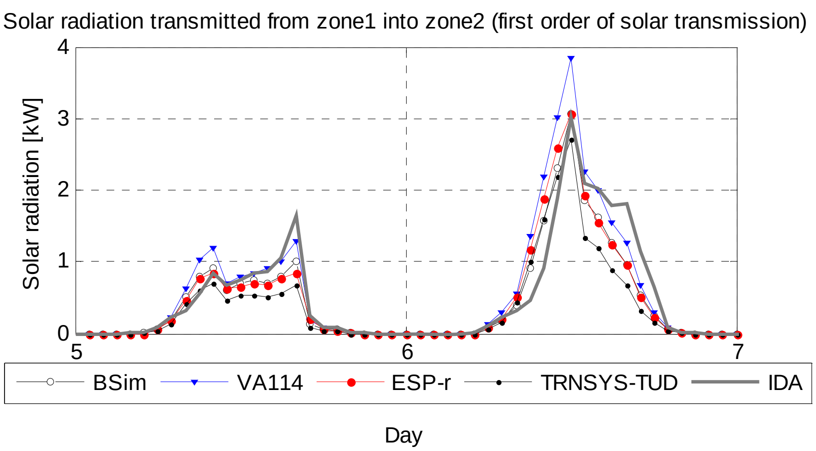


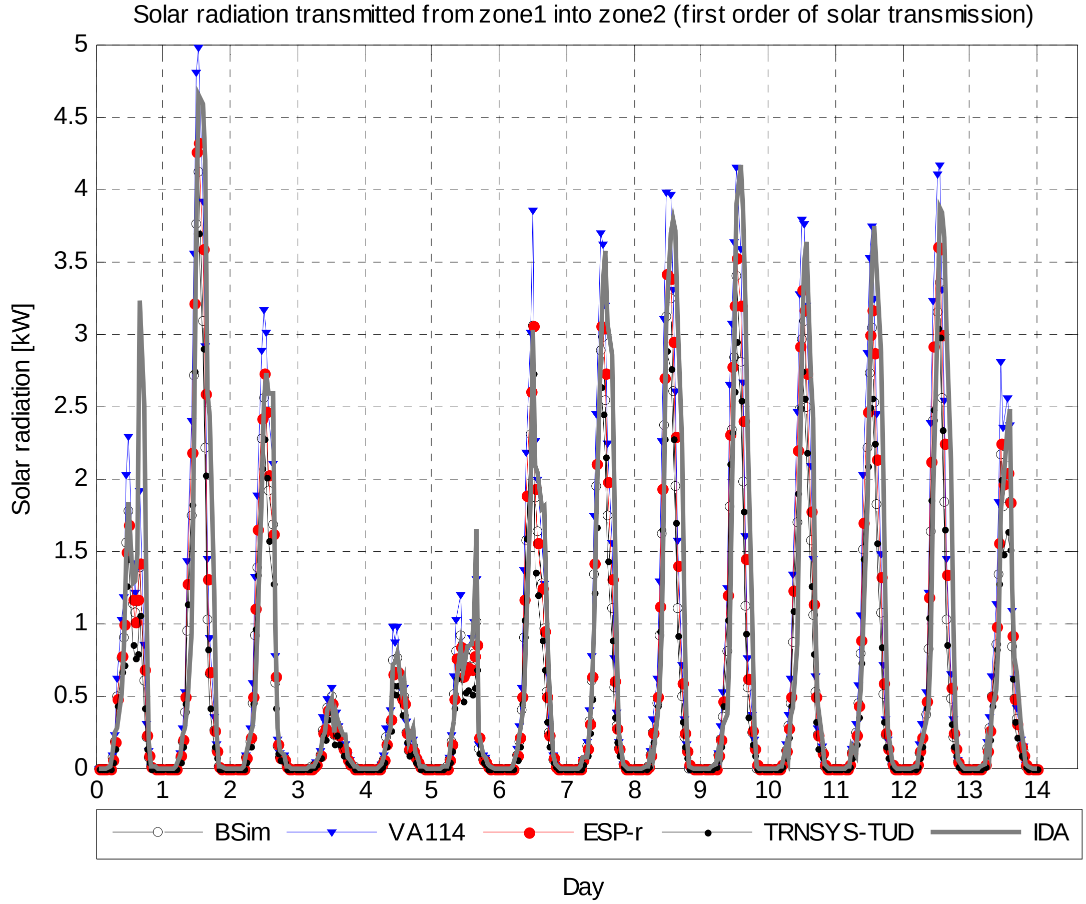
Solar radiation transmitted from the outside into zone 1
Solar radiation [kW]
0
2
4
6
8
10
12
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day

3.2.6 Solar radiation transmitted into the zone2 (first order of solar transmission)



Solar rad. transmitted into zone 2	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, kW	0	0	0	0	0
Max, kW	4.1	5.0	4.3	3.7	4.7
Average, kW	0.6	0.8	0.6	0.5	0.7





There were two groups of the results in the previous section of solar radiation transmitted into the zone 1: the group with the higher values [VA114, TRNSYS-TUD and IDA] and the group with the lower values [BSim and ESP-r]. Now, results of solar radiation transmitted into the zone 2, reform the high and low value groups differently: the high value group includes IDA and VA114, while the low value group is formed by BSim, TRSYS-TUD and ESP-r.

Investigation of the results starting with the solar radiation incident on the window surface, solar radiation transmitted into the zone 1 and the one transmitted into the zone 2 do not demonstrate any consistency in forming the groups of high an low values. Therefore, it is necessary to perform further analysis of the results applying some measures to complete the examination, which is done in the next section 3.2.7. For now, it is possible to say only that in these comparative exercises different window models used by the different software. However, the correspondence of the mean and maximum values is reasonable.

3.2.7 Transmission of solar radiation

This section is focused on investigation of the window model used in different software. The reason for that was explained in the previous section, however, there the quantitative measures were lacking for the final evaluation.

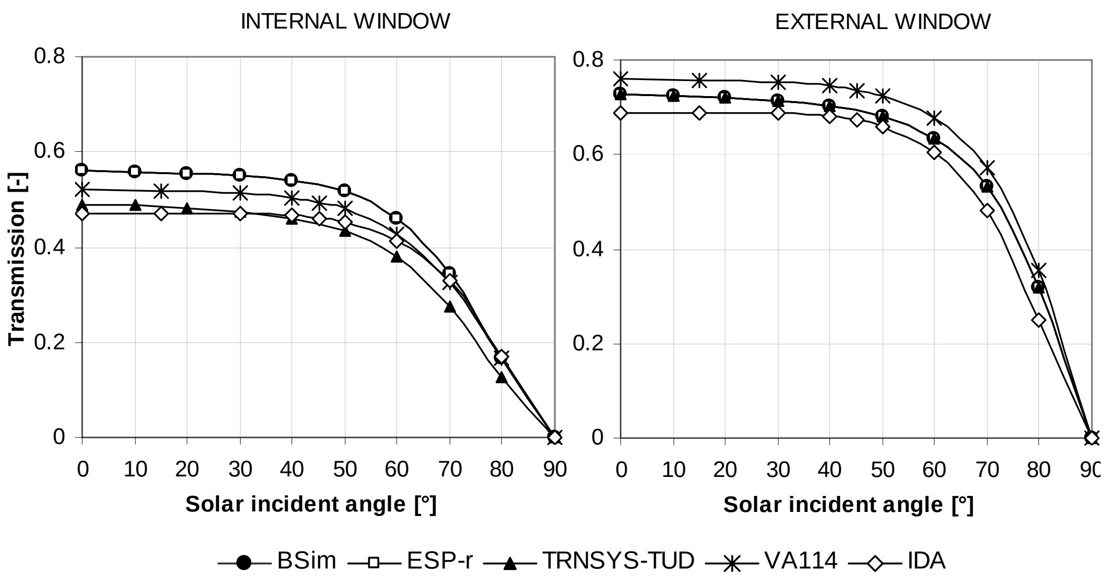
It is possible to assess how is the solar radiation received on the external window surface, reflected and transmitted into the zone 1 and into the zone 2. Total solar radiation received on the external surface calculated by VA114 is considered as a reference, representing 100 % of solar radiation received (see table below). Correspondingly, the external surface in BSim receives 2%, ESP-r 4%, TRNSYS-TUD 6% and IDA 5% less of solar energy compared to VA114.

Software	MAximum total solar radiation on external window surface		Maximum solar radiation transmitted into the zone 1		MAximum solar radiation transmitted into the zone 2	
	W/m²	%	kW	%	kW	%
BSim	893	-2	9.8	-8	4.1	-18
*VA114**	*912*	*0*	*10.7*	*0*	*5*	*0*
ESP-r	875	-4	9.4	-12	4.3	-14
TRNSYS-TUD	859	-6	10.1	-6	3.7	-26
IDA	864	-5	10.4	-3	4.7	-6

* Reference data, representing 100 %

The table above demonstrates that none software, except TRNSYS-TUD, have the same increase/decrease percentage when calculate solar radiation transmitted into the zone 1 compared with the incident solar radiation. It allows to infer, that the processing of solar radiation through the glazing differs between the software in the task. The modeler reports support that conclusion: some software uses the default optical properties for glazing while the others allow their advanced input and simulations. Below, the inputs to the different models are compared.

TRANSMITTANCE OF THE DIRECT SOLAR RADIATION



The transmission and reflection of solar radiation is provided as user defined function of solar incidence in TRNSYS-TUD, ESP-r and BSim. The incidence angle dependency was calculated on a basis of IGDB number, specified in the comparative test case specification [2]. The above figure shows good correspondence of input for the transmitted solar radiation as a function of incidence for ESP-r and BSim, some disagreement is seen for TRNSYS-TUD when compare the internal window transmittance property.

Regarding VA114 and IDA, the default function for calculation of solar heat gain coefficient used (g-value), in this case the g-value for the normal angle of incidence used as the main input.

Another important issue in calculations of transmitted solar radiation is the form that the solar energy takes when passes the first bounce with the glass (direct or diffuse). This is not a physical question, as the form of solar energy, direct or diffuse, depends purely on the assumptions in the mathematical model of simulation tool. However, various software tools treat the diffuse and direct solar radiation separately, when calculating the transmission or distribution of solar radiation. Different calculation procedures are used depending whether the solar radiation is diffuse or direct. Therefore the final error in predictions of transmitted or distributed solar radiation will depend on the level of detail in each of these calculations.

The following table is prepared in order to make a clear picture of solar calculations by different building simulation tools:

Property	Bsim	VA114	ESP-r	TRNSYS-TUD	IDA
Transmittance of the direct solar radiation into the zone 1	f(α)	f(α), fixed	f(α)	f(α)	f(α), fixed
Transmittance of the direct solar radiation into the zone 2	f(α)	f(45°)	f(α)	f(α)	f(α), fixed
Transmittance of the diffuse solar radiation into the zone 1	f(60°)	f(58°)	f(51°)	f(const)	~f(45°)
Form of the direct solar radiation after the 1st bounce	direct	direct	diffuse	diffuse	direct

α- an incidence angle

Previously, the relation between predictions of the solar radiation striking the DSF and transmitted into the zone 1 and 2 was assessed and no correlation was found. The summary of the information given in the modeler reports and questionnaires is given in the table above. The table demonstrates the variety in the window models used. The main differences are noteworthy for the zone 2, while in the zone 1 the differences are in the function of incidence.

3.2.8 Summary

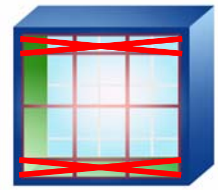
One of the most essential measures for the validation of simulation programs for buildings with the double skin facade is their ability to predict air temperature and air flow in the double facade cavity, moreover the cooling/heating load to the adjacent room is significant. Therefore differences in the boundary conditions, such as solar flux on the DSF surface, can be crucial. Glazing area of the double skin facade windows at the outer skin is 16.158m^2 and the differences in predictions of solar irradiation of ±100 W/m^2 will result in ±1.6 kW difference in received solar radiation on the glazing surface.

For the defined comparative test cases the solar altitude was verified in the first place, it is unfortunate that it was possible to asses it only for three programs (TRNSYS-TUD, ESP-r and VA114). Investigated direct and diffuse solar irradiation demonstrates some minor discrepancies in the predictions, and thus for the total incident solar radiation, still these deviations are low. It is particularly noticeable the time-shift in IDA of incident solar radiation.

Concerning transmission of solar radiation into the zone 1 and zone 2, the results contain some deviations, but these are possible to follow through the whole validation process and the comparative validation can be completed even with these disagreements. The deviation in predictions for the zone 1 is apx. ±0.1kW for the mean values and ±0.6kW for the maximum values. Even more deviation is noticed in the zone 2: ±0.15 kW for the mean values and ±0.7kW for the maximum values. This is caused by the different window models used by different software, as demonstrated in the previous section.

By any means, calculation of the incident, transmitted and distributed solar radiation is not the focus of these comparative exercises. However, the results of these calculations are the tool and the quality measure for completing the exercises. From this perspective, one can disregard the calculation methods and even the input parameters used for calculation of the incident, transmitted, distributed solar radiation, as long as all the software tools participating in the comparative validation calculate these values in reasonable correspondence and as long as it is possible to perform further comparison of the results.

DSF100_2

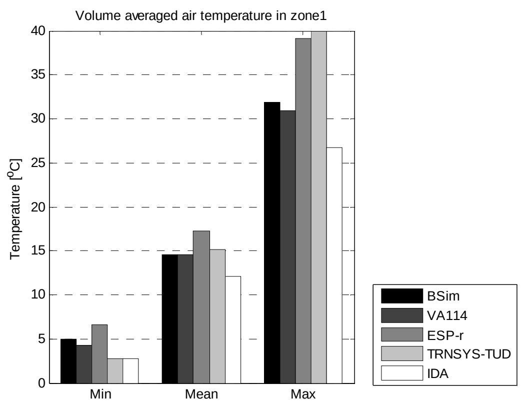


3.3 Test case DSF100_2

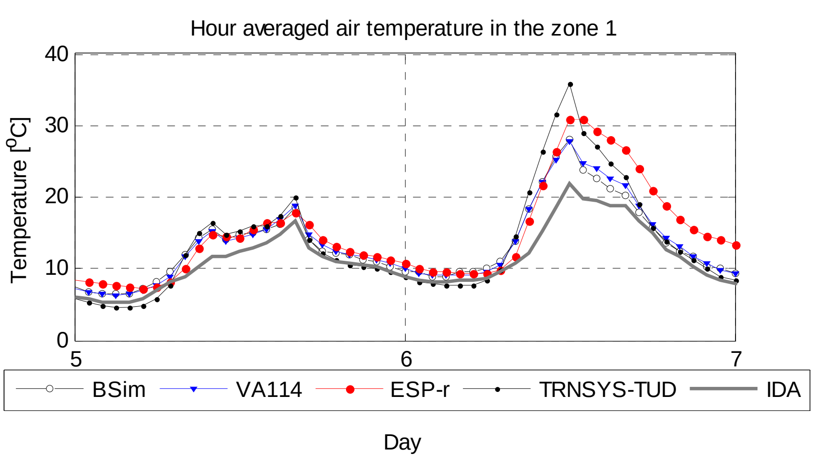
This test case is different from the any other case because it doesn't include air flow through the double skin façade cavity. In this case, a complex convective flow field can develop in the DSF cavity, which can be significant for the final result. The complexity of such a cavity flow can be solved by an advanced convection model: model with the dynamic calculation of the convection heat transfer surface coefficients, more than one temperature node calculations and even the mass balance for the convective flows. The maximum level of detail can be obtained by CFD.

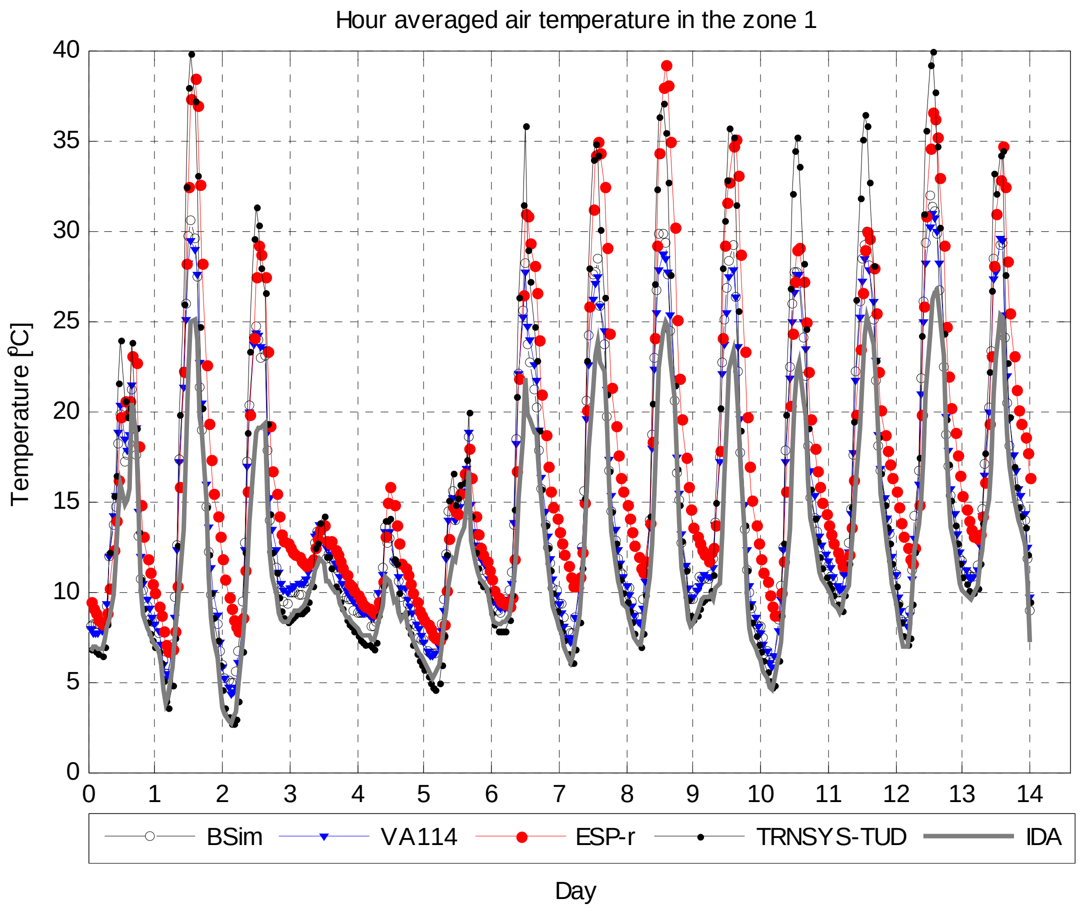
Since, the participants in this comparative exercise haven't used the CFD-calculations, their flow models aren't able to count on the mass flow rate in the convective boundary layer and the calculation of the convective surface heat transfer coefficient is reasonably simplified, see 2.2, then this test case become relatively easy to model compared to the test cases DSF200. In the simple model DSF100_2 the double skin façade actions as a conventional window and the heat transfer processes are relatively straight forward. Consequently, it was very essential to perform the first validation of the programs and models starting with this test case.

3.3.1 Air temperature in the double façade cavity



Volume averaged air temperature in zone 1	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	4.9	4.3	6.7	2.7	2.7
Max, °C	31.9	31.0	39.1	40.0	26.7
Average, °C	14.5	14.6	17.2	15.2	12.2



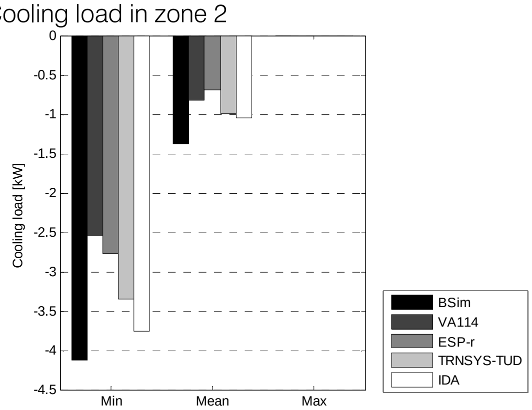


The slope of the temperature curve in the ESP-r results seem to be less than in the other models, this is also the reason for the generally higher temperatures at night. It might be something to do with the definition of the concrete floor in the zone 1, 2 and the time constant in the model.

Interesting is the fact that the TRNSYS-TUD model represents the DSF as a few zones stacked on the top of each other, these also the model which predicts the maximum air temperatures in the cavity. It follows that the TRNSYS model was able to model the temperature gradient in the cavity that resulted in the higher volume averaged temperature.

3.3.2 Energy load to the zone 2

Cooling load in zone 2

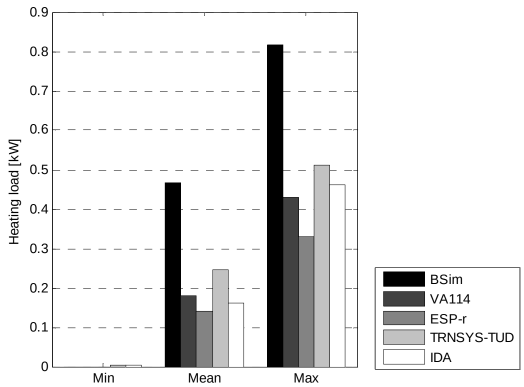


Cooling load in zone 2	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, kW	-4.1	-2.5	-2.8	-3.3	-3.8
Max, kW	0	0	0	0	0
Average, kW	-1.4	-0.8	-0.7	-1.0	-1.0

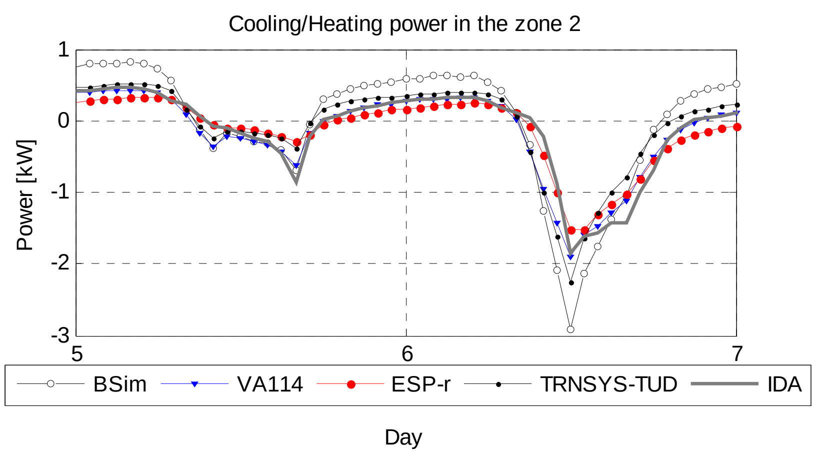
Total, kWh	-178.5	-164.3	-175.5	-149.6	-190.7

The order of disagreement between the programs when comparing the mean values of the cooling loads is ±0.4kW, while the order of disagreement in transmitted solar radiation is only ±0.15kW. Here, serious disagreements in prediction of the air temperature in the zone 1 can have an impact.

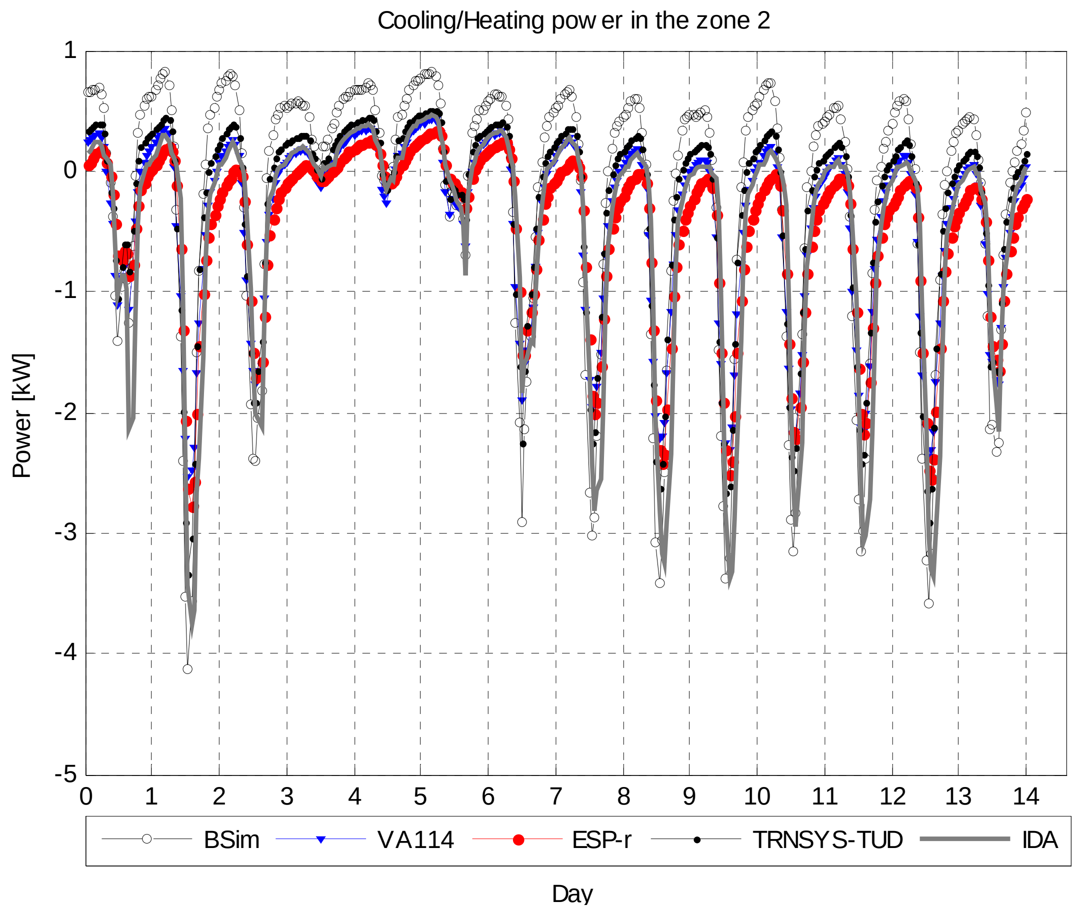
Heating load in zone 2



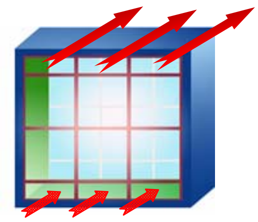
Heating load in zone 2	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, kW	0	0	0	0	0
Max, kW	0.8	0.4	0.3	0.5	0.5
Average, kW	0.5	0.2	0.1	0.2	0.2
Total, kWh	96.9	25.3	11.5	45.7	24.8



Since the heating load to the zone was necessary when the building wasn't exposed to the solar radiation, thus the heating load parameter carries information mainly about the heat transfer, the heat accumulation in the constructions and the longwave radiation exchange in the model. Exceptionally high heating load is calculated by BSim, although the thermal bridges are not included in the models. Mean values are in reasonable correspondence for all of the programs except BSim and the maximum values have slightly higher disagreements (±0.3kW), while total loads are very different. Much better agreement is obtained for total energy consumption for cooling load to the zone.


Cooling/Heating pow er in the zone 2
Power [kW]
1
0
-1
-2
-3
-4
-5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day

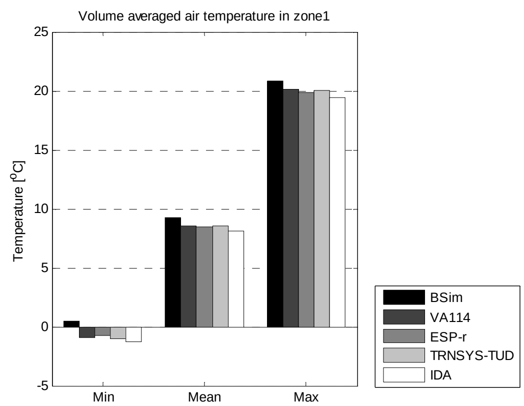
DSF400_3



3.4 Test case DSF400_3

This is the case with the mechanically driven flow in the cavity; the air is taken from the outside, heated up in the double façade cavity and supplied into the zone 2.

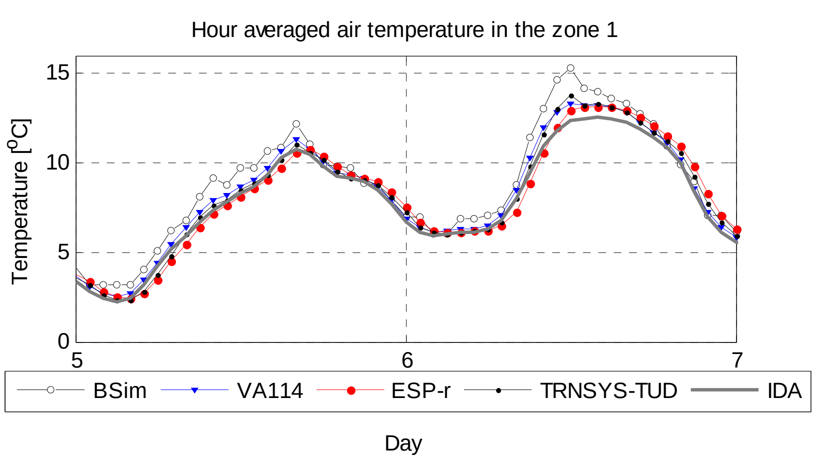
3.4.1 Air temperature in the double façade cavity

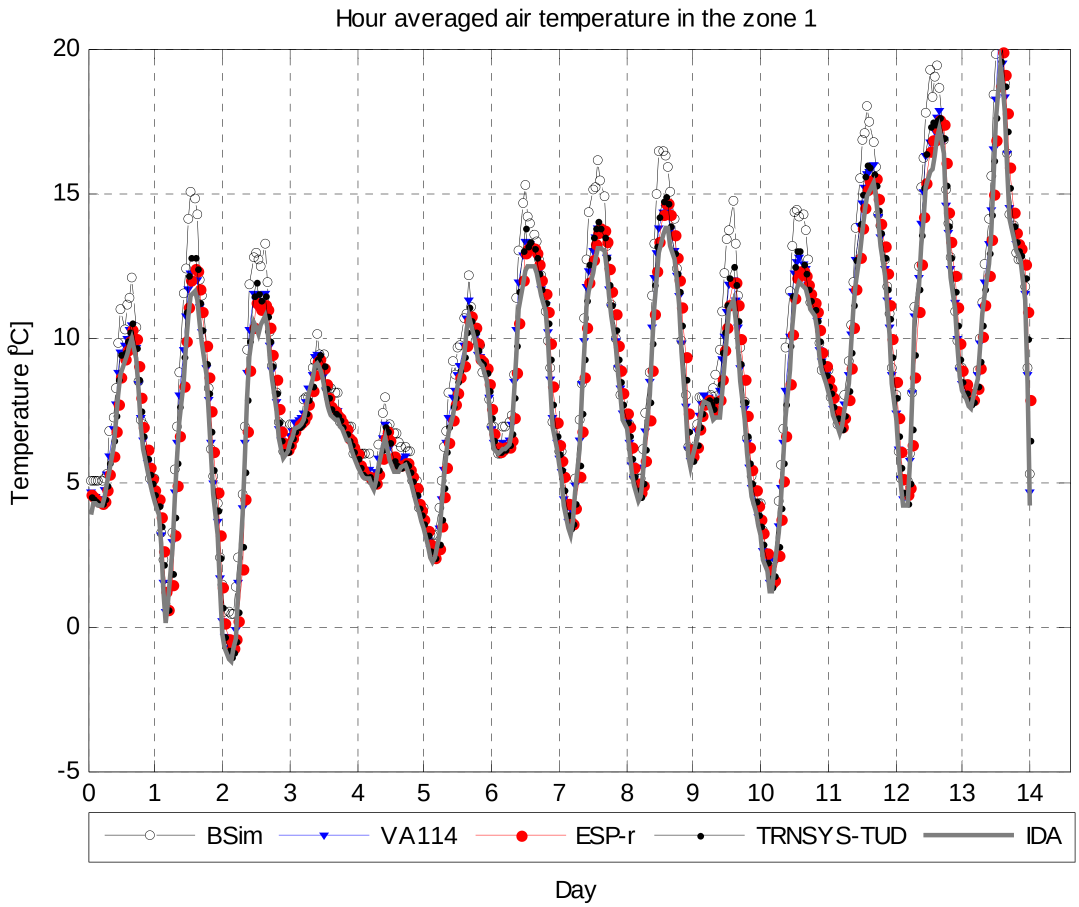


Volume averaged air temperature in zone 1	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	0.5	-0.9	-0.8	-1.0	-1.2
Max, °C	20.9	20.1	19.9	20.1	19.4
Average, °C	9.2	8.6	8.5	8.5	8.1

Temp. raise in zone 1 compared to outside	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	-0.1	0.2	-1.9	-1.1	-0.4
Max, °C	5.1	2.2	3.8	2.8	1.5
Average, °C	1.4	0.7	0.7	0.7	0.3

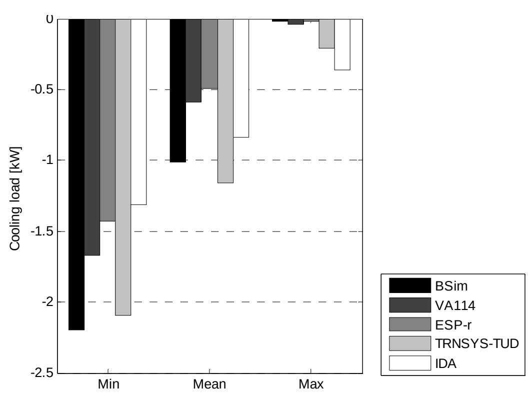
Fairly good correspondence in the boundary conditions calculated by the participating programs, known air flow rate and flow regime in the double skin façade cavity results demonstrate almost identical average and maximum air temperature in the DSF for VA114, ESP-r and TRNSYS-TUD. BSim and IDA calculate different from the others air temperature. IDA underestimates the air temperature and BSim overestimates it.





3.4.2 Energy load to the zone 2

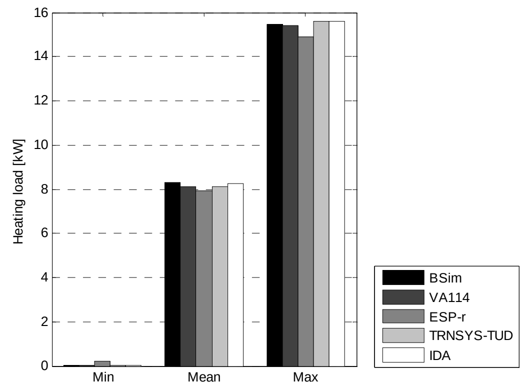
Cooling load in zone 2



Cooling load in zone 2	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, kW	-2.2	-1.7	-1.4	-2.1	-1.3
Max, kW	0.0	0.0	0.0	-0.2	-0.4
Average, kW	-1.0	-0.6	-0.5	-1.2	-0.8
Total, kWh	-11.1	-3.5	-3.9	-9.3	-4.2

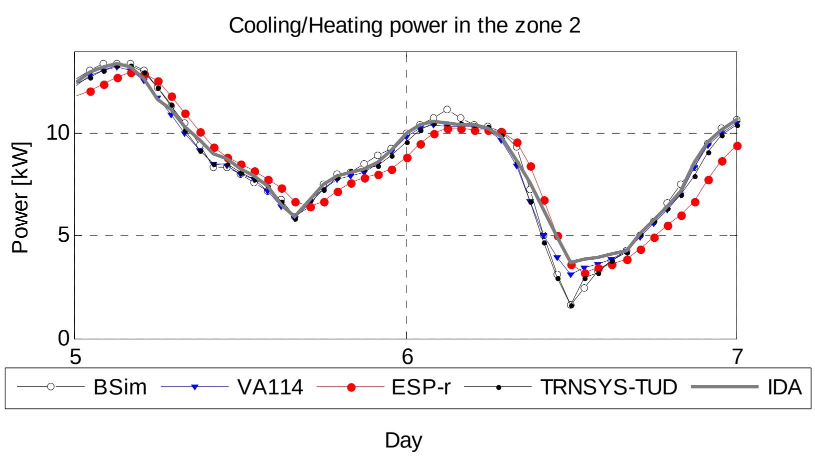
Overestimation of the air temperature in the DSF cavity by BSim, results in increased cooling loads in the zone 2 (-11.1kWh total). Surprisingly high cooling load to zone 2 simulated also by TRNSYS-TUD (-9.3kWh), although the solar gains into the zone 2 for TRNSYS-TUD are low. VA114, ESP-r and IDA obtained better correspondence.

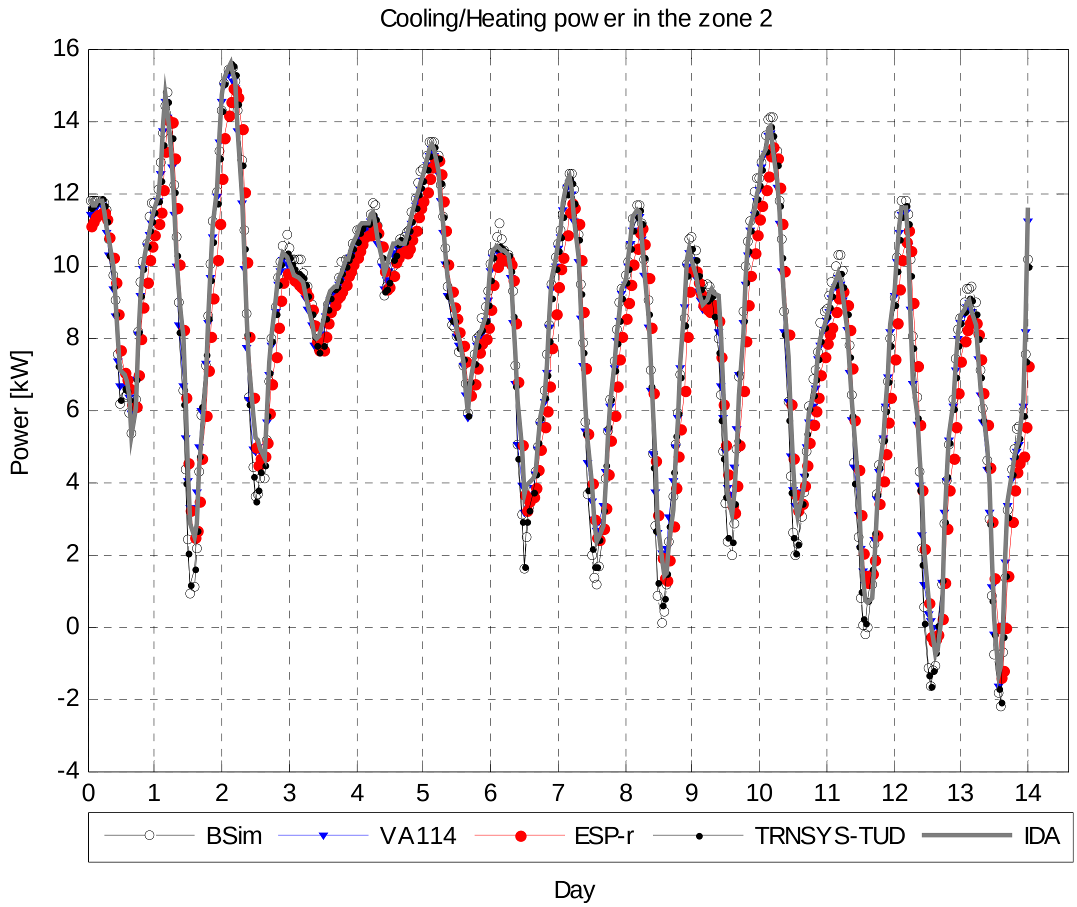
Heating load in zone 2



Heating load in zone 2	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, kW	0.0	0.0	0.2	0.0	0.0
Max, kW	15.5	15.4	14.9	15.6	15.6
Average, kW	8.3	8.1	7.9	8.1	8.3
Total, kWh	2696.8	2677.6	2602.3	2655.0	2736.2

Comparison of the heating load into the zone shows much better correspondence of the results: min, max and average values are in extremely good agreement, except for minor deviations calculated by ESP-r. Heating load is also the prevailing power consumer for this test case that also explains the disagreements when cooling load is compared.




Cooling/Heating pow er in the zone 2
Power [kW]
Day
BSim
VA114
ESP-r
TRNSYS-TUD
IDA

DSF200_3

3.5 Test case DSF200_3

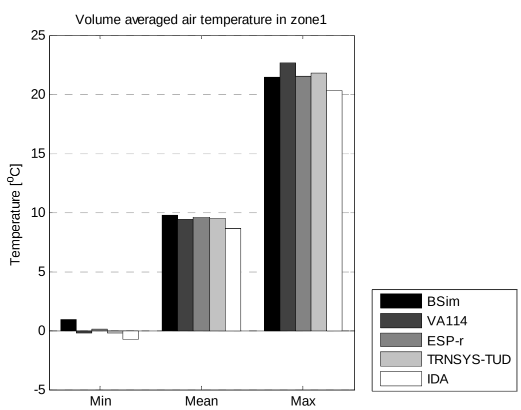
This is the natural ventilation case with buoyancy driven flow. The solar radiation on window surfaces, calculated by different programs is investigated earlier together with the prediction of the transmitted solar radiation into the DSF and zone 2. As it has been shown in the chapter 3.2, the boundary conditions calculated by all programs are in good correspondence.

Solar radiation absorbed by the surfaces of the DSF is then retransmitted to DSF cavity air by means of convection. Since the wind force is not taken into the consideration, the flow motion in the DSF cavity is determined by the air density differences (buoyancy) and, hence, by the heat transfer processes between the DSF surfaces and the air.

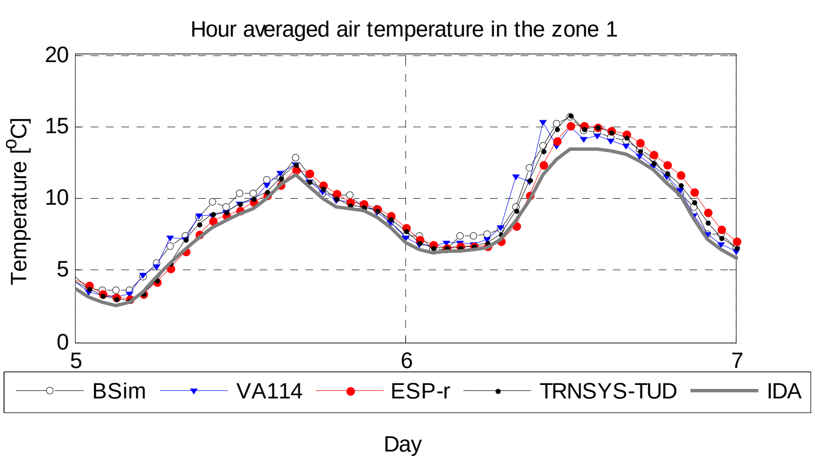
In view of the fact that the convective heat transfer coefficients were not specified in the test case specification [2], and the results of this test case are very sensitive to the convection model chosen by user, reader should be provided with information about the convection models used for the comparative cases, which are compared in the chapter 2.2.

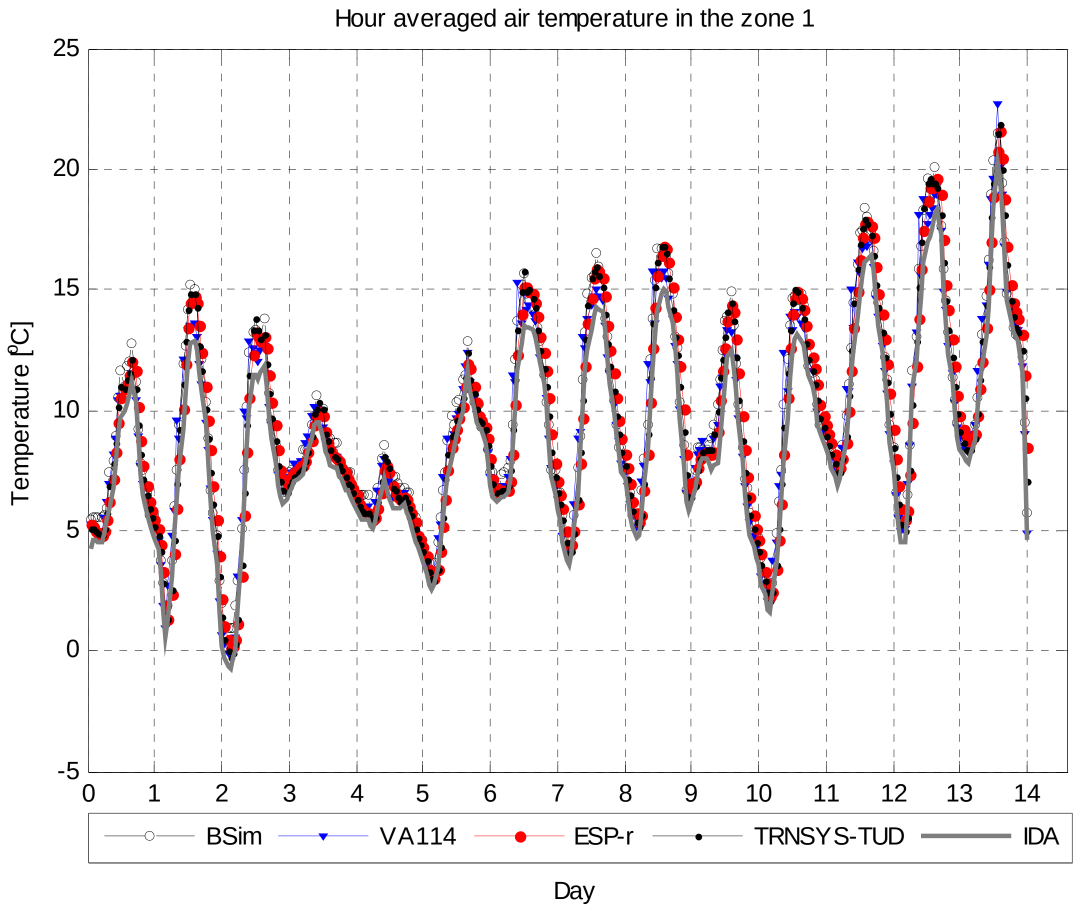
Another sensitive matter for this test case results is the ability of the software to calculate the naturally driven flow. A summary of the different flow models used for the test case DSF200_3 and DSF200_4 is given in chapter 2.3

3.5.1 Air temperature in the double façade cavity

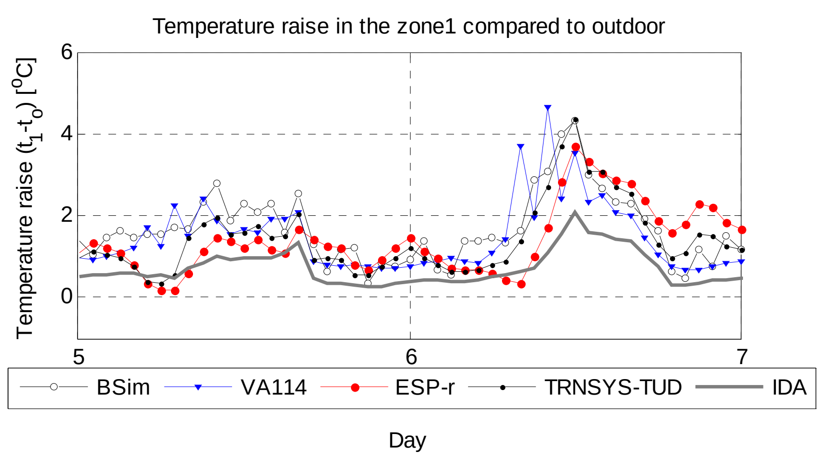


Volume averaged air temperature in zone 1	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	1.0	-0.2	0.1	-0.2	-0.7
Max, °C	21.5	22.7	21.6	21.8	20.3
Average, °C	9.7	9.5	9.6	9.5	8.7





Temp. raise in zone 1 compared to outside	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	0.35	0.47	-0.99	-0.31	-0.08
Max, °C	5.18	5.40	4.68	4.87	2.79
Average, °C	1.92	1.63	1.77	1.69	0.84

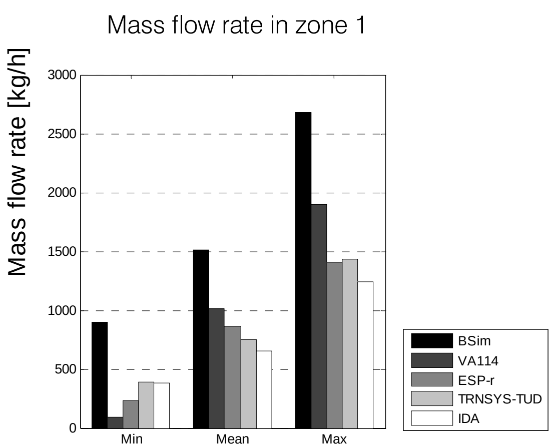


The average values of the air temperature appear to be in good correspondence, still BSim predicts slightly higher temperature (average: 9.7°C for BSim vs. 9.5°C for VA114,ESP-r and TRNSYS-TUD), while IDA predicts it slightly lower (average 8.7 °C). The temperature raise in the DSF cavity compared to the outdoor air temperature is noteworthy, as the order of magnitude is the same for all models and even the deviations in predictions for different models is less than 0.5°C . However, looking upon the magnitude of the flow rate in the cavity one can picture the scale of disagreement between the results. If consider the average temperature raise and the air flow in the cavity then the differences in amount of energy removed from the DSF will be apx. ±0.4kW (1.1kW removed according to BSim results and 0.2kW, according to IDA)

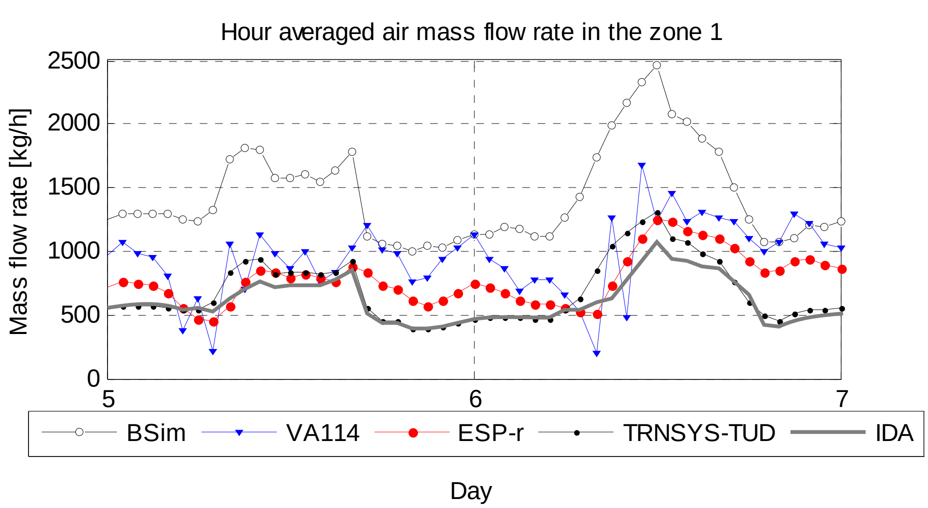
3.5.2 Air flow rate in the zone 1

In this test case the air flow rate in the DSF cavity is buoyancy driven, therefore the prediction accuracy of the air temperature in the double façade cavity (zone 1) is very important. As it is demonstrated above, the air temperature in the zone is in agreement between all programs, both for the day with low and high solar radiation.

Normally, the natural air flow is caused by two components: buoyancy and wind. It is common that various building simulation tools use different methods and coefficients for the determination of wind effect (wind pressure coefficients, wind profile, definition of the discharge coefficients etc.). Meanwhile calculation of the buoyancy flow is straight forward if the heat transfer processes and thus the air temperature in the zone are known. Still, the modeling of the temperature stratification in the double façade cavity is important, as it has a vital role in the air flow predictions. It depends on limitations of the software tool, model and the author. It is common to stack a few zones on the top of each other and in that way forming the zone, where the air temperature is calculated separately for the every stacked sub-zone. In that way the accuracy in predictions of thermal stratification is improved. Although, this method has been used in ESP-r and TRNSYS-TUD models, there is no indication of severe disagreements in predictions of air temperature between [ESP-r +TRNSYS-TUD] and [VA114+IDA+BSim]. This is, most likely, to be explained by the high air flow rates and low temperature differences between cavity air and outdoor air.



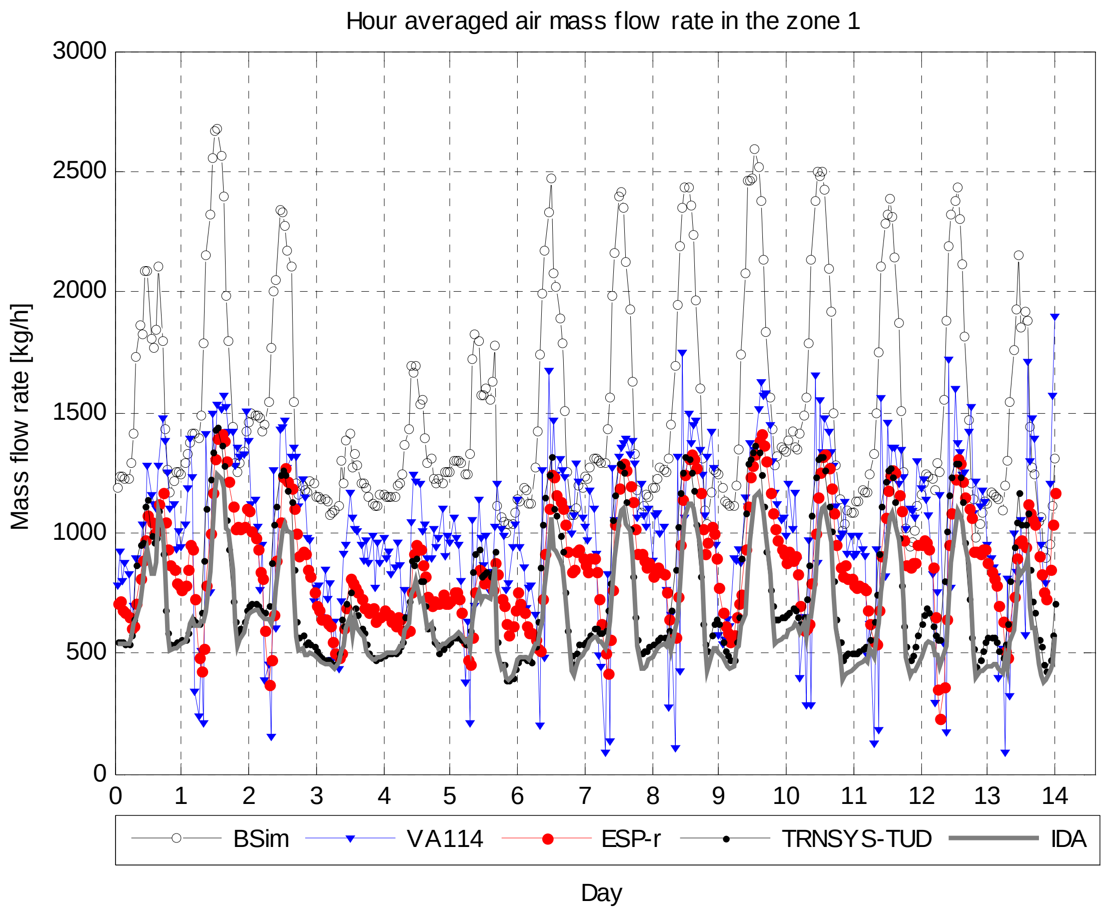
Mass flow rate in zone 1	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, kg/h	898	88	229	388	381
Max, kg/h	2681	1897	1410	1438	1239
Average, kg/h	1509	1015	866	746	652

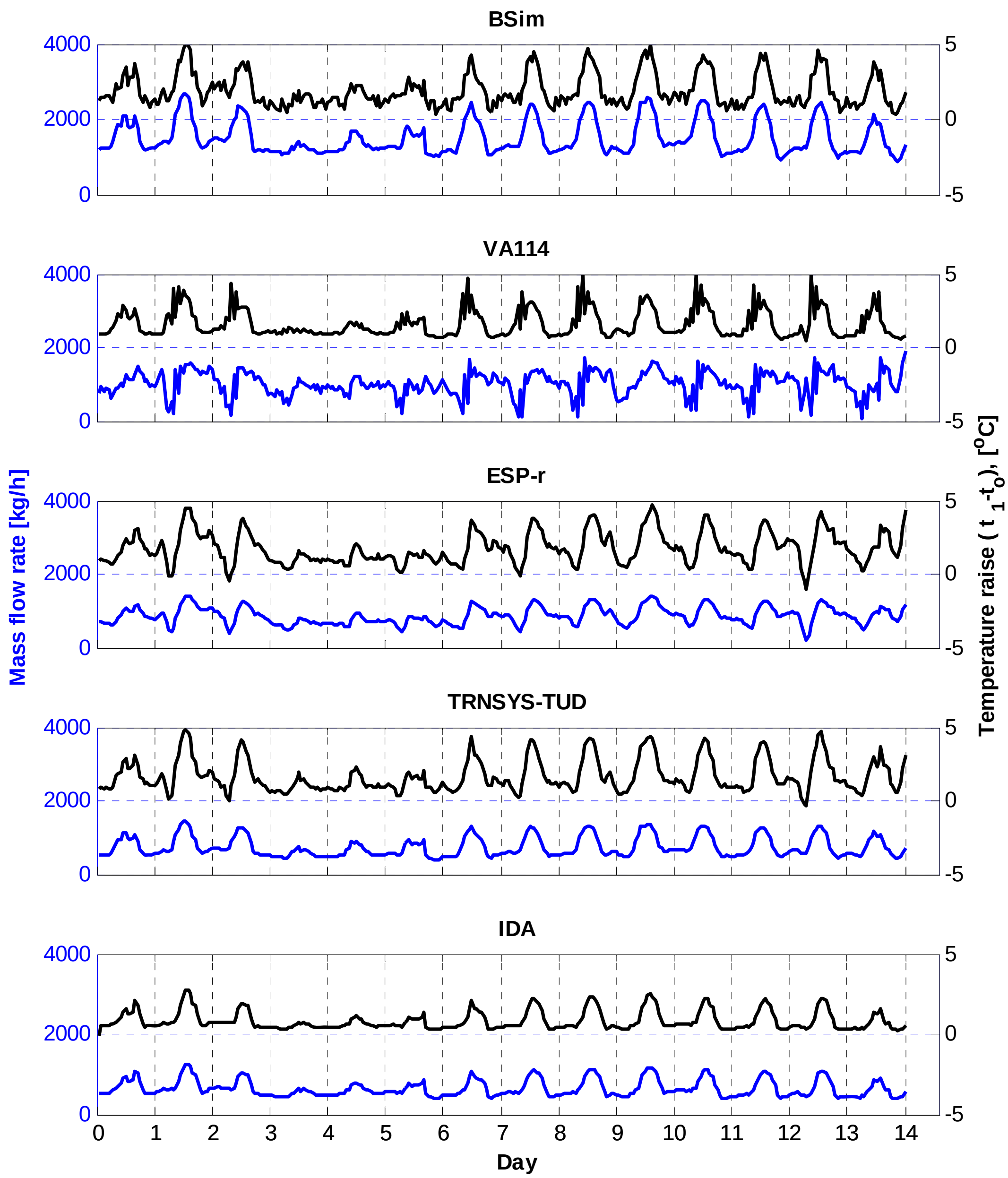


The flow model in BSim is simplified compared to the other programs (see 2.3) also the air mass flow rate in the DSF cavity is seriously overestimated. At the same time the temperature raise in the DSF cavity by BSim is one of the highest.

Regarding the air mass flow rate calculated by other tools TRNSYS-TUD, ESP-r, VA114 and IDA results are in agreement for all values (min, mean and max). Apparently, IDA and TRNSYS-TUD often are in agreement when consider the shape of plots, especially for the night time. For all the other simulation tools no parallels can be found, both for the night time periods and days with the low solar gains, although the statistical data demonstrates some agreement.

It is remarkable that even without the wind influence and for the night period without the solar radiation, it was impossible to demonstrate the direct link between results of any model.

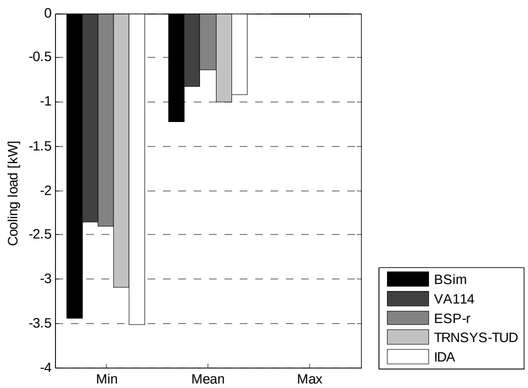




BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Mass flow rate [kg/h]
Temperature raise (t1-t0), [°C]
Day
4000
2000
0
5
0
-5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14

3.5.3 Energy load to the zone 2

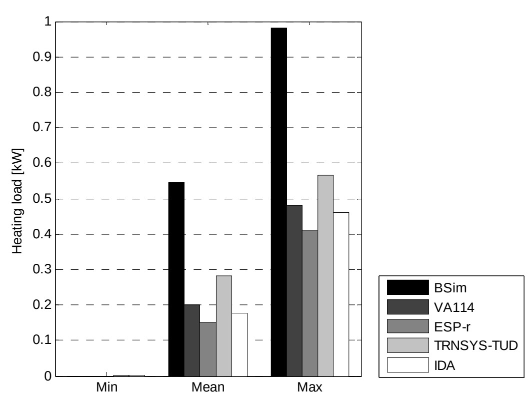
Cooling load in zone 2



Cooling load	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, kW	-3.4	-2.4	-2.4	-3.1	-3.5
Max, kW	0	0	0	0	0
Average, kW	-1.2	-0.8	-0.6	-1.0	-0.9
Total, kWh	-135.6	-147.2	-140.7	-129.7	-178.0

The above plot demonstrates that even for the simplified case with the buoyancy driven flow in the DSF cavity, it is difficult to find an agreement between the models. The contrast in the calculated air mass flow rates is not only the reason for the disagreement, as the diversity in the predicted airflow rates is interrelated with the with the air temperature in the DSF cavity. Correspondingly, the issues of the disagreement are more complex, these involve the investigation of the flow regime in the cavity, calculation of the convective heat transfer coefficients, longwave radiation exchange etc.

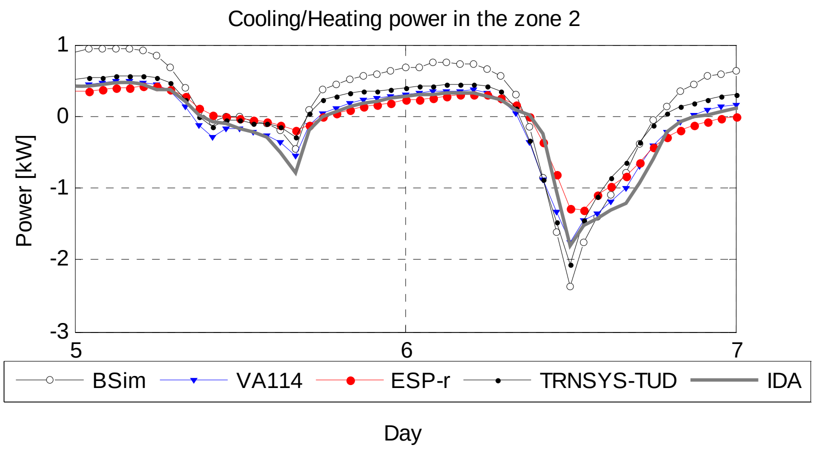
Heating load in zone 2

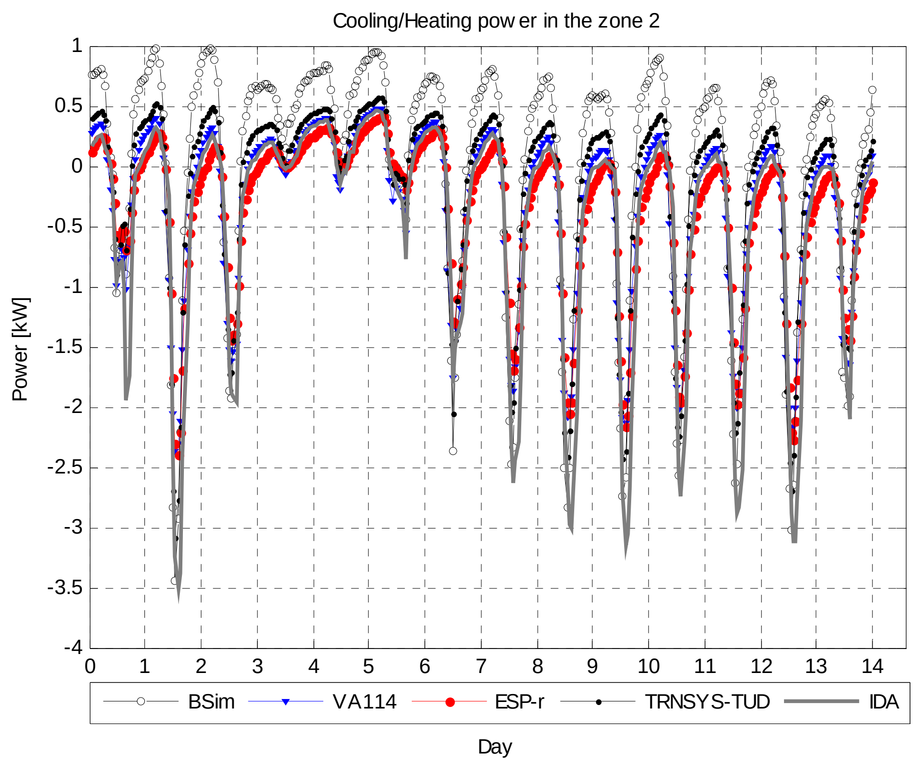


Heating load	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, kW	0	0	0	0	0
Max, kW	1.0 (25%)*	0.5 (25%)	0.4 (33%)	0.6 (16%)	0.5 (0%)
Average, kW	0.5	0.2	0.2	0.3	0.2
Total, kWh	123.5 (27%)	32.7 (29%)	19.3 (67%)	58.1 (27%)	24.9 (0%)

*(…%) - increase, in % compared to the test case DSF100_2

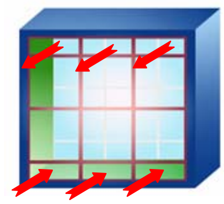
The distribution of the heating loads to the zone 2 is similar to the test case DSF100_2. All models, except IDA demonstrate the same range of increase of the heating load to the zone compared with the test case DSF100_2.





BSim highly overestimates the heating load at night compared with the other predictions, the same behavior of the BSim predictions have also been noticed for the DSF100_2 test case.

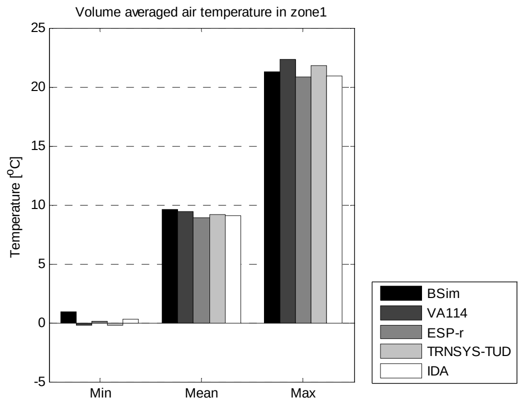
DSF200_4



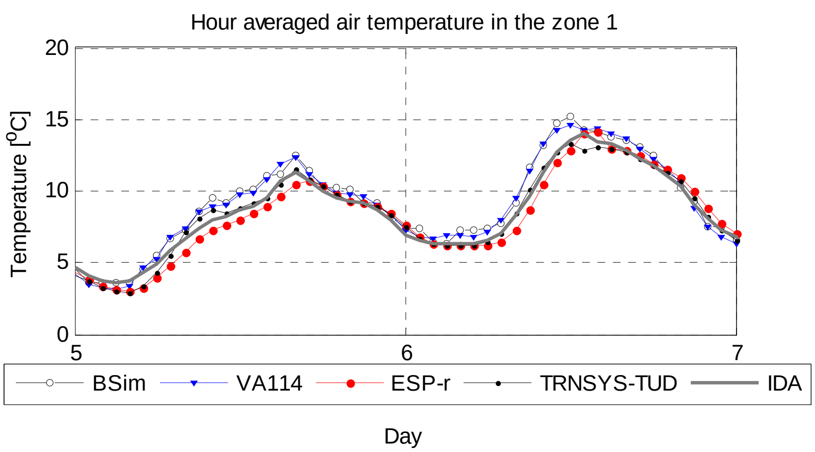
3.6 Test case DSF200_4

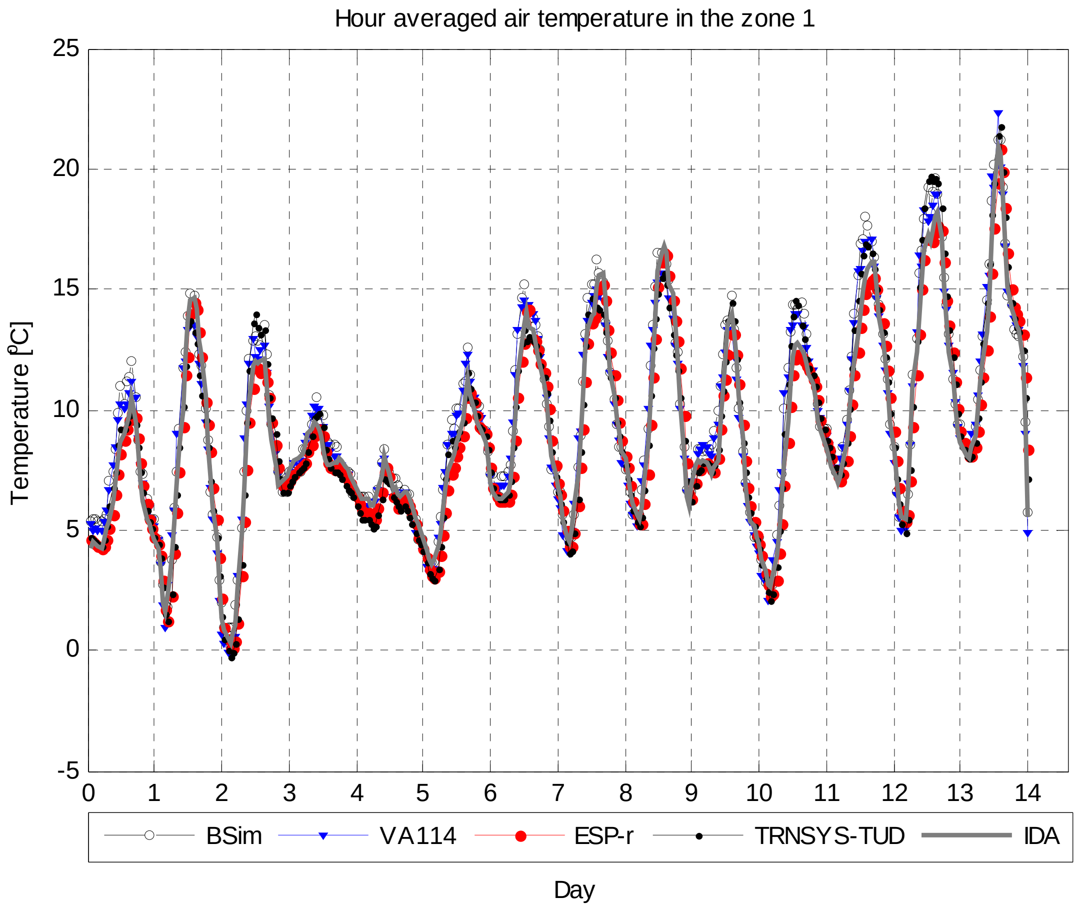
In this test case the most complex phenomenon of the double façade cavity is investigated – the naturally ventilated double skin façade, which includes impact both from the buoyancy and wind forces. The ventilation strategy in this test case belongs to the single sided ventilation with the openings in the different levels. In the previous case the influence of the buoyancy force is considered and illustrates difficulties to obtain correspondence in predictions of the air flow rates and energy loads, consequently, it is interesting how does the situation change when the wind phenomenon is involved.

3.6.1 Air temperature in the double façade cavity

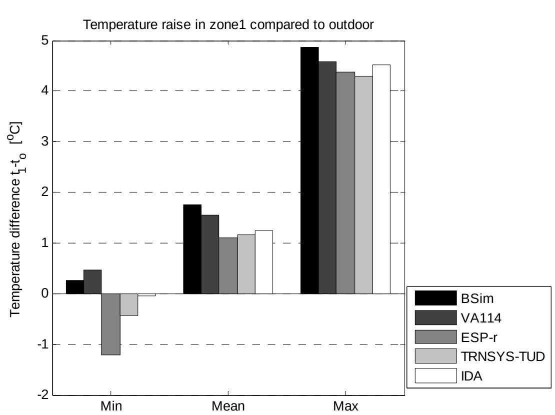


Air temperature in the zone 1	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	1.0	-0.2	0.1	-0.2	0.3
Max, °C	21.3	22.3	20.9	21.8	20.9
Average, °C	9.6	9.4	8.9	9.1	9.1

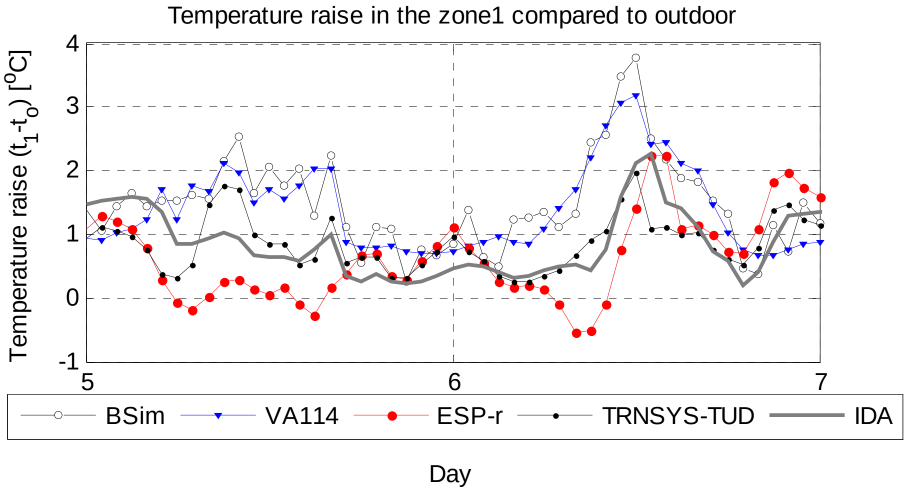


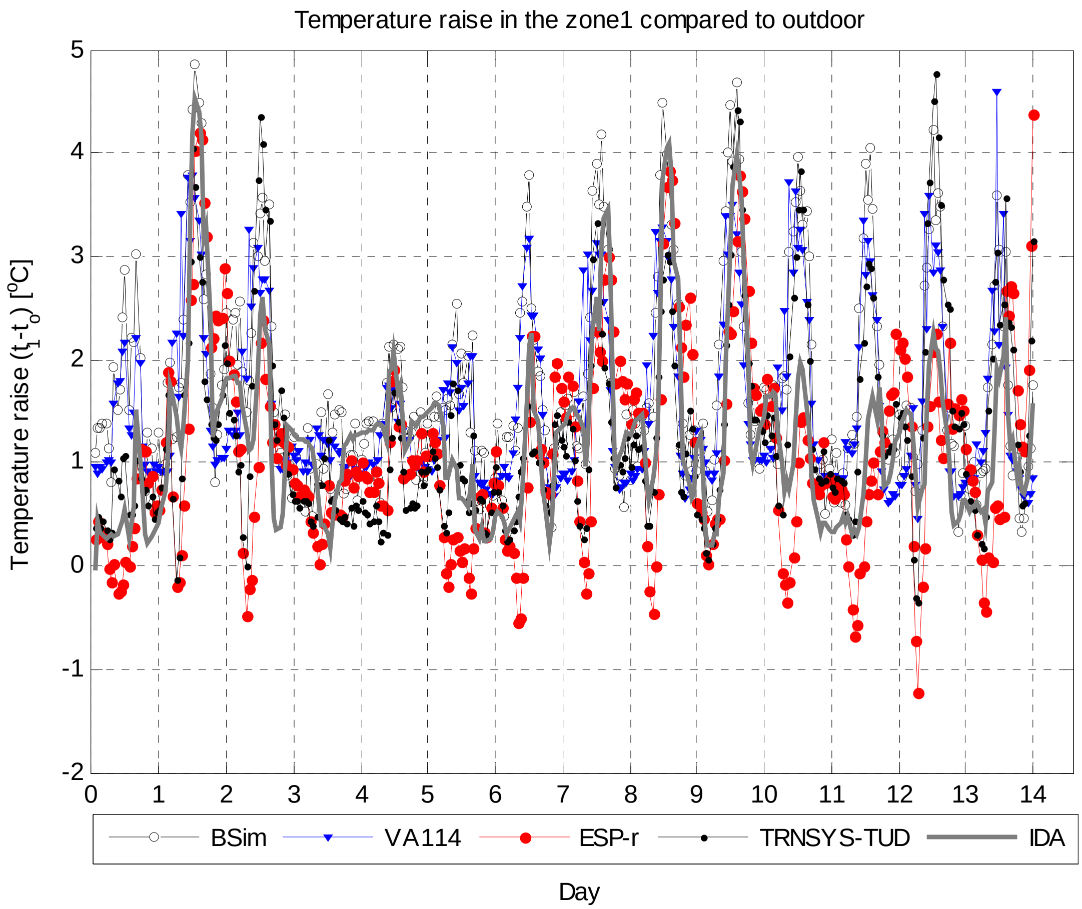


In this test case the air temperature calculated by different tools haven't changed a lot compared with the test case DSF200_3. Predicted air temperature in the DSF seems to be in a good agreement between the models. However, when compare the average temperature raise in the DSF cavity together with the air flow rate in the cavity, then the amount of energy removed from the DSF cavity vary between 1.0 and 0.25kW, although the differences between predicted air temperature seem insignificant. This is caused by simulated outdoor conditions with the relatively high outdoor air temperature, thus with the high air change rate the air temperature in the DSF cavity approach the outdoor air temperature, as can be seen in the plots below.

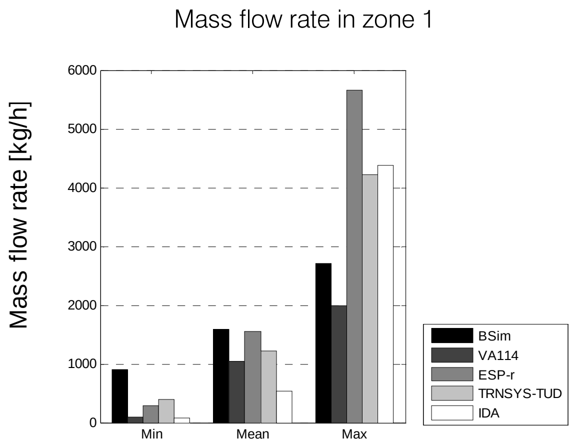


Temp raise in zone 1 compared to outdoor	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	0.27	0.47	-1.22	-0.44	-0.04
Max, °C	4.86	4.59	4.38	4.30	4.52
Average, °C	1.75	1.56	1.10	1.17	1.25


Temperature raise in the zone1 compared to outdoor
Temperature raise (t_1-t_0) [^{o}C]
4
3
2
1
0
-1
5
6
7
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day


Temperature raise in the zone1 compared to outdoor
Temperature raise (t_1-t_0) [^{o}C]
5
4
3
2
1
0
-1
-2
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day

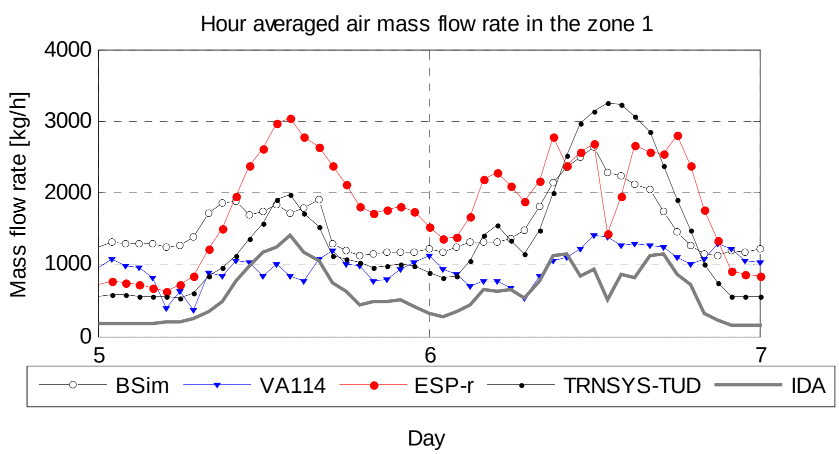
3.6.2 Air flow rate in the zone 1

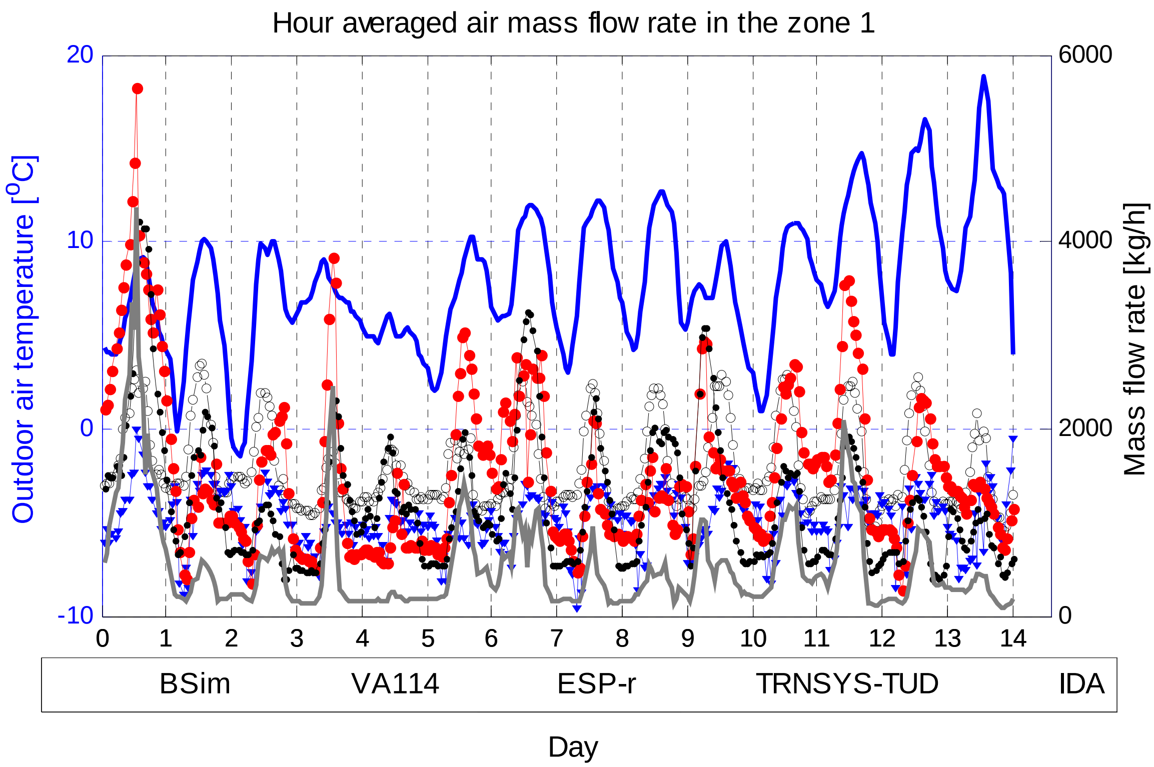


Mass flow rate in zone 1	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min	903 (1%)	91 (3%)	286 (24%)	393 (1%)	79 (-79%)
Max	2704(1%)	1992(5%)	5657 (301%)	4225 (193%)	4375 (253%)
Average	1590 (5%)	1036 (2%)	1551 (79%)	1225 (64%)	531 (-18%)

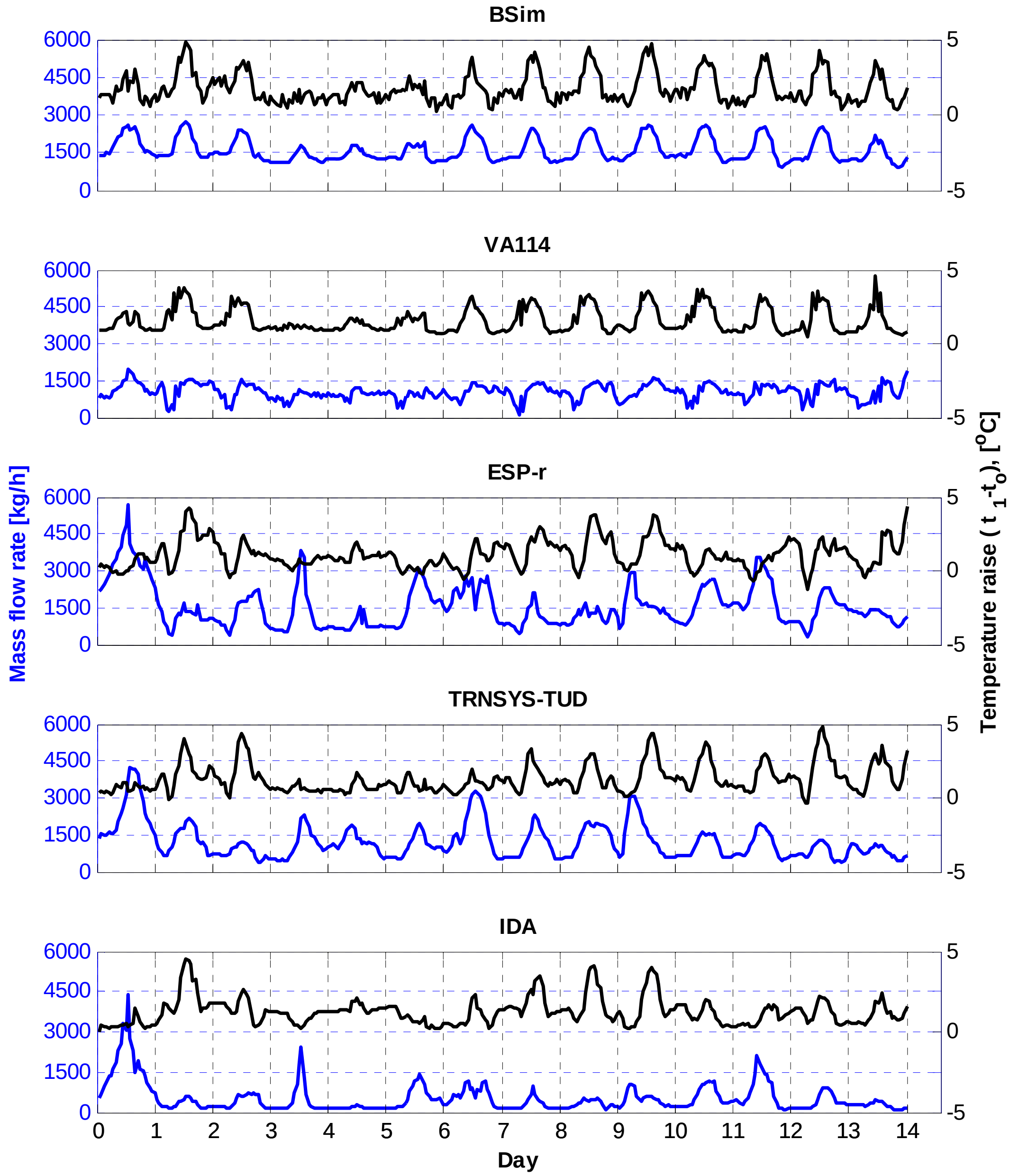
(…%) - increase, in %, compared to the test case DSF200_3

Again, the air mass flow rates in the DSF cavity calculated by different programs are far from each other. This is also the most difficult test case to model, due to the combination of the wind and buoyancy driving forces. The deviation between the average values is ±650kg/h that corresponds to apx.60ACH in the DSF cavity. It is not possible to observe any agreement in predictions even for the night time periods.



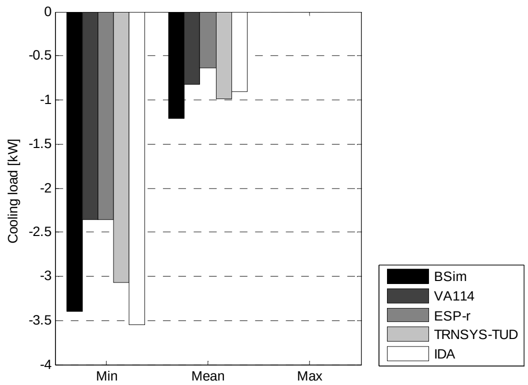


Hour averaged air mass flow rate in the zone 1
Outdoor air temperature [°C]
Mass flow rate [kg/h]
20
10
0
-10
6000
4000
2000
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day


BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Mass flow rate [kg/h]
Temperature raise (t_1-t_0), [^oC]
Day
0
1500
3000
4500
6000
-5
0
5
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14

3.6.3 Energy load to the zone 2

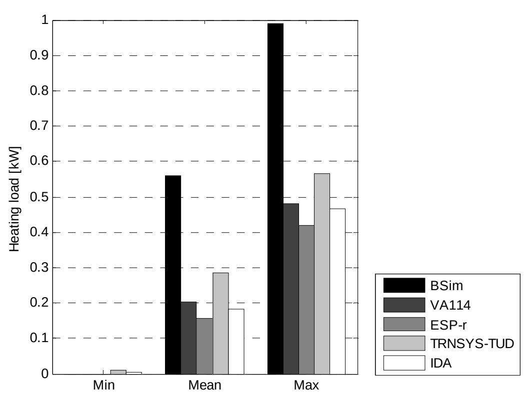
Cooling load in zone 2



Cooling load in zone 2	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, kW	-3.4	-2.4	-2.4	-3.1	-3.6
Max, kW	0	0	0	0	0
Average, kW	-1.2	-0.8	-0.6	-1.0	-0.9
Total, kWh	-131.3	-146.9	-130.9	-128.4	-177.9

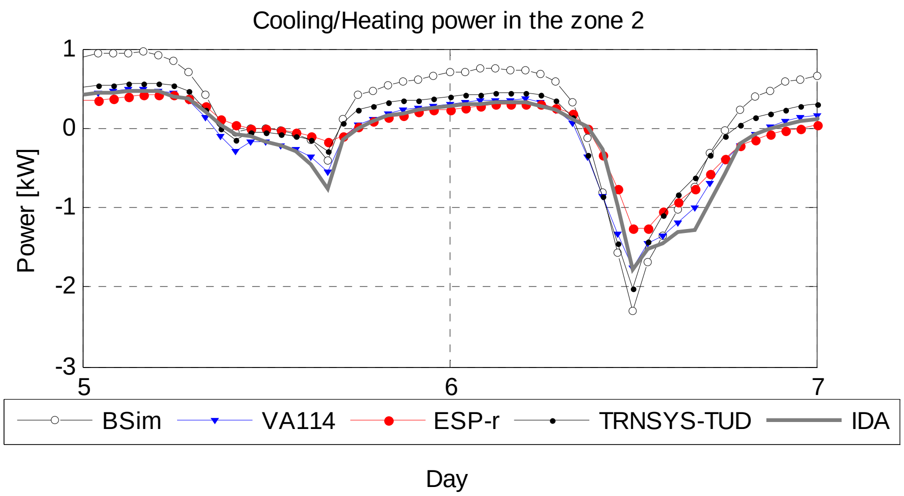
Similar to the test case DSF200_3, the above plot demonstrates that it is difficult to find any agreement between the models, moreover, the table includes the data for the total energy consumption for cooling in the zone 2, which differs a lot between the models although the average results seem to be in the same range.

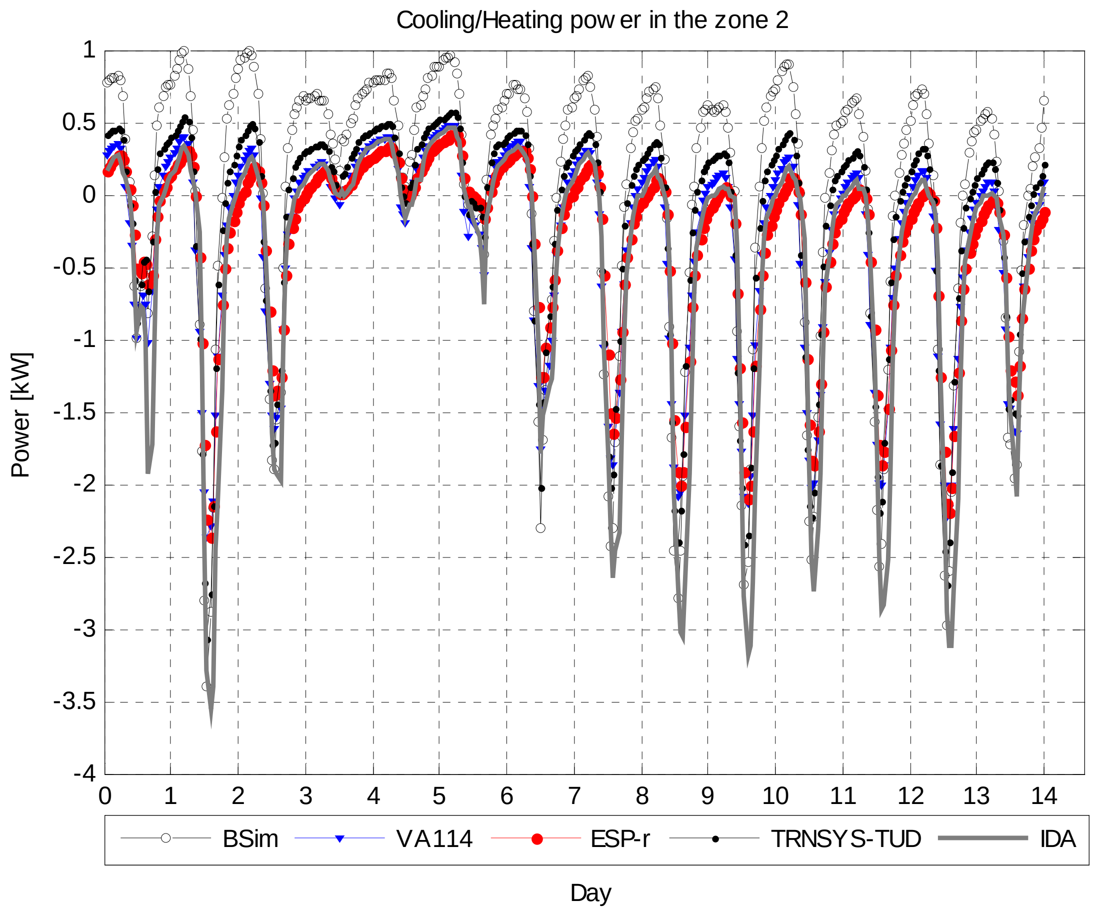
Heating load in zone 2



Heating load in zone 2	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, kW	0	0	0	0	0
Max, kW	1.0	0.5	0.4	0.6	0.5
Average, kW	0.6	0.2	0.2	0.3	0.2
Total, kWh	127.4	32.7	21.7	58.9	25.8

The heating load in the zone 2 is almost identical to the test case DSF200_3, the energy consumption has slightly increased for all of the models, while the min, max and mean results almost haven't changed.


Cooling/Heating power in the zone 2
Power [kW]
1
0
-1
-2
-3
5
6
7
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day


Cooling/Heating pow er in the zone 2
Power [kW]
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day

3.7 Summary over surface temperatures

Solar radiation striking on the window surface of the DSF is partly transmitted, reflected and absorbed by glass or shading device (if available). The air is assumed to be transparent to the shortwave and longwave radiation, thus the air temperature in the DSF cavity is the result of the convective heat transfer from the DSF surfaces and thus from the glass (dominant part of all DSF surfaces) and/or shading. From this point of view, the prediction of the absorbed solar radiation in the glass panes and their temperature are essential for the accurate predictions of the DSF performance.

The plots of the results for the surface temperatures are included in Appendix. The figures demonstrate obvious differences between various simulation tools. The spread between the results indicates difficulties related to this sort of predictions, moreover it denotes the fact that it is not possible to validate these parameters without empirical support. Such diversity of the results is caused by differences in the window model used for calculation of transmission of solar radiation, differences in the convective heat transfer models together with the differences in the air flow magnitude in the DSF.

3.8 Discussion and summary for the comparative validation test cases

The scope of this subtask is to perform a comparative validation of the building simulation software for the buildings with the double skin façade. As explained in the literature review [1], the physics of the double skin façade involves complex processes and therefore require detailed calculations of optics, flow regime, convection, natural air flow etc. Often, building simulation software is not able to perform such detailed level of computations. When the detailed computations are not possible, then the simplified models are used as an alternative and it is not always possible to validate the advanced physical processes, however, this is not the objective. The building simulations must be validated on their performance *together with their limitations,* yet the best possible software performance must be achieved.

In this comparative validation process the attempt was made to consider the importance of the glazing surface temperature as an essential factor in the DSF performance. Obtained results demonstrate the general disagreement in the predictions. As there is no analytical solution neither any experimental data exists, it is not possible to evaluate properly the calculated surface temperatures. Resulting surface temperatures depend on computations and assumptions in a model, such as distribution of solar radiation and shadow to the surfaces, level of detail in longwave radiation exchange, flow regime at the surface and assumptions made for calculation of the convective heat exchange at the surface etc. These computations and assumptions vary from one tool to another, but the building simulation tools stay focused on the predictions of energy consumption and occupants' comfort and therefore the quantitative measure for this comparative validation were chosen between the global parameters such as energy consumption, air temperature and air flow rate, but not in the surface temperatures.

Before comparing the global parameters, it was necessary to perform the verification of the boundary conditions, which was done in two steps:

- Evaluation of the boundary external conditions. If an agreement is achieved in computations of solar radiation striking to the surface, then it can be demonstrated that the models perform computations for the same external boundary conditions

- Validation of the boundary internal conditions. If an agreement is achieved in computations of solar radiation transmitted into the zone (first order of solar transmission), then it can be agreed that the models perform computations for the same initial boundary conditions and the final validation can take place

The first step of verification was completed with a good agreement between the simulations tool to model the solar radiation incident on the vertical surface of the double skin façade, the only disagreements were found for IDA, which results include a 1 hour time shift of the results. Not only the total solar radiation on a surface but also it's diffuse and direct component were calculated with a good agreement between programs. The most characteristic differences which were observed during the earlier iterations of the comparative exercises are now corrected.

The second step is more indefinite, as various software apply different window models. There is a comparison made for the different window models in the comparative exercise, in the section 3.2.7, which reveals that the window models used in the exercises were different, moreover the main differences exist when calculating the transmission of solar radiation into the zone 2. This is confirmed when comparing the reported results.

Although, the calculated boundary conditions in the models demonstrate some deviations, these were evaluated as acceptable for further comparison. Besides, the comparison of the window models has created an awareness of the differences in the calculations and these must be kept in mind when perform a comparison of global parameters.

Looking upon the air temperatures in the DSF cavity it is easiest to consider the raise of the air temperature in the DSF cavity compared to the temperature of the outdoor air. It is remarkable that both of the cases with the naturally induced air flow in the cavity (DSF200_3 and DSF200_4) demonstrated relatively small temperature raise, moreover the order of disagreements between the tools appears as insignificant (±0.2°C), however, this is not so. When comparing the energy removed from the DSF cavity, the magnitude of the air flow plays the vital role, as the small variation in predicted air temperatures together with vast air flow result in energy removed from the DSF cavity that varies between 1.0 and 0.25kW.

As a consequence, the cooling load to the zone 2 show continuous disagreements, which exist not only for the test case DSF100_2, but for the other cases as well. Talking about the heating loads only, all of the models agree in the test case DSF400_3, due to the cool air supplied to the zone, which is highly dominating heat loss parameter compared to the level of the heat losses sue to heat transmission in the zone. While in the other test cases the heating load is defined by the heat losses, which differ from model to model. In general, the maximum heating and cooling loads are characteristic for BSim, while the predictions from the other software vary from one test case to another.

As it was argued before, the energy consumption is one of the global parameters which represent the performance of the buildings simulation software when modeling a building with DSF. The great deviation in the energy consumption in the zone is a result of interplay of many parameters, such as air flow rate, convection and radiation heat transfer, transmission of solar radiation etc. At the same time it is not possible to validate all of the inter-related parameters in this subtask, as many of those are the challenge for the whole field of building simulations. However, the air flow rate is particularly interesting and influencing factor for the DSF performance, moreover the airflow in the DSF is unavoidable part of the whole DSF concept. Thus the air flow rate was chosen as one of the main targets in evaluation and validation of Building simulation software for buildings with DSF.

The comparison of the models used for the airflow modeling in these exercises is done in the subchapter 2.3, there, it was shown, that even with the different approaches used in the models, they have many features in common. Nevertheless, the spread of the air flow results is tremendous – there are absolutely no results that can show any agreement. Even the simplified case DSF200_3 shows significant disagreements and also the night time periods do not have any correspondence.

The lack of the experimental data doesn't allow any conclusions about the modeling of the air flow rate. However a discussion of the models upon the results should be made.

3.8.1 Discussion of the airflow models and influencing matters in the air flow modeling.

It is well known that any model for calculations of natural air flow is very sensitive to number of empirical parameters such as the discharge coefficient, the wind pressure coefficients, the terrain parameters, coefficients in the power-law equations etc. The situation is extremely rare when the experimental data for estimation of these coefficients exists for a particular building which is to be modeled. In real life the modeling takes part prior to construction and therefore a user of the simulation tool takes the decision upon different recommendations, standards and experience.

In order to avoid or minimize the sensitivity of the air flow models to the input parameters, these were specified in the comparative test case specification (discharge coefficient and pressure difference coefficients). The function of the wind reduction according to the type of terrain was not specified, but the reduction coefficients were compared between the tools and demonstrate to be the same for almost all models.

However, it is not always possible to use the specified data; therefore the discharge and the pressure coefficients for the openings used in the models were also compared. In fact, the differences in input values for the discharge and pressure difference coefficients are noteworthy. Furthermore, they could have played a vital role in calculations and can be a reason for disagreements in predicted air flow rate due to the sensitivity of the air flow models to these parameters. As for example in VA114 the difference between the pressure coefficients is set to zero, and as a results the wind pressure force is left out of consideration. In BSim an empirically obtained relationship is used to calculate wind induced air flow rate . ESP-r, TRNSYS-TUD and IDA use nearly the same pressure difference coefficients and the discharge coefficients, thus one should expect better agreement of the air flow rates. Though, these tools use different air flow models to describe the relationship between the pressure drop in an opening and air flow.

Earlier, it was mentioned that the application of the orifice model assumes the fully developed turbulent flow and in most of the cases this assumption is valid as even the laminar flow regime turns to turbulent due to the opening size, sharp edges of the opening etc. However, the orifice equation is not accurate enough when the laminar flow or flow in transition to turbulent occurs. In this case the power-law model has the priority as it can be adjusted to one or another regime as long as it is know what flow regime one deals with. Yet, there is no empirical data available to verify the application of one or another relationship (orifice or power-law), thus this discussion must be taken when the empirical test cases will be completed.

Another issue to discuss is the consideration of the wind turbulence effect on the air flow rates in the DSF cavity. Only one of the models in the comparative exercises considers the wind fluctuations as a contributor to the total air flow rate in the cavity (VA114 uses the wind fluctuation model described in [7,8]). At the same time the design of the DSF in many cases represents a construction with the openings at the different levels of the same surface. This is also the case in the comparative exercises. Although, the openings located at different levels (single-sided ventilation), the wind pressure, does not have as much effect on the air flow, as in case of cross ventilation. From this point of view the wind fluctuation effect can have an increased importance and can influence the accuracy. Another expression for taking into account the wind fluctuations can be used, it is developed by Larsen [9] and it takes into consideration the location of the opening (windward/leeward side) and a combination of wind pressure and temperature differences.

Previously, it was explained that the air temperature in the DSF cavity is the result of the convective heat transfer between the glass surfaces and the cavity air. The surface temperature of the glass can become relatively high and as a part of convective heat transfer appears the boundary layer flow. The air flow rate in the boundary flow normally increases with the distance from the inlet opening and in some circumstances it is likely that the air flow in the boundary layer can exceed the main flow rate in the cavity. This can cause the appearance of the reverse flow and even more intricate the flow field in the cavity.

At the moment the network method and the loop method are the best suitable for the calculation of the dynamic air flow rate in a naturally ventilated space. The network method is also the one used for almost all models in the comparative exercise. However, one of the limitations of this method is that it is not suited to model the airflow patterns within the zone [10], such as reverse flow, local recirculation, etc.

Often this limitation is solved by dividing a zone into several sub zones, as explained in the modeler reports for TRNSYS-TUD and ESP-r models. The DSF is differently subdivided in ESP-r and TRNSYS-TUD models: there are three equal zones in ESP-r and 4 zones in TRNSYS-TUD, where two of the smaller zones located at the bottom and at the top and two bigger ones located in the middle of the cavity. Splitting up the cavity into a few zones stacked on the top of each other can highly improve the accuracy of simulation, but this solution is more suitable when it is necessary to count on the vertical temperature gradient only, as this doesn't solve the complexity of the local recirculation.

Looking upon the topics of the discussion in this section one can argue that the topic of the subject of naturally driven flow is complex and it is possible that there is a lack of model able to deal with the naturally driven flow in the DSF cavity. But, the software tools performed the simulations of the comparative exercises and as there is no agreement between the results it is not possible to make a final conclusion until the empirical validation is completed.

3.9 Summary

The outline of the results in the comparative validation identifies the areas where is no correspondence achieved, i.e. calculation of the air flow rate, surface temperatures heating load at night and cooling load in the peaks of solar gains etc. Meanwhile, the comparative exercises have built a strong foundation for the empirical test cases. Two main empirical test cases were identified, these correspond to the comparative test case DSF100_2 and DSF200_4, the third empirical test case is also specified as DSF400_3, but it's completion is under consideration.

The comparative test cases can not be directly used for the validation of the software due to often disagreement of the results, however the result of the exercises is that the comparative validation can be regarded as the main argument to continue the validation of the building simulation software for the buildings with the double skin façade with the empirical validation test cases.

LITERATURE

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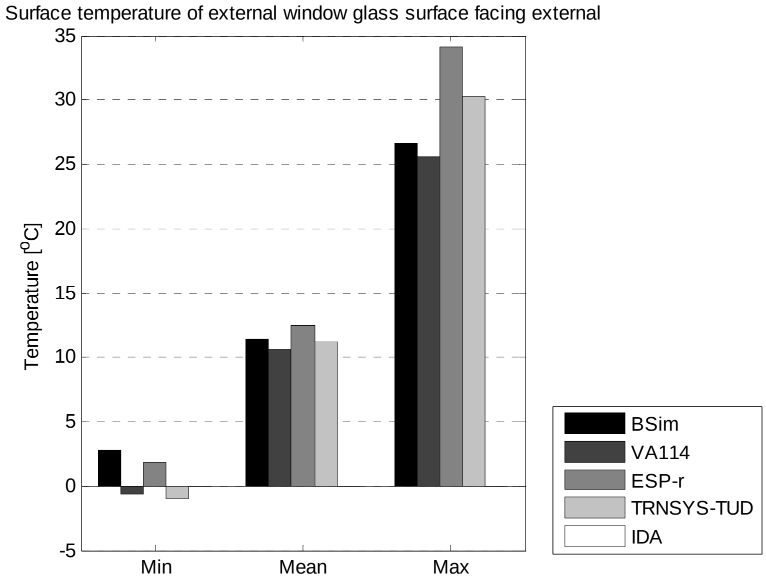
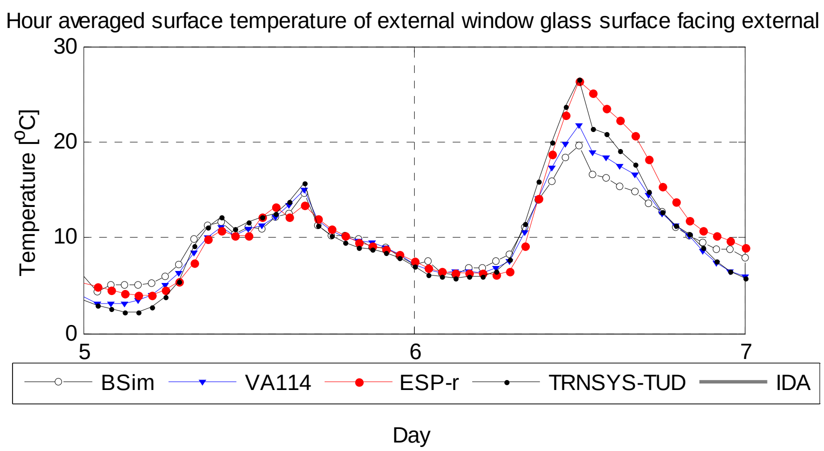
APPENDIX: Surface Temperatures

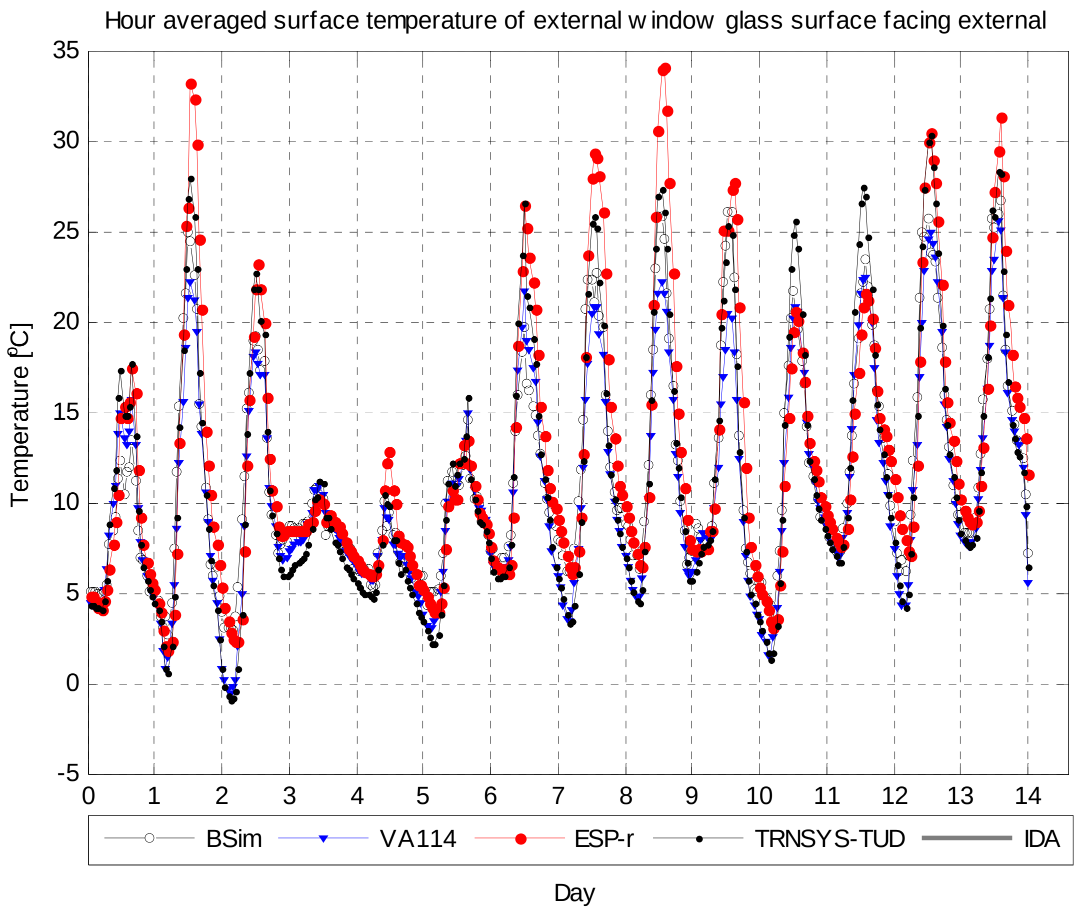
DSF100_2

Surface temperature of the glazing

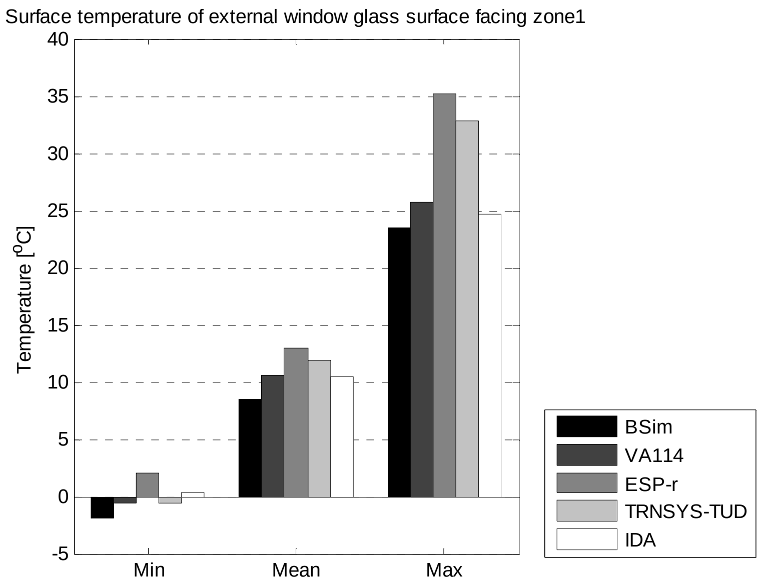


Surface temperature of external widow glass surface facing external	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	2.7	-0.6	1.8	-1.0	-
Max, °C	26.7	25.6	34.1	30.3	-
Average, °C	11.4	10.6	12.5	11.3	-

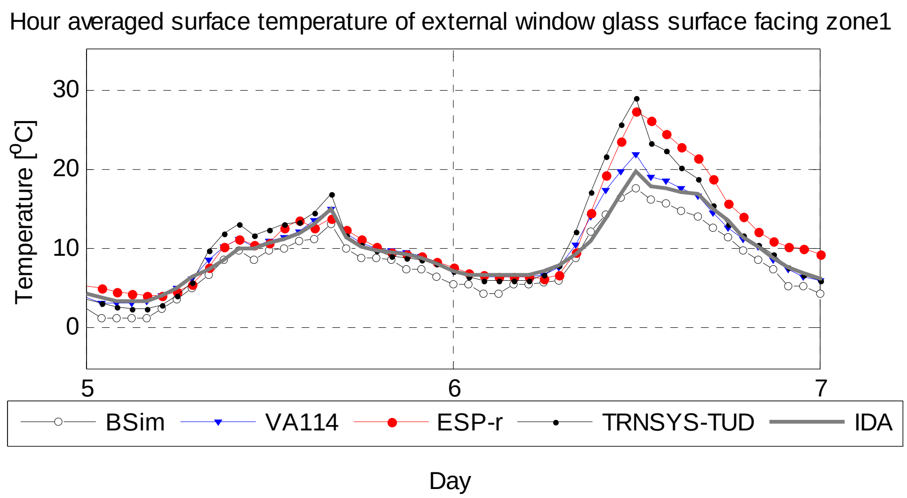


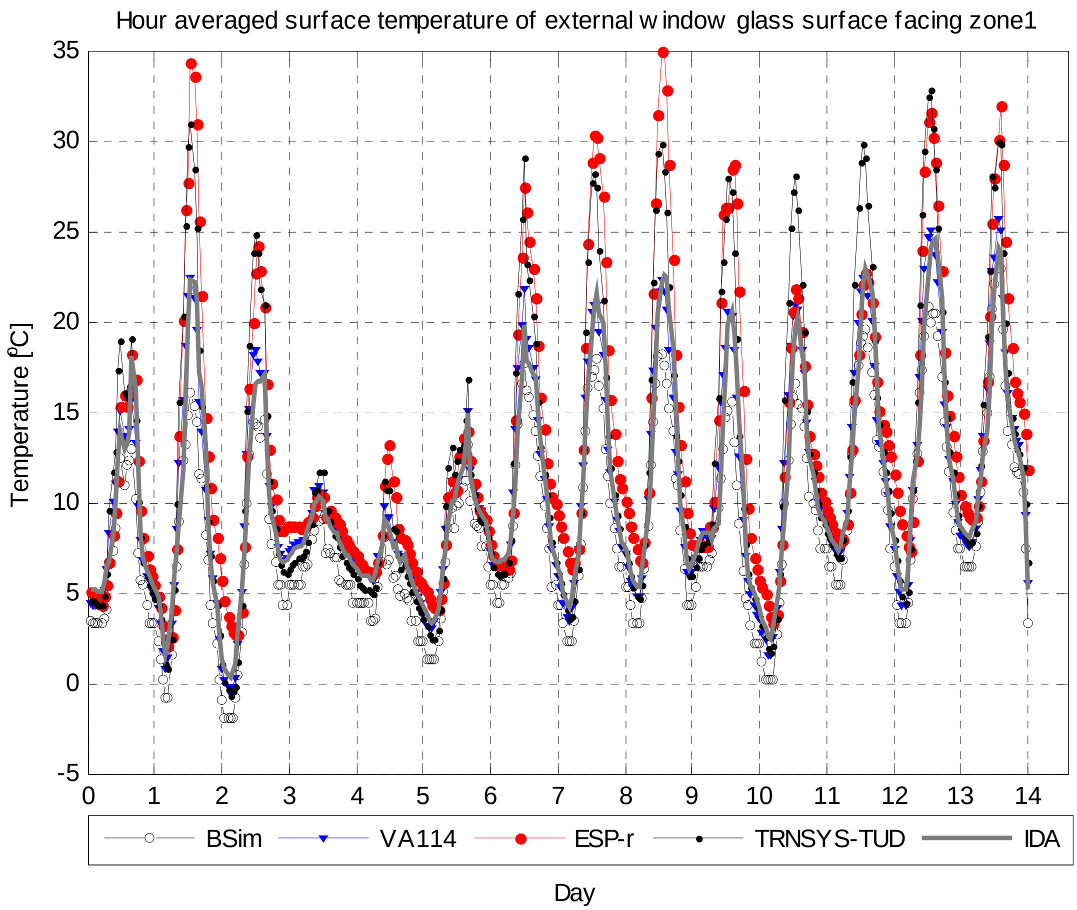


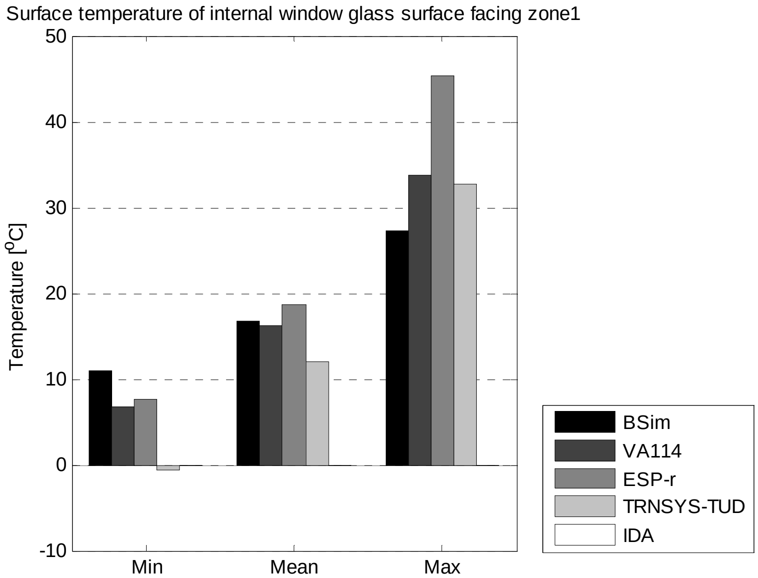
Hour averaged surface temperature of external w indow glass surface facing external
Temperature [ºC]
35
30
25
20
15
10
5
0
-5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day



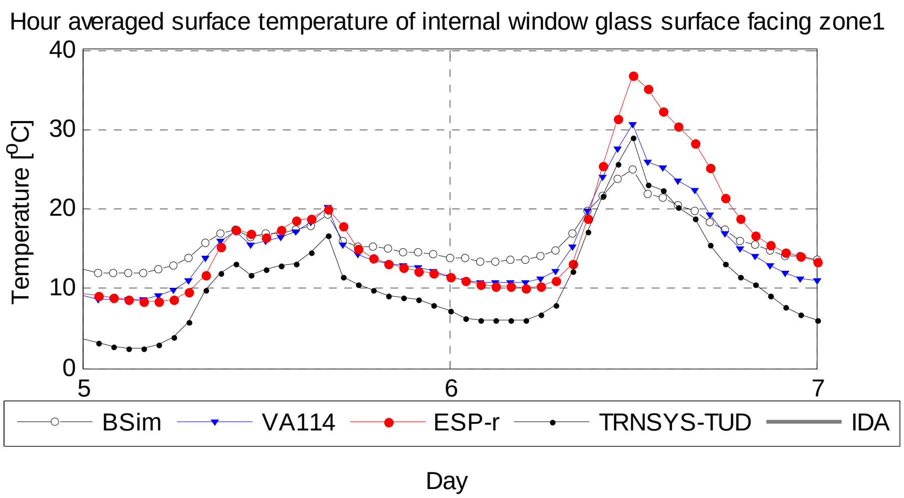
Surface temperature of external window glass surface facing external	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	-1.9	-0.6	2.1	-0.6	0.3
Max, °C	23.5	25.7	35.2	32.8	24.6
Average, °C	8.5	10.6	12.9	12.0	10.5

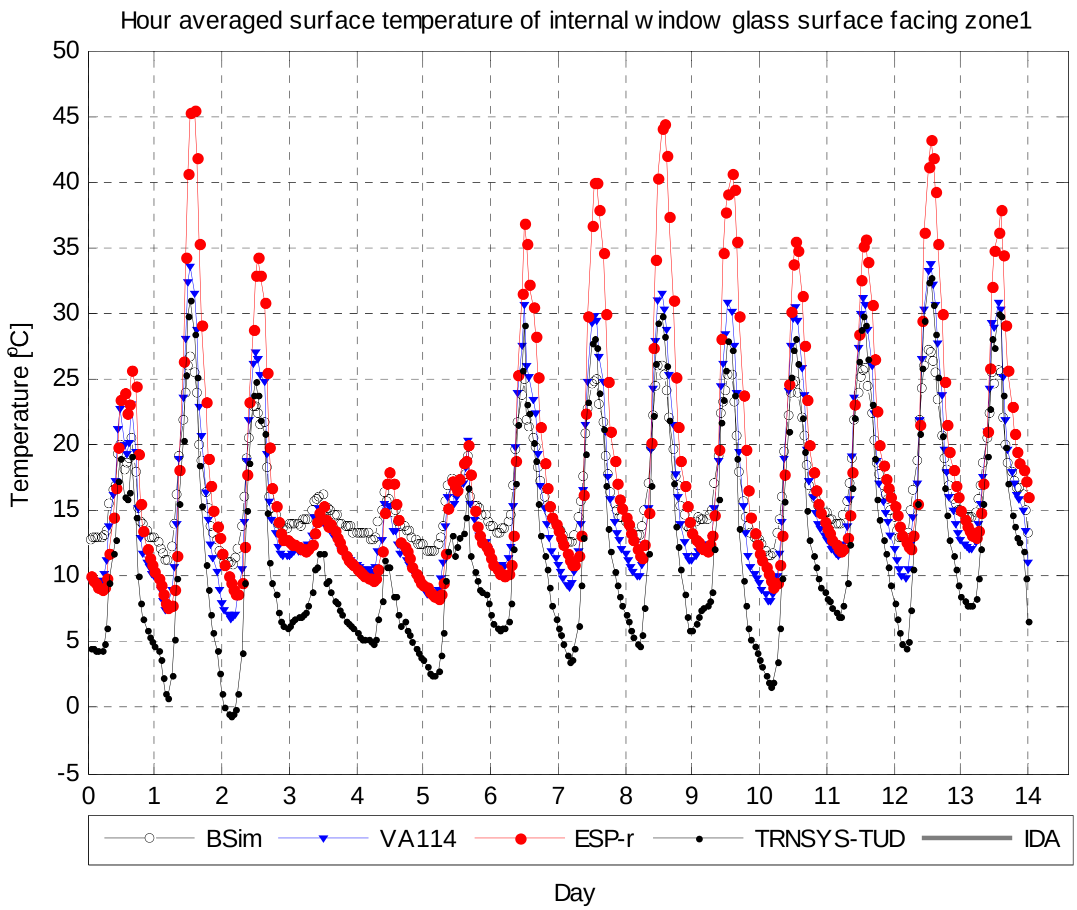


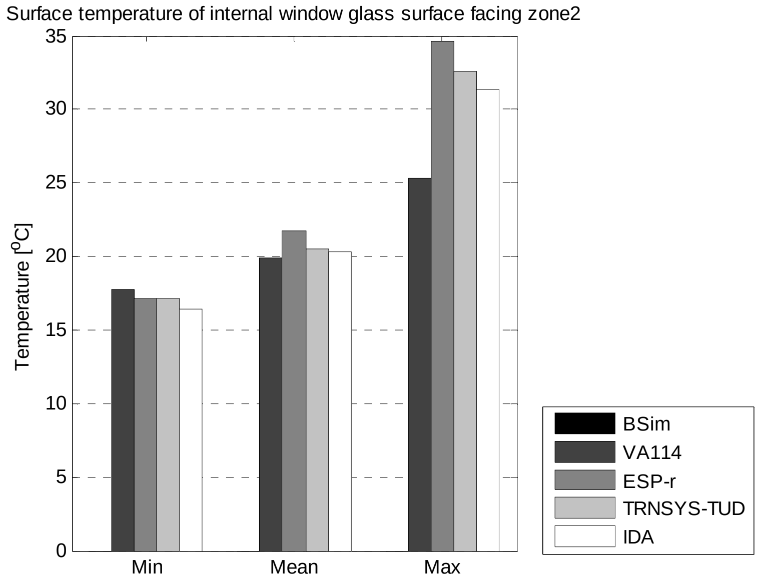

Hour averaged surface temperature of external window glass surface facing zone1
Temperature [ºC]
Day
BSim
VA114
ESP-r
TRNSYS-TUD
IDA



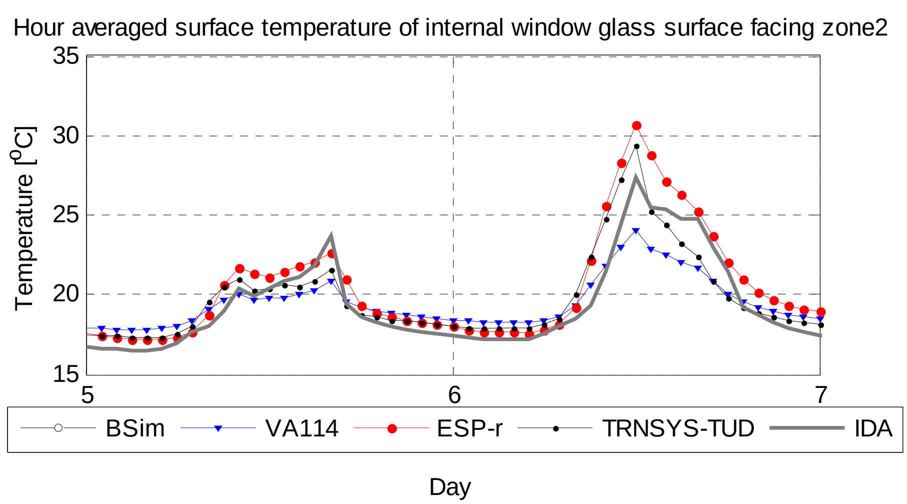
Surf. temperature of internal window glass surface facing zone 1	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	11.0	6.8	7.6	-0.6	-
Max, °C	27.2	33.8	45.4	32.8	-
Average, °C	16.7	16.1	18.7	12.0	-

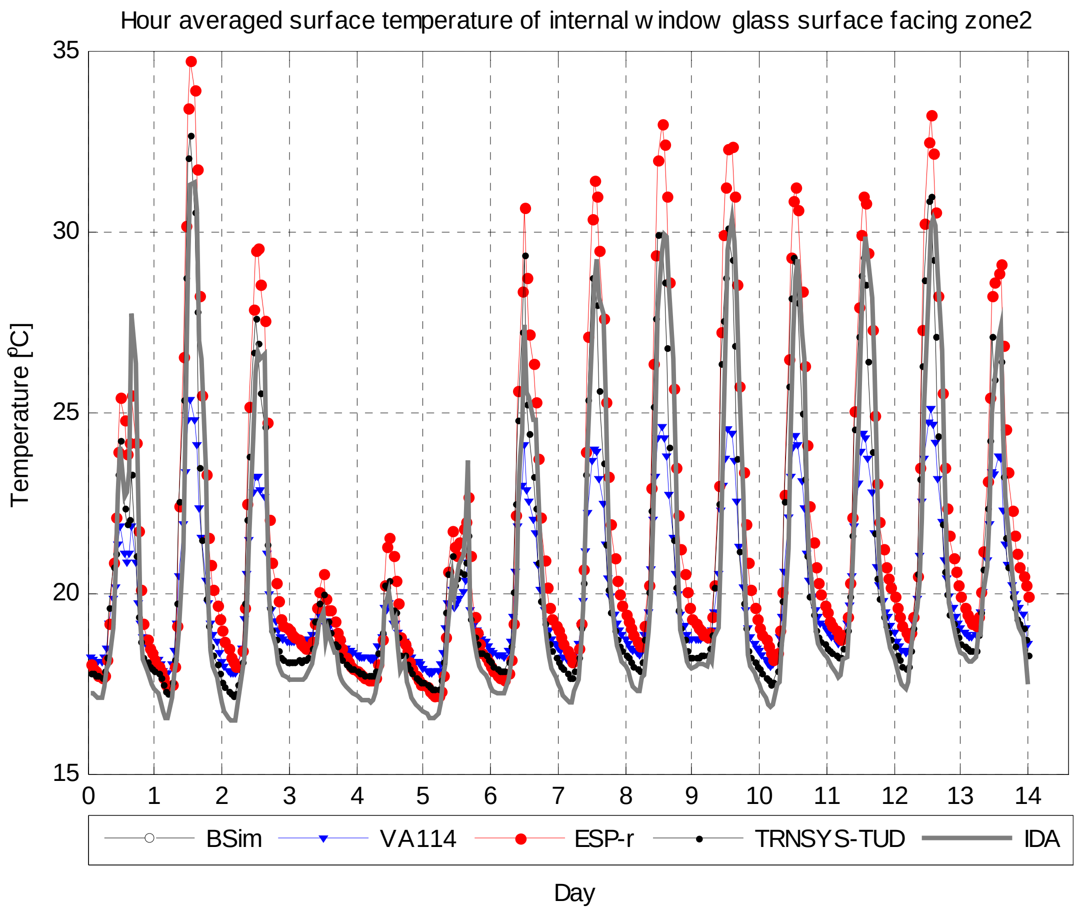



Hour averaged surface temperature of internal window glass surface facing zone1
Temperature [ºC]
50
45
40
35
30
25
20
15
10
5
0
-5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day



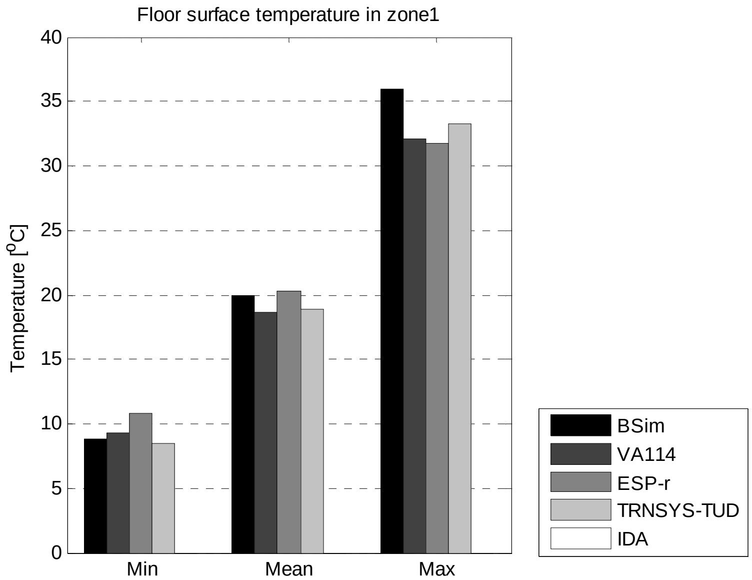
Surface temperature of internal window glass surface facing zone 2	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	-	17.7	17.2	17.2	16.5
Max, °C	-	25.3	34.7	32.6	31.4
Average, °C	-	19.9	21.8	20.5	20.3



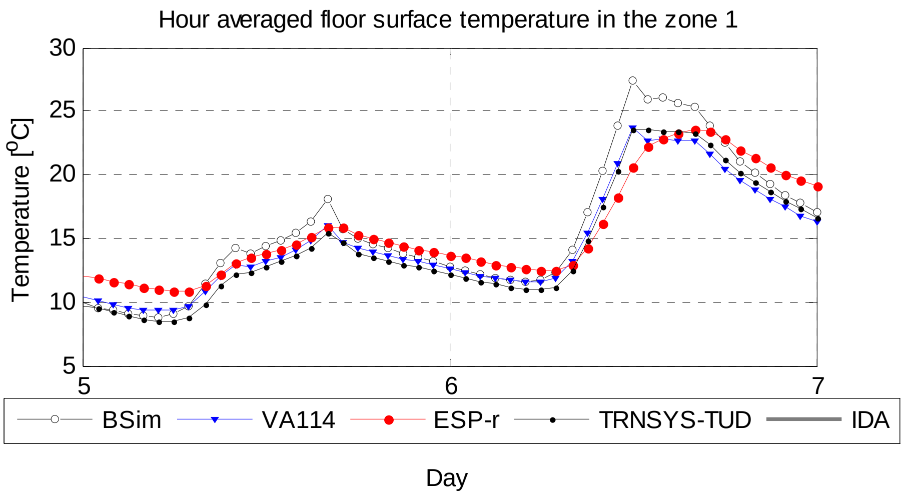


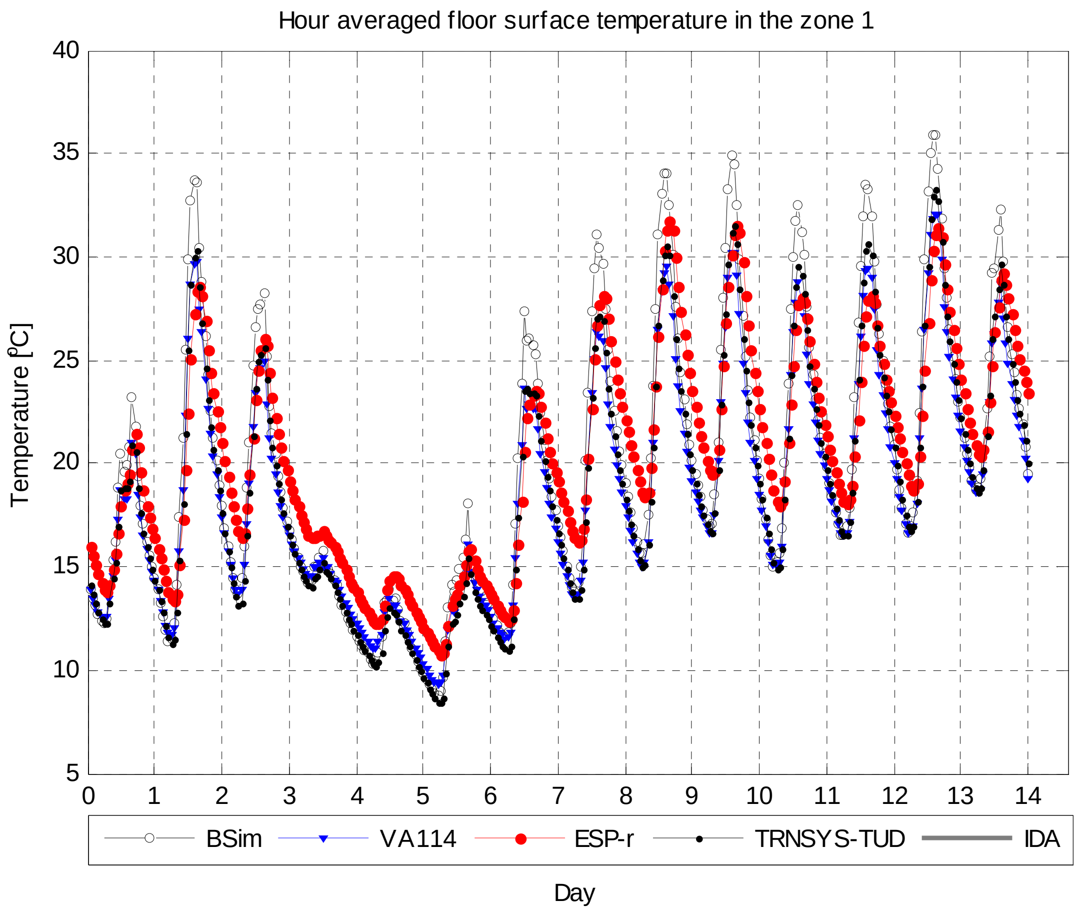
Hour averaged surface temperature of internal window glass surface facing zone2
35
30
25
20
15
Temperature [°C]
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day

Floor and ceiling surface temperature

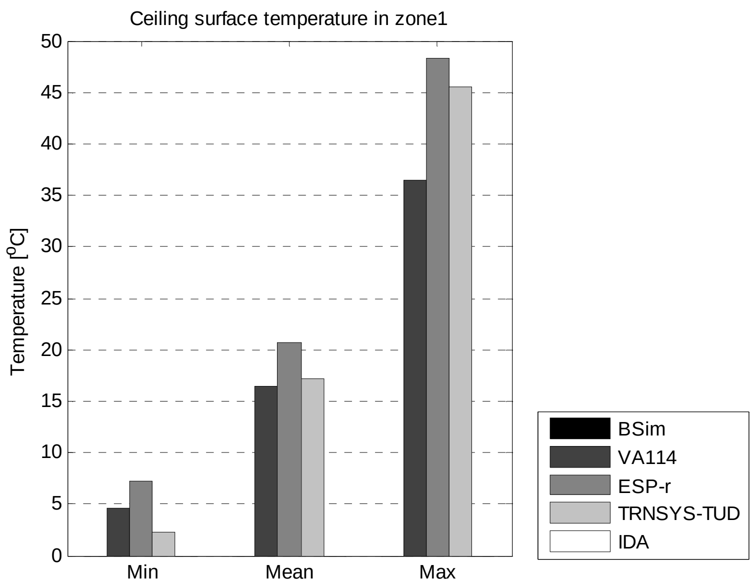


Floor surface temperature in zone 1	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	8.8	9.3	10.8	8.5	-
Max, °C	35.9	32.1	31.8	33.3	-
Average, °C	19.9	18.7	20.3	18.8	-

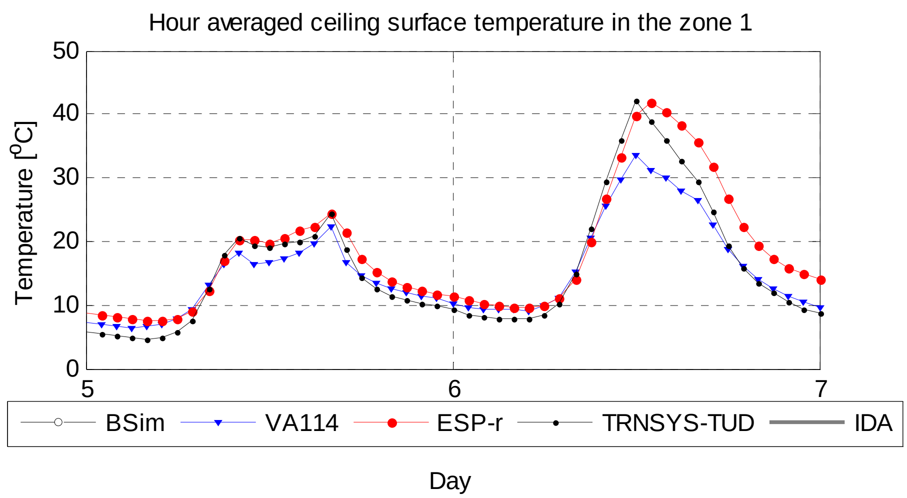


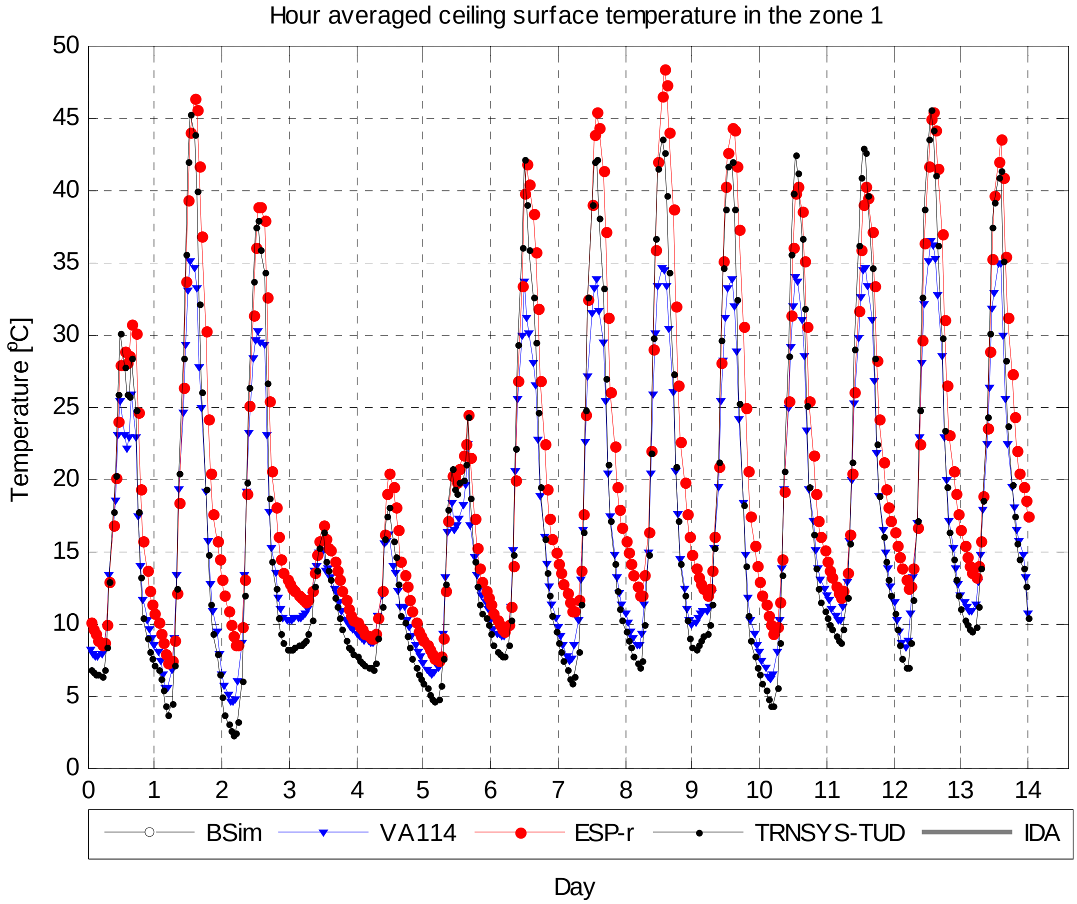


Hour averaged floor surface temperature in the zone 1
Temperature [°C]
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day

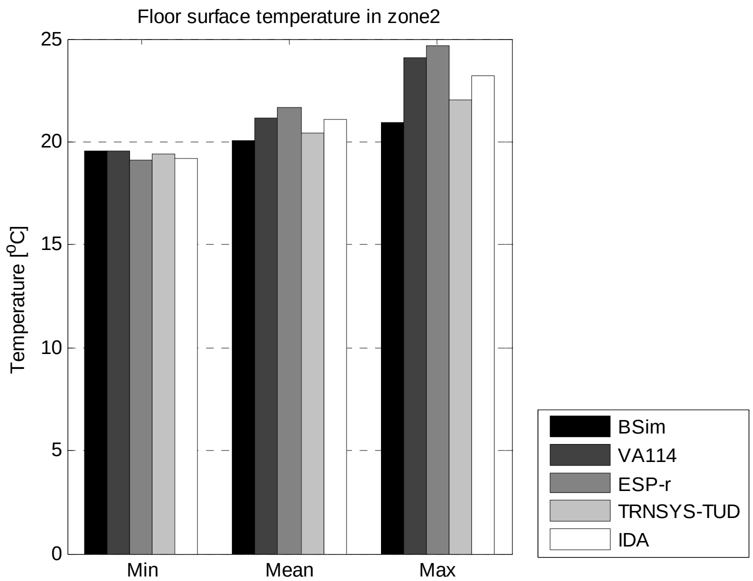


Ceiling surface temperature in zone 1	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	5.4	4.6	7.3	2.3	-
Max, °C	93.3	36.4	48.3	45.5	-
Average, °C	27.3	16.5	20.7	17.2	-

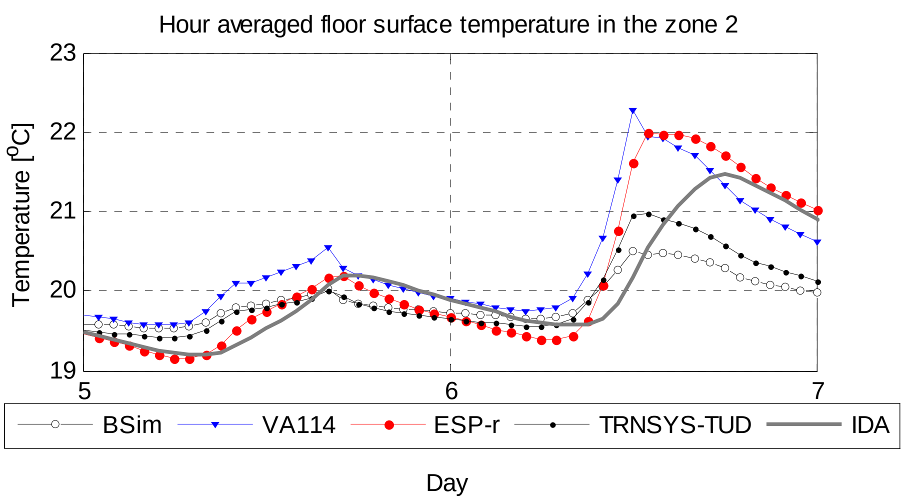


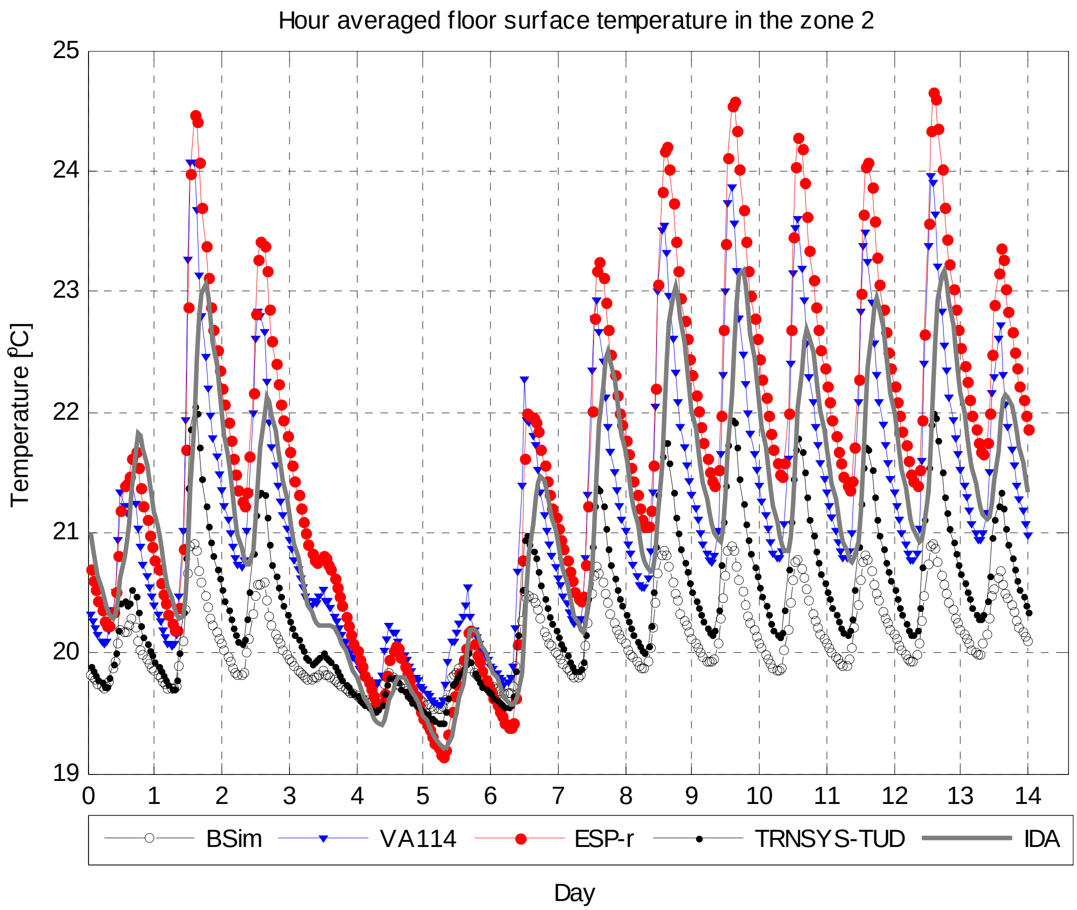


Hour averaged ceiling surface temperature in the zone 1
Temperature [ºC]
Day
0
5
10
15
20
25
30
35
40
45
50
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA

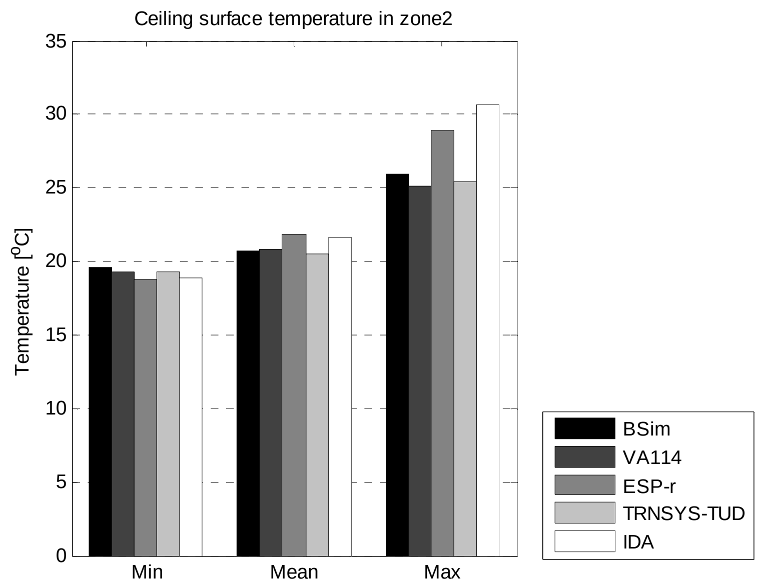


Floor surface temperature in zone 2	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	19.5	19.6	19.2	19.4	19.2
Max, °C	20.9	24.1	24.7	22.0	23.2
Average, °C	20.1	21.2	21.6	20.4	21.1

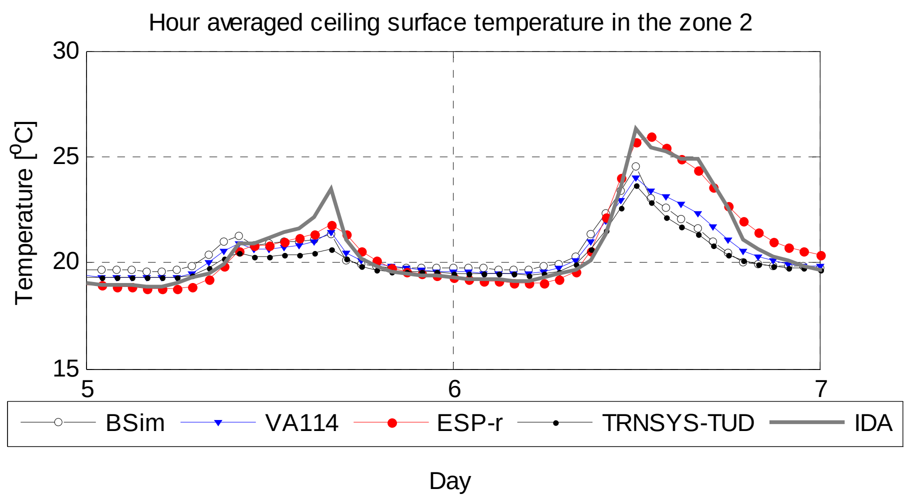


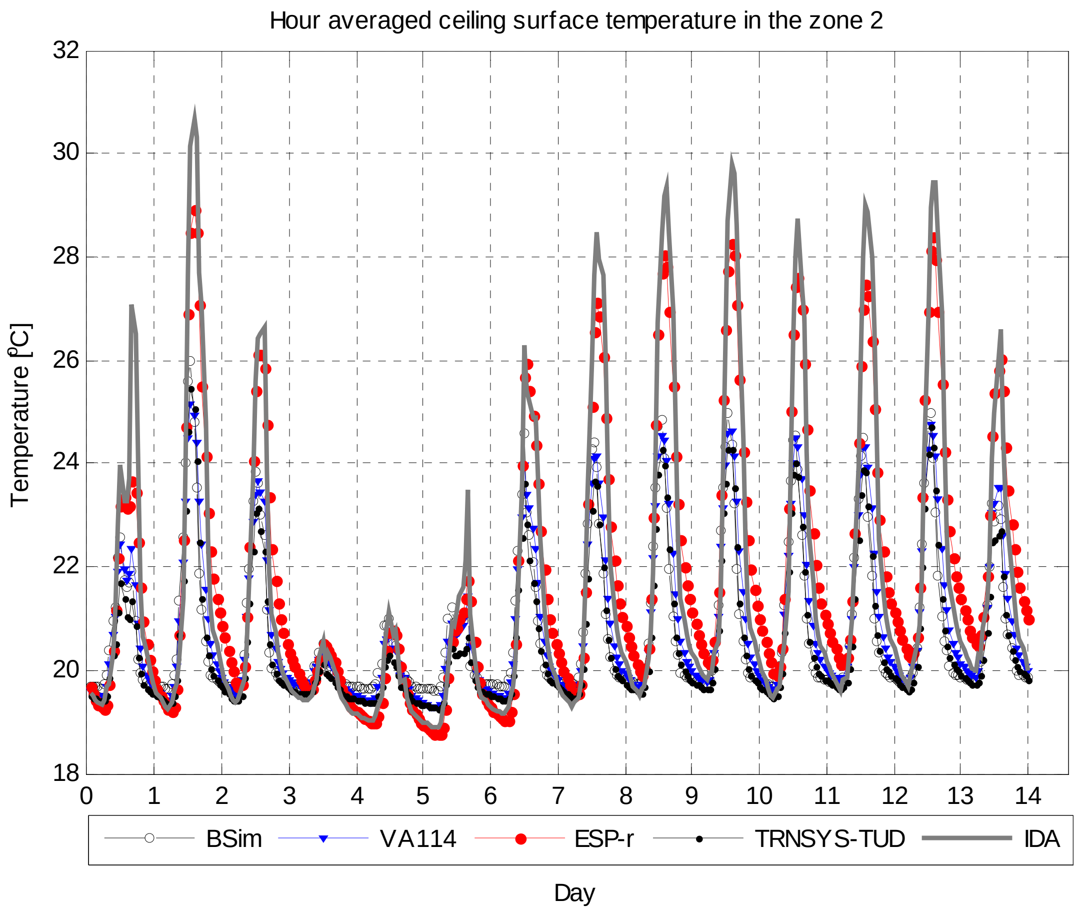


Hour averaged floor surface temperature in the zone 2
25
24
23
22
21
20
19
Temperature [°C]
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day



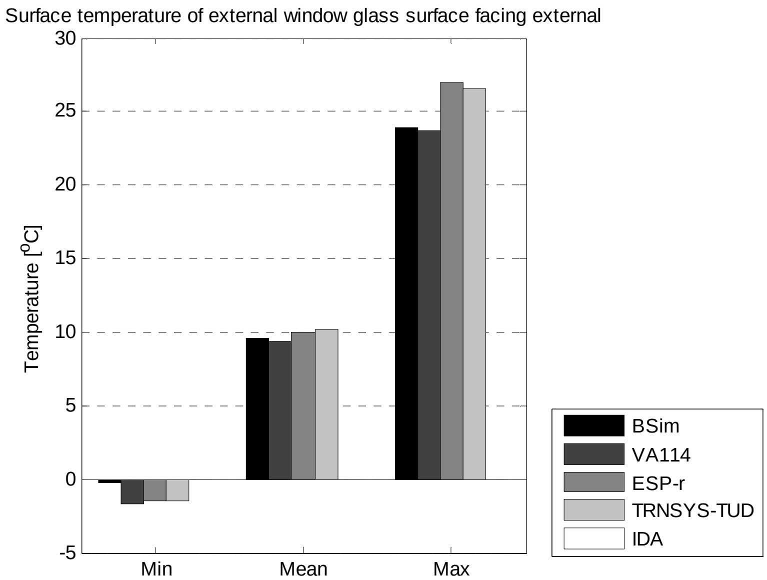
Ceiling surface temperature in zone 2	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	19.6	19.3	18.8	19.3	18.9
Max, °C	26.0	25.1	28.9	25.5	30.7
Average, °C	20.7	20.9	21.8	20.5	21.7



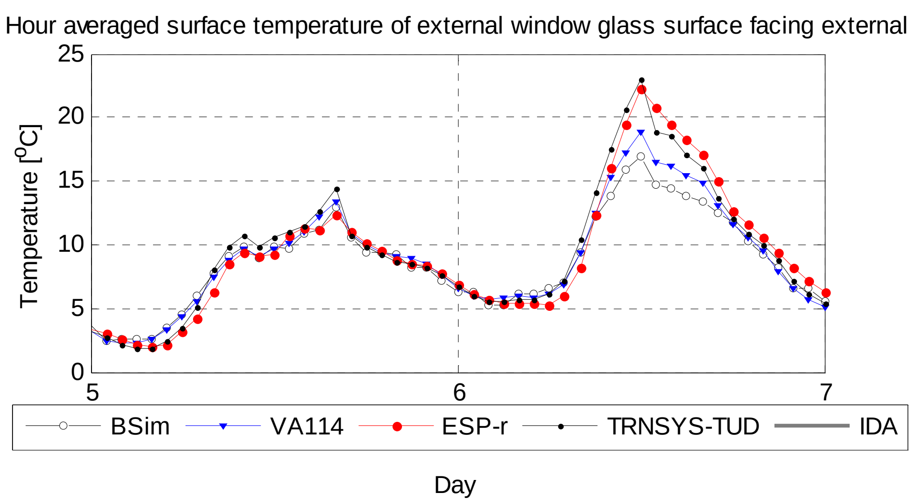

Hour averaged ceiling surface temperature in the zone 2
Temperature [ºC]
32
30
28
26
24
22
20
18
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day

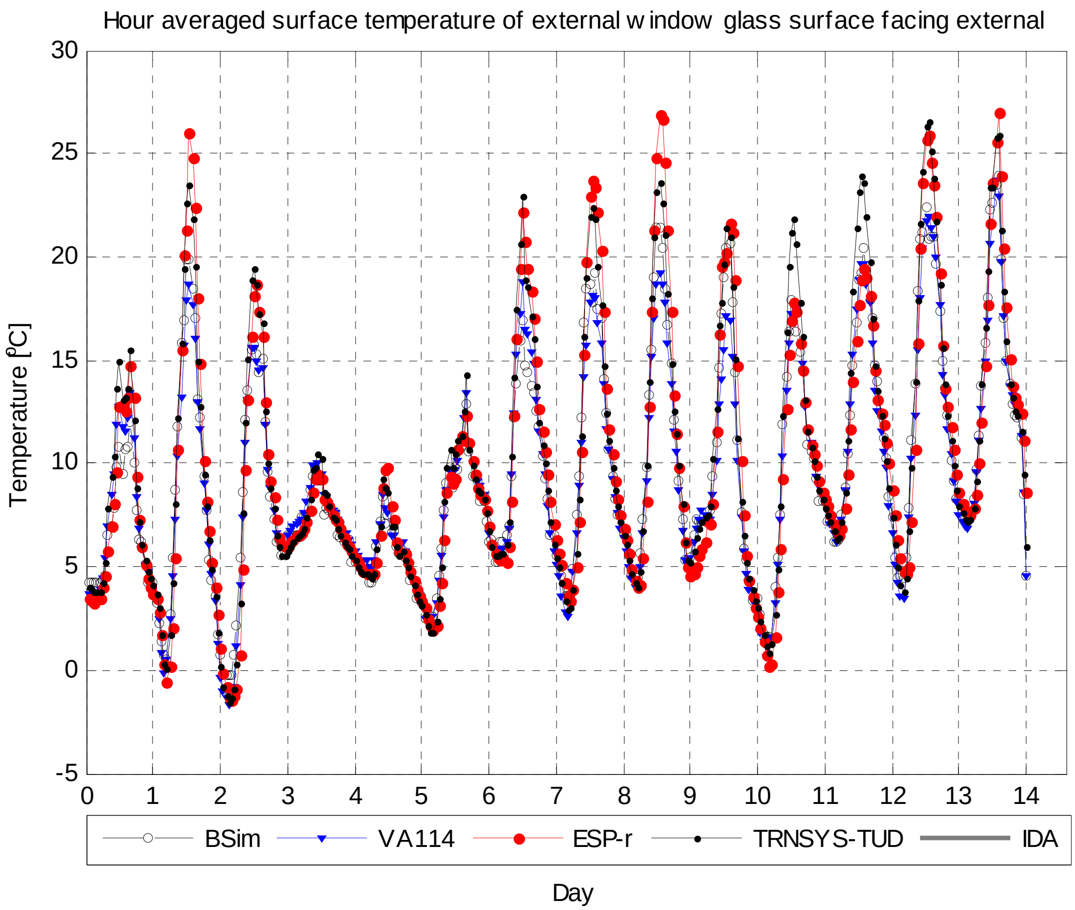
DSF400_3

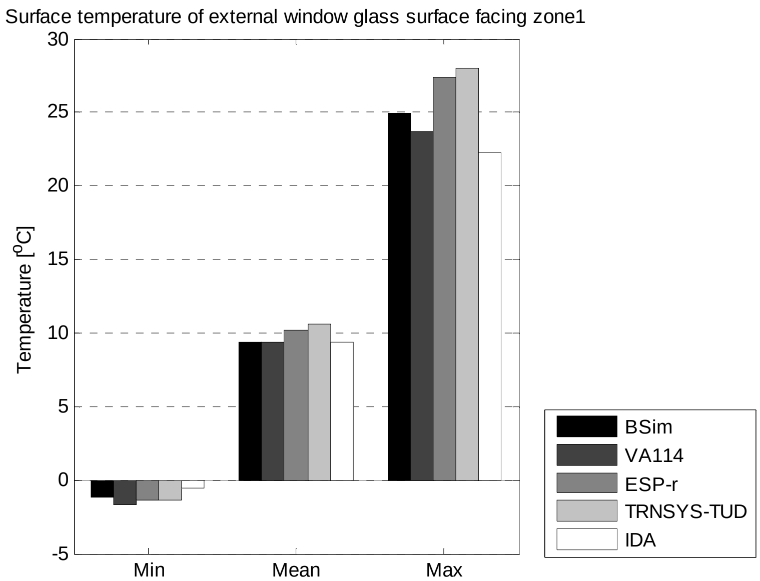
Surface temperatures of the glazing



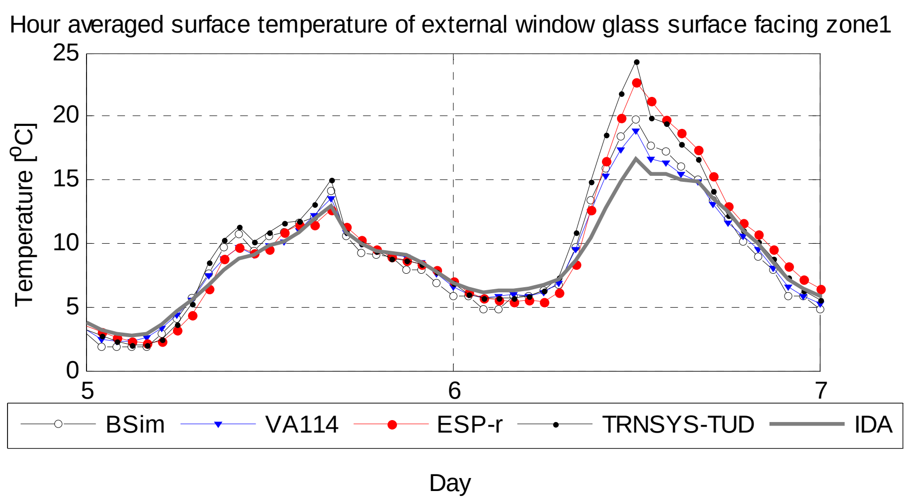
Surface temperature of external window glass surface facing external	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	-0.3	-1.7	-1.4	-1.5	-
Max, °C	24.0	23.7	27.0	26.5	-
Average, °C	9.5	9.3	10.0	10.2	-

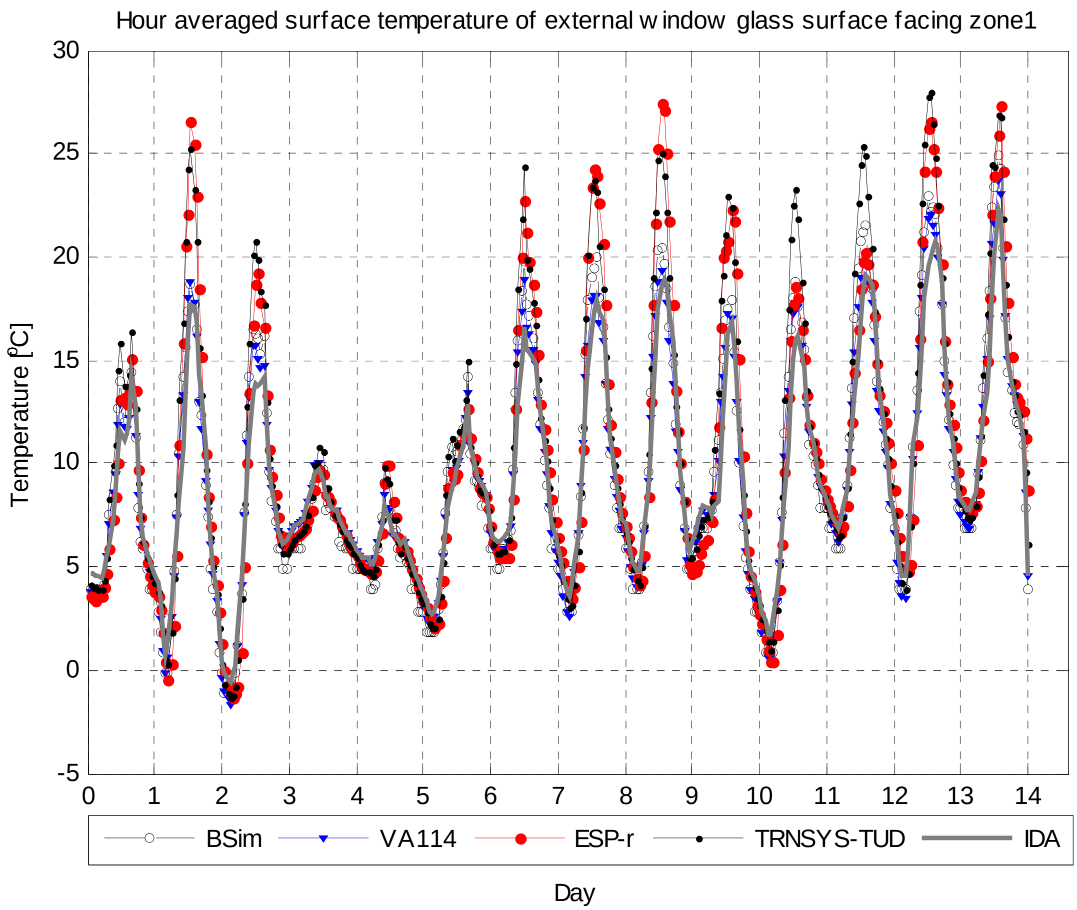



Hour averaged surface temperature of external window glass surface facing external
Temperature [ºC]
30
25
20
15
10
5
0
-5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day

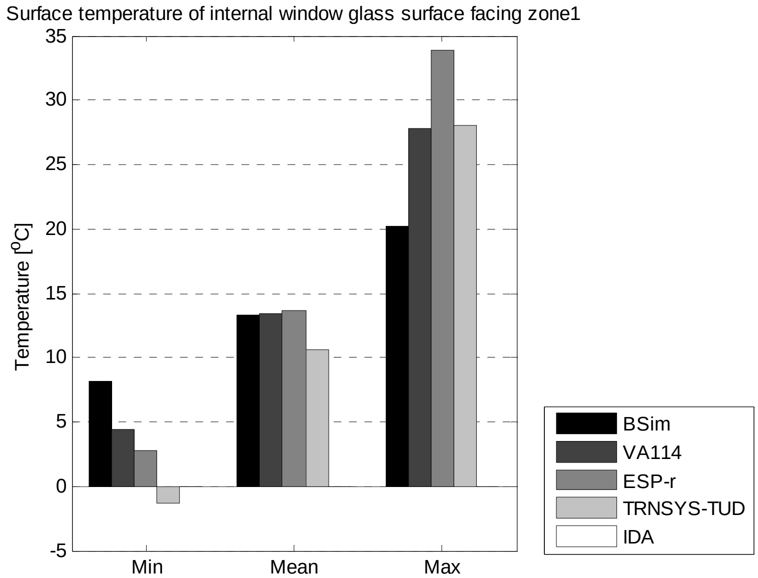


Surface temperature of external window glass surface facing zone 1	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	-1.2	-1.7	-1.3	-1.4	-0.6
Max, °C	24.9	23.7	27.4	28.0	22.2
Average, °C	9.4	9.4	10.2	10.6	9.4

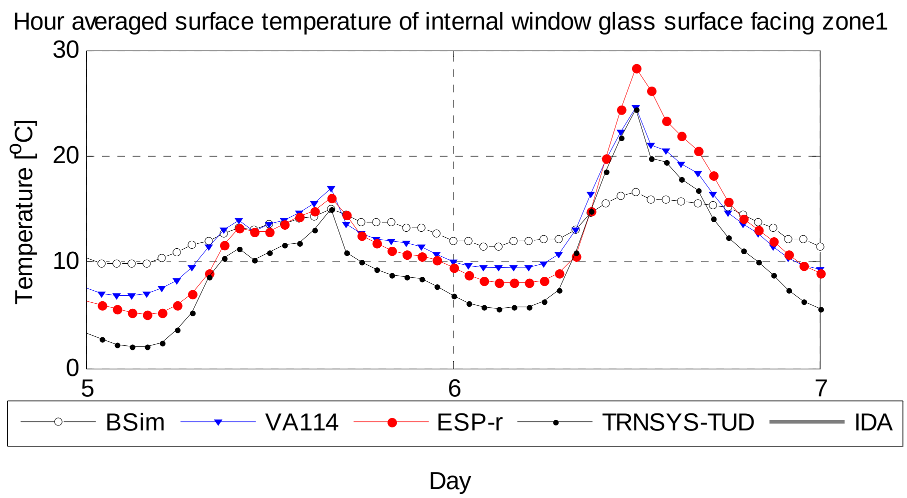


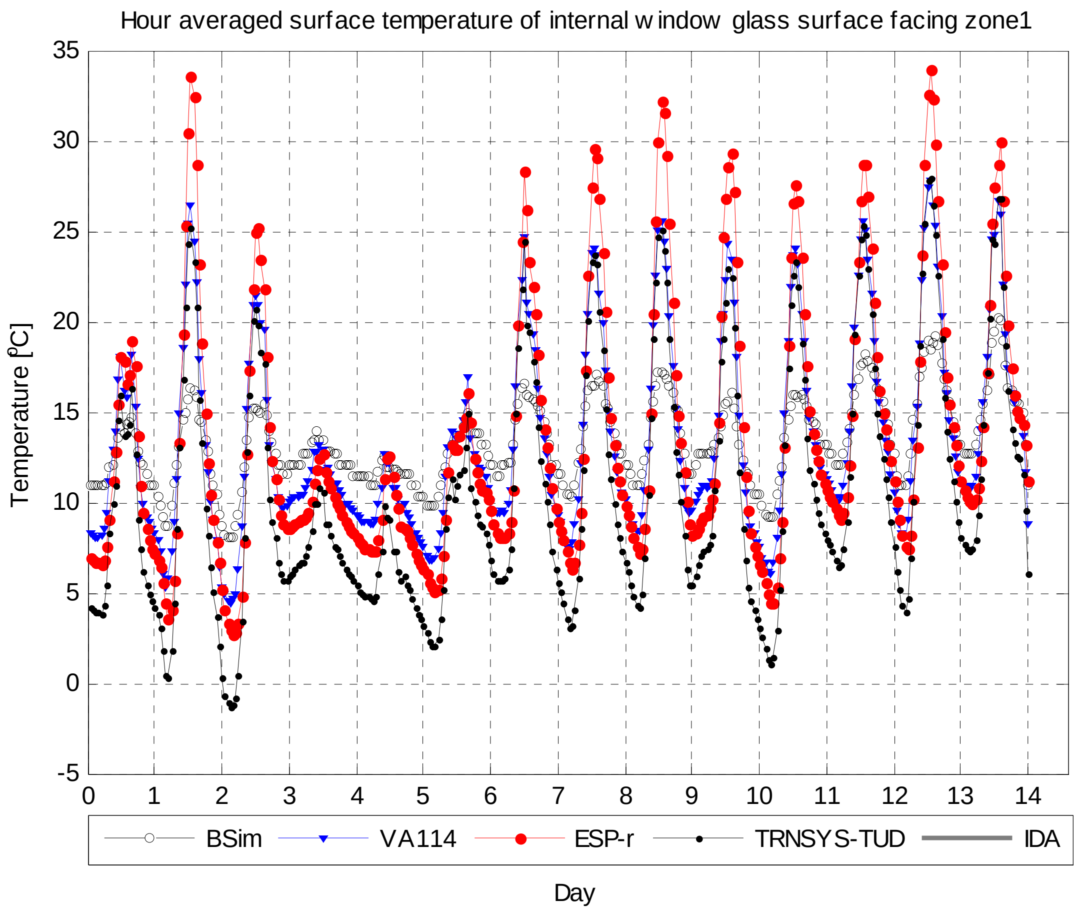


Hour averaged surface temperature of external w indow glass surface facing zone1
Temperature [°C]
Day
BSim
VA114
ESP-r
TRNSYS-TUD
IDA

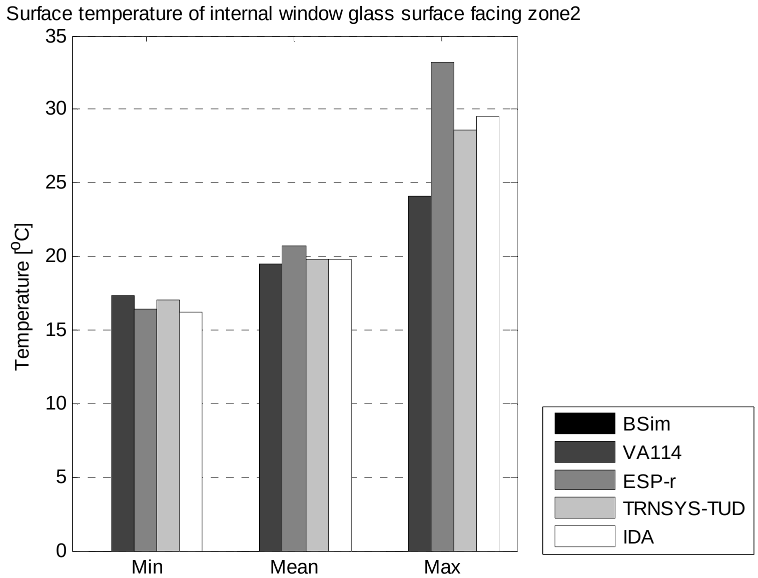


Surface temperature of internal window surface facing zone 1	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	8.1	4.4	2.7	-1.4	8.1
Max, °C	20.2	27.8	33.9	28.0	20.2
Average, °C	13.3	13.5	13.6	10.6	13.3

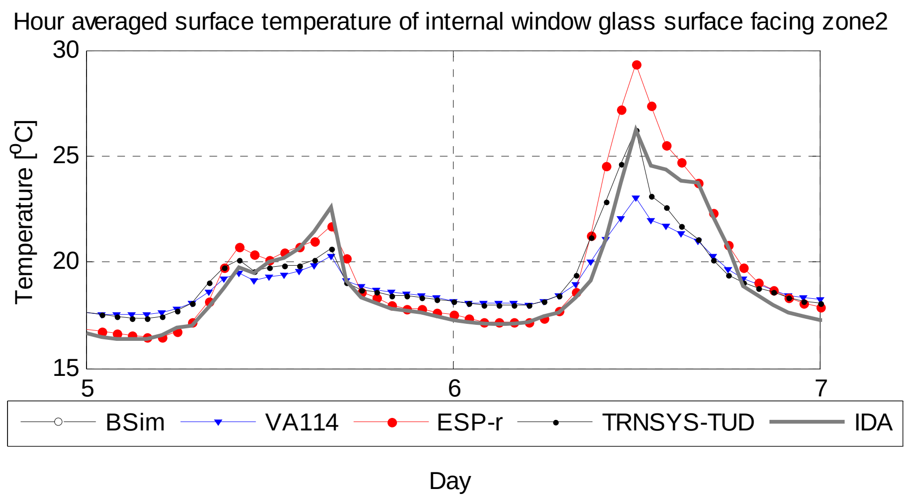


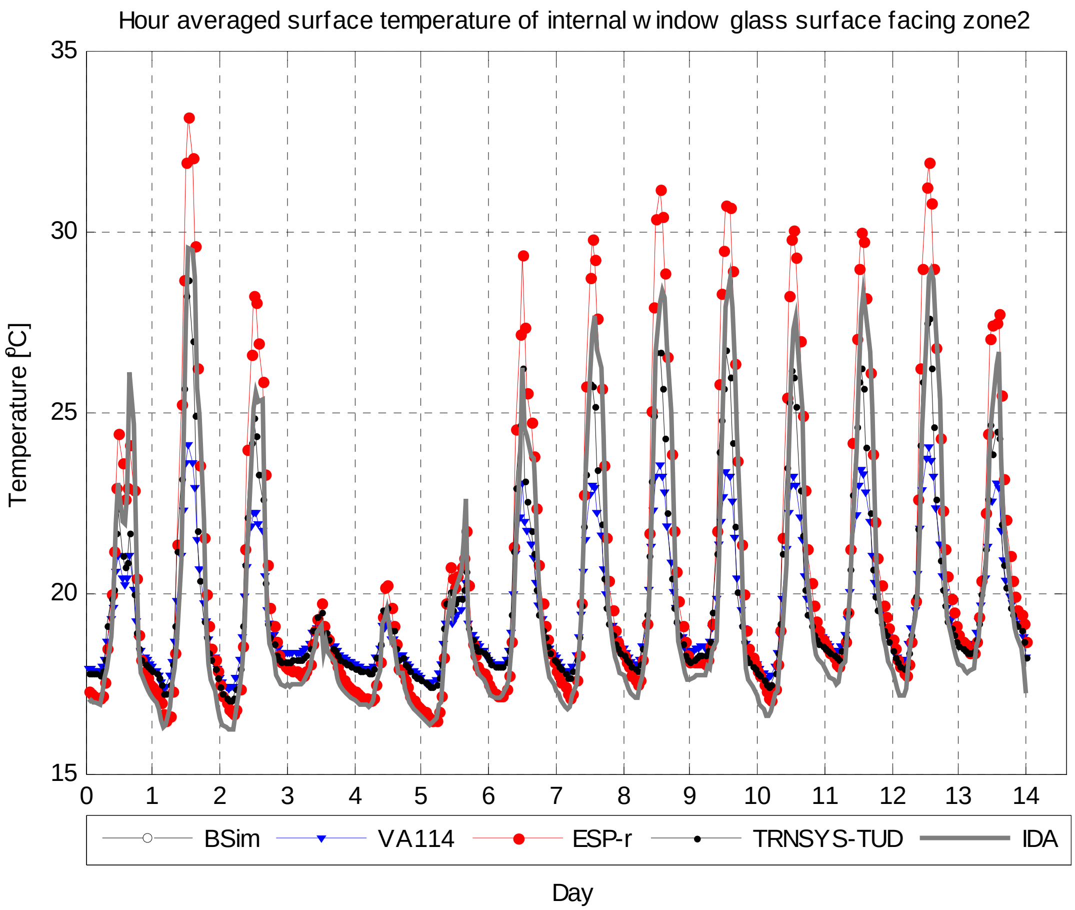


Hour averaged surface temperature of internal w indow glass surface facing zone1
Temperature [ºC]
35
30
25
20
15
10
5
0
-5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day

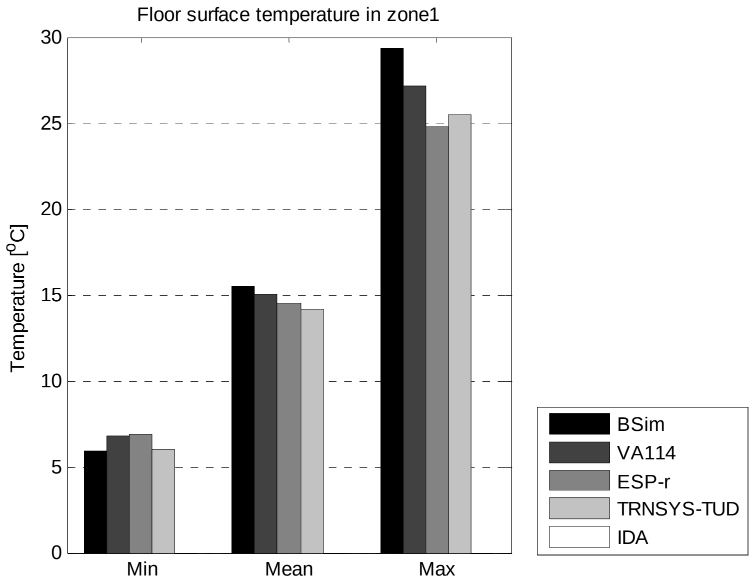


Surface temperature of internal window glass surface facing zone 2	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	-	17.4	16.5	17.1	16.2
Max, °C	-	24.1	33.2	28.7	29.6
Average, °C	-	19.5	20.7	19.8	19.8

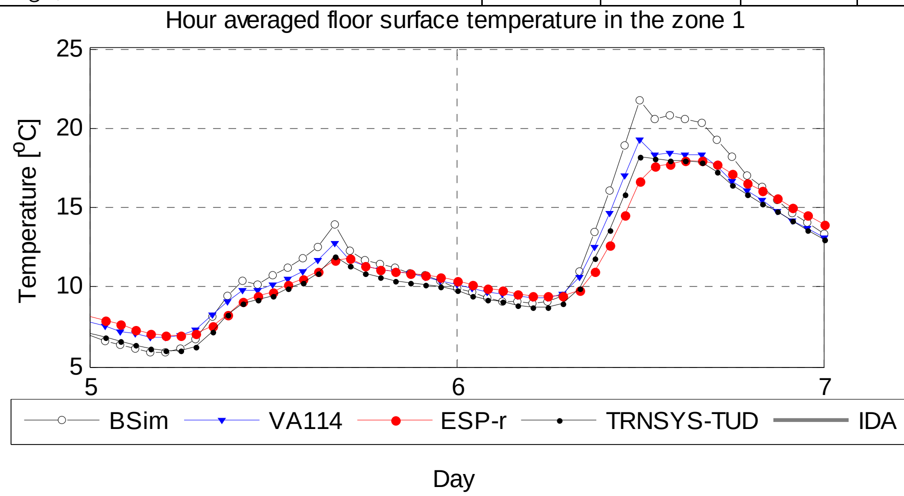


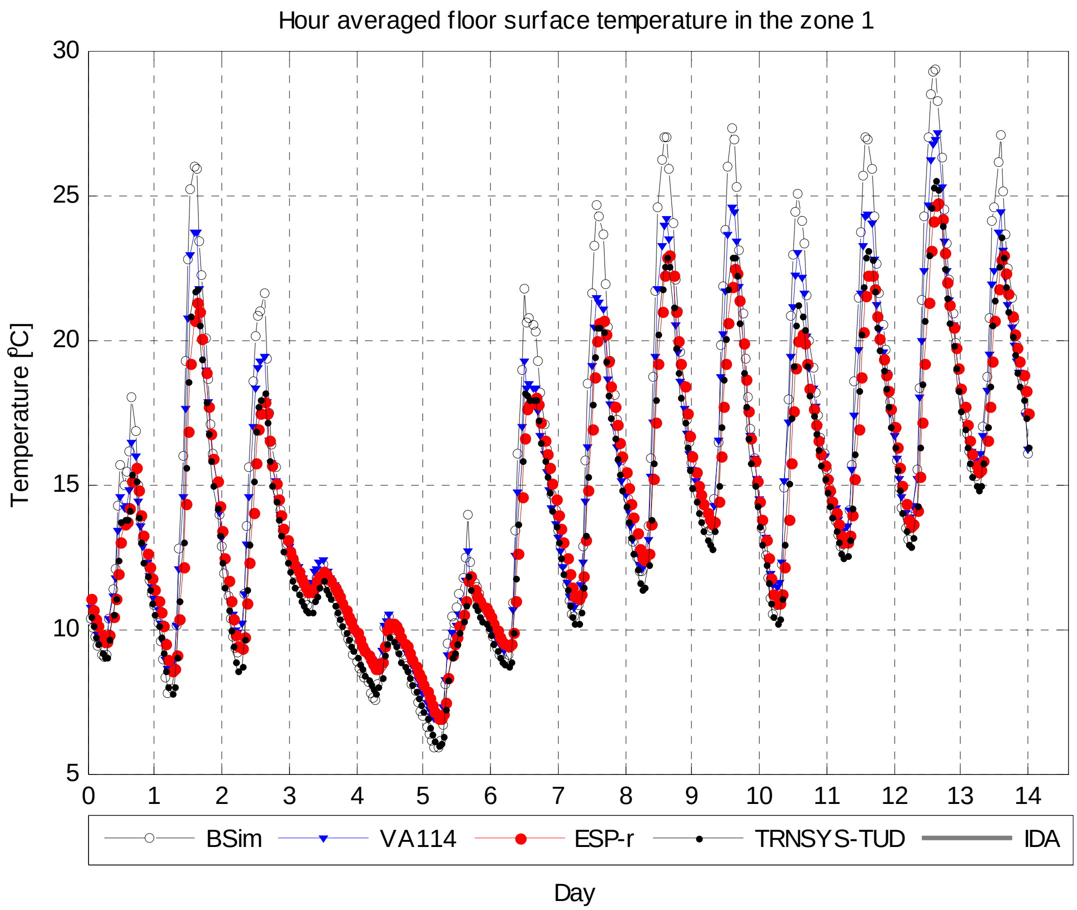

Hour averaged surface temperature of internal w indow glass surface facing zone2
35
30
25
20
15
Temperature [ºC]
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day

Floor and ceiling surface temperature

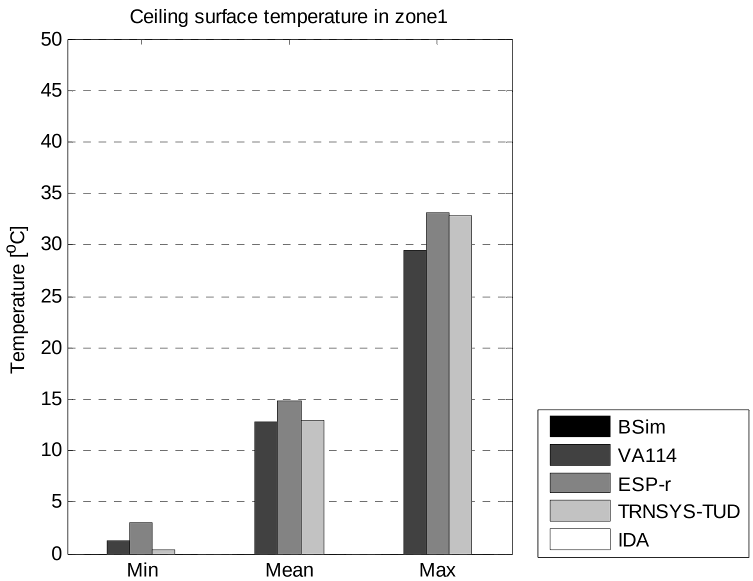


Floor surface temperature in zone 1	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	5.9	6.8	6.9	6.0	-
Max, °C	29.4	27.2	24.8	25.5	-
Average, °C	15.5	15.0	14.5	14.2	-

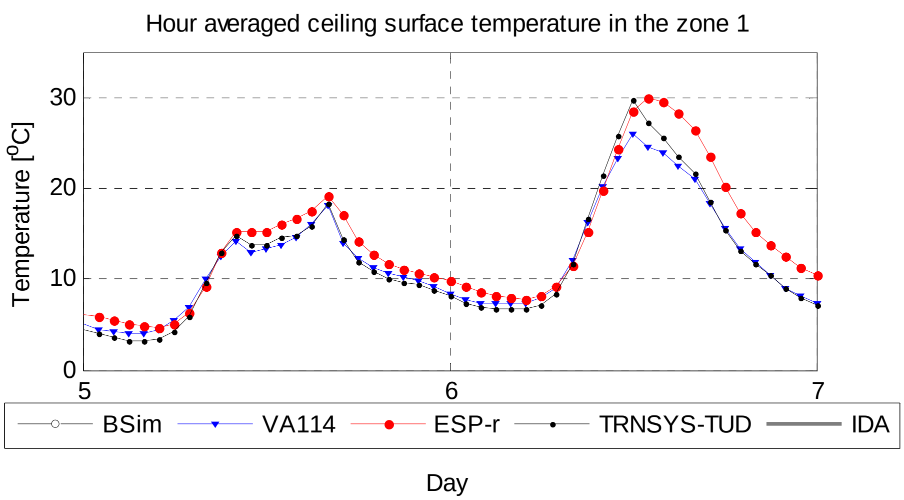


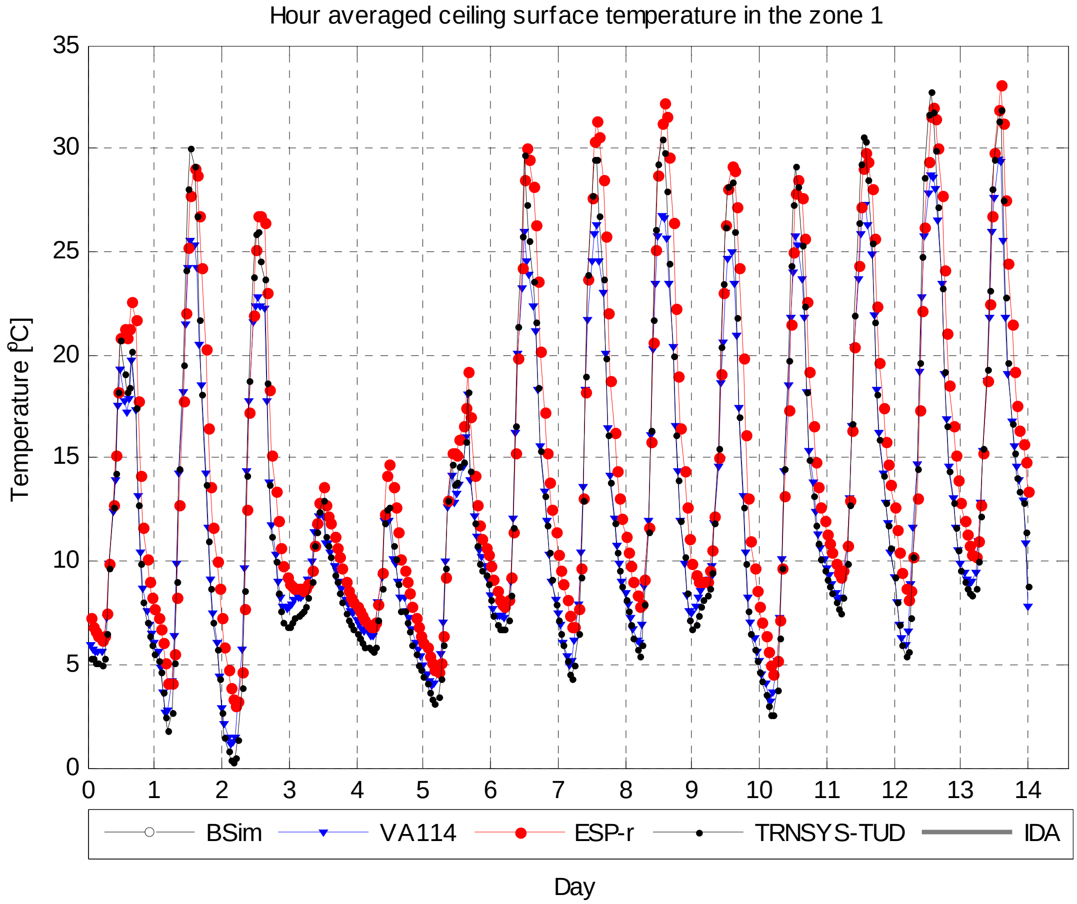


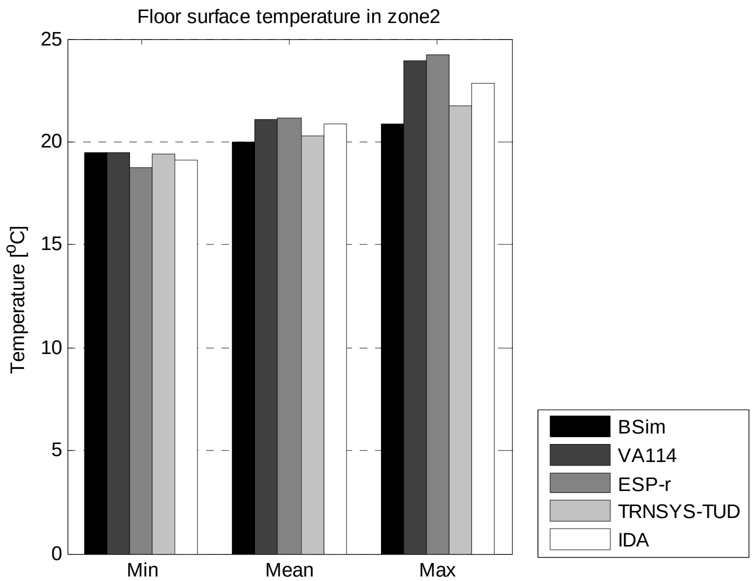
Hour averaged floor surface temperature in the zone 1
30
25
20
15
10
5
Temperature [ºC]
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day



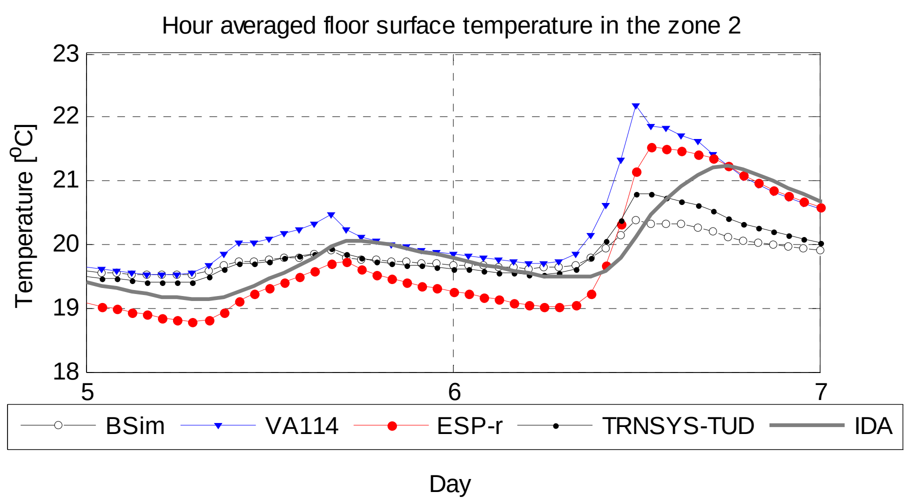
Ceiling surface temperature in zone 1	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	1.4	1.2	3.0	0.3	-
Max, °C	83.5	29.5	33.1	32.8	-
Average, °C	23.2	12.8	14.9	13.0	-

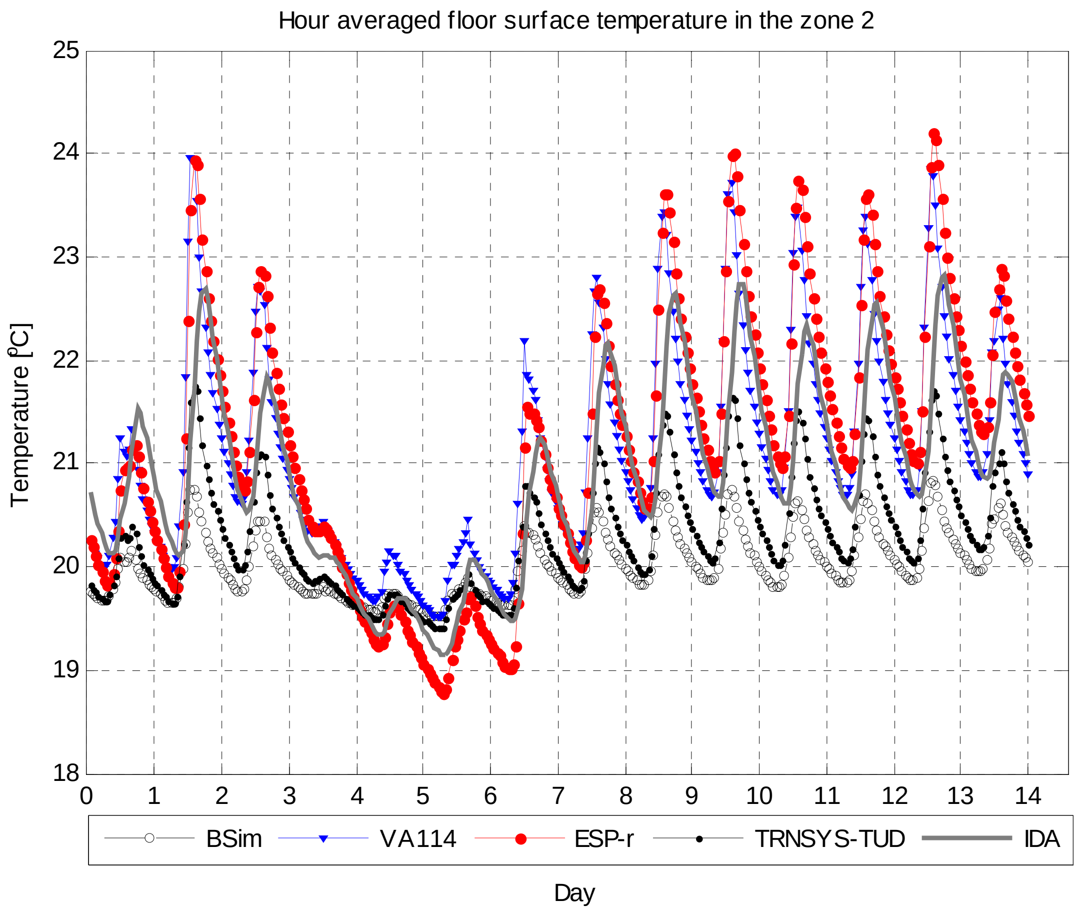



Hour averaged ceiling surface temperature in the zone 1
Temperature [ºC]
Day
0
5
10
15
20
25
30
35
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA

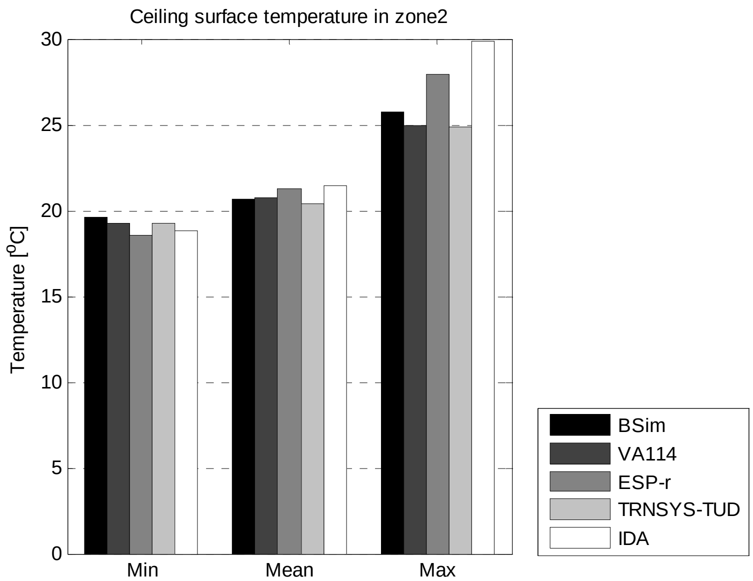


Floor surface temperature in zone 2	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	19.5	19.5	18.8	19.4	19.1
Max, °C	20.8	24.0	24.2	21.7	22.8
Average, °C	20.0	21.1	21.2	20.3	20.9

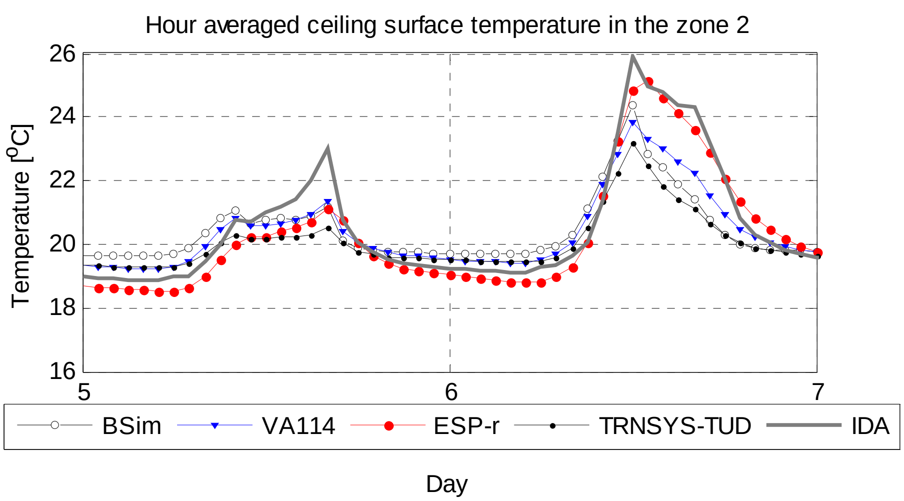


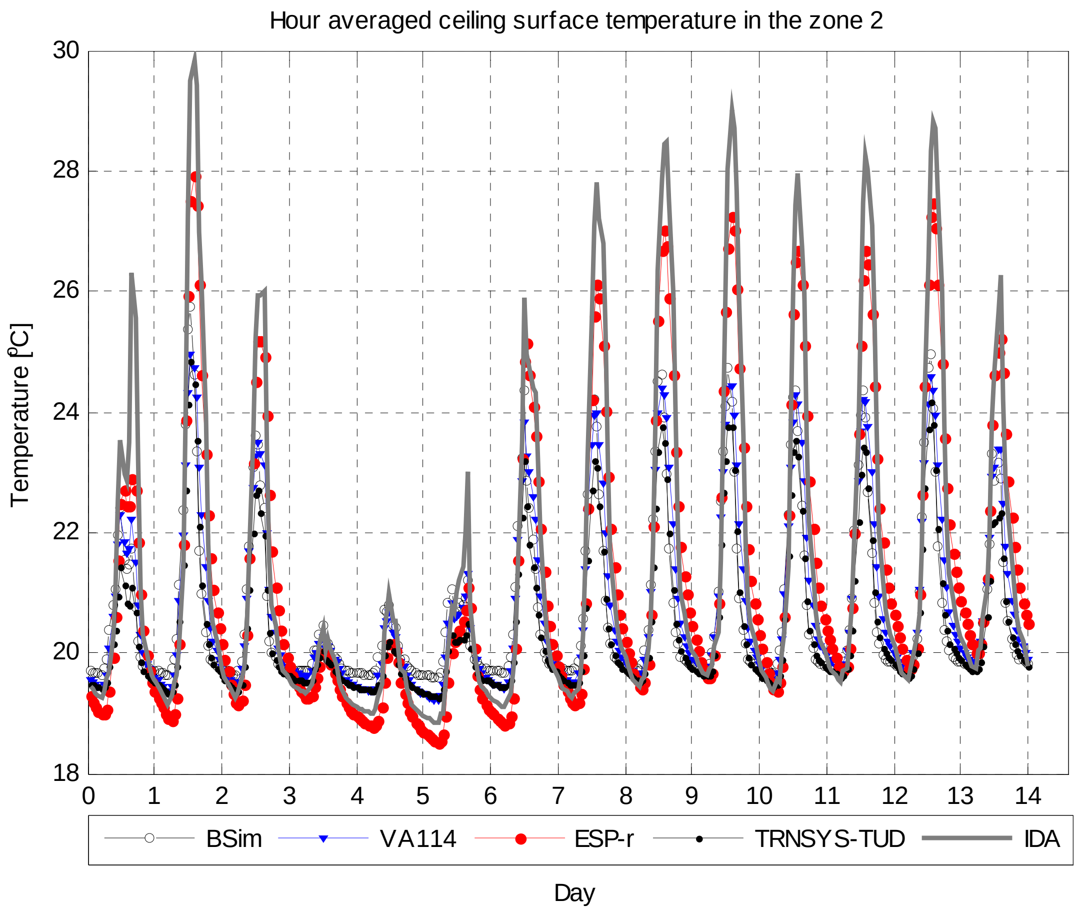


Hour averaged floor surface temperature in the zone 2
Temperature [ºC]
25
24
23
22
21
20
19
18
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day



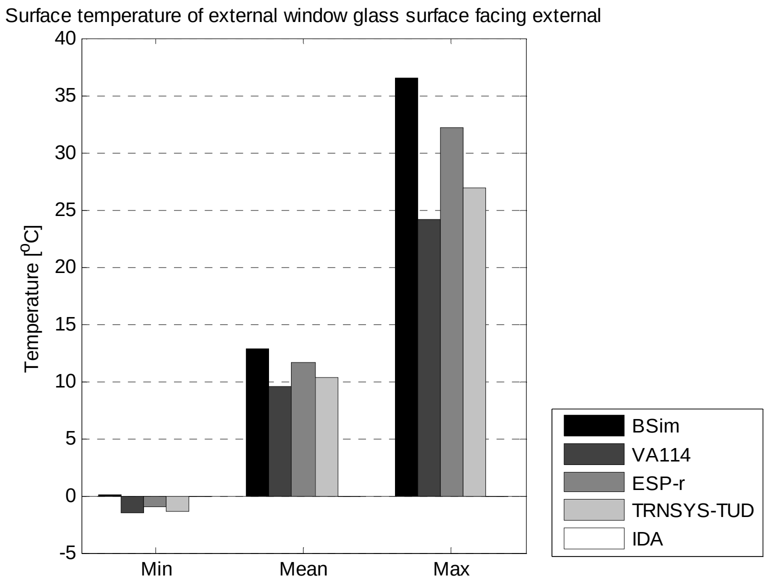
Ceiling surface temperature in zone 2	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	19.6	19.2	18.5	19.3	18.9
Max, °C	25.8	25.0	27.9	24.9	29.8
Average, °C	20.7	20.8	21.2	20.4	21.4



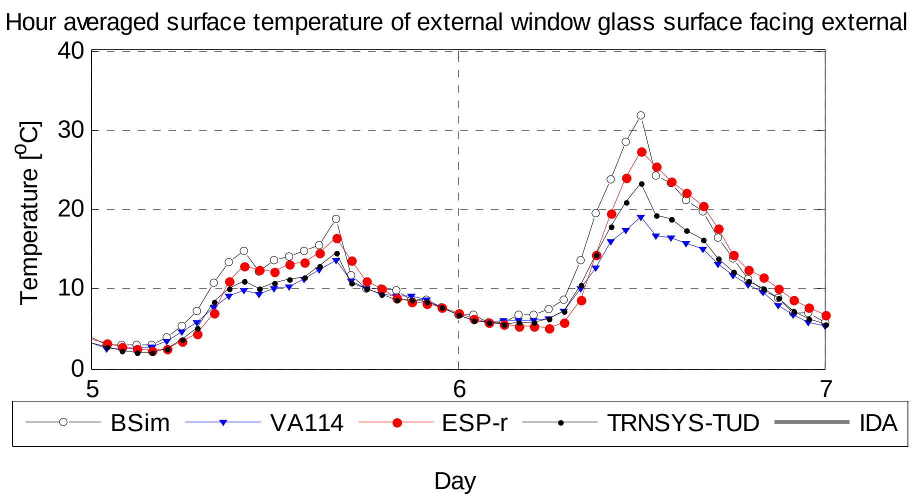

Hour averaged ceiling surface temperature in the zone 2
Temperature [ºC]
30
28
26
24
22
20
18
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day

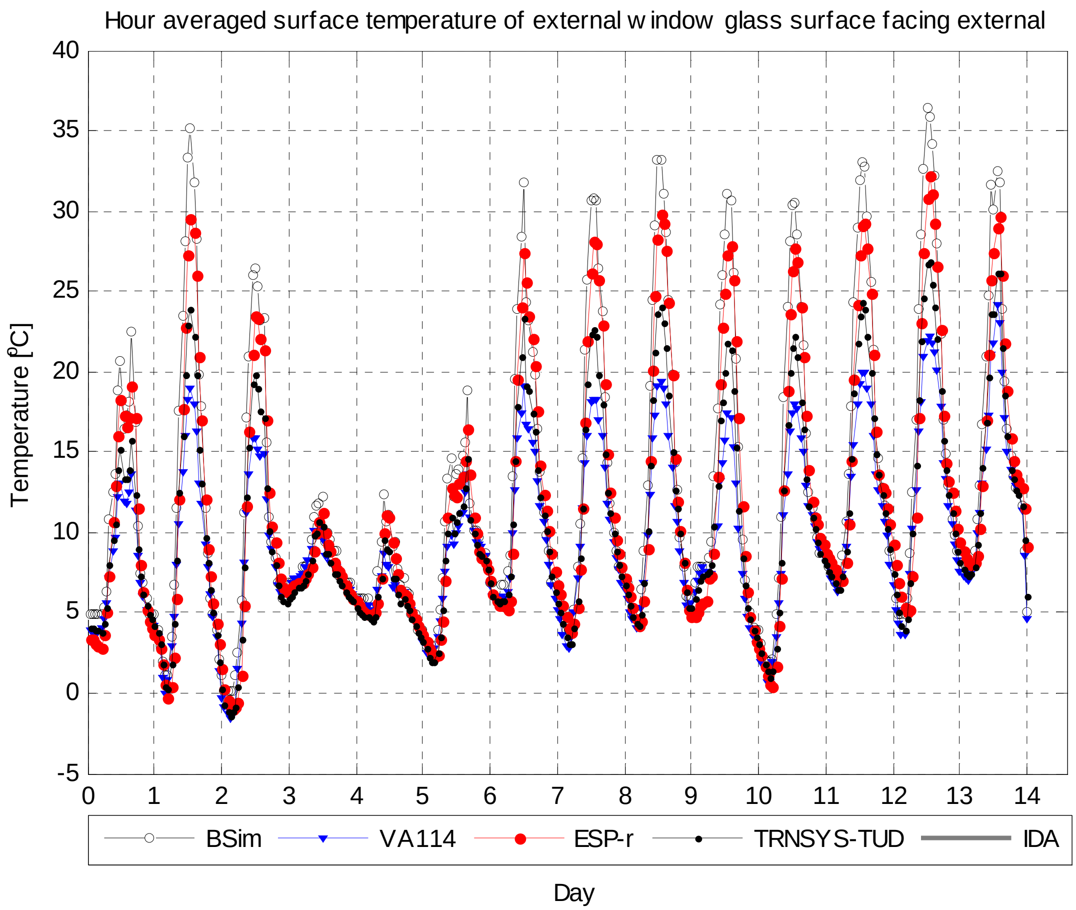
DSF200_3

Surface temperatures of the glazing

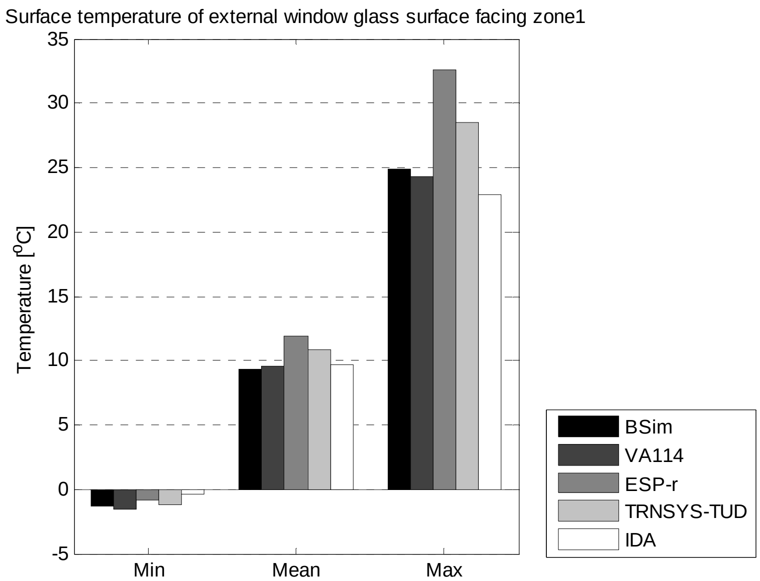


Surface temperature of the external window glass surface facing external	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	0.1	-1.6	-1.0	-1.4	-
Max, °C	36.5	24.2	32.2	26.9	-
Average, °C	12.8	9.5	11.7	10.4	-

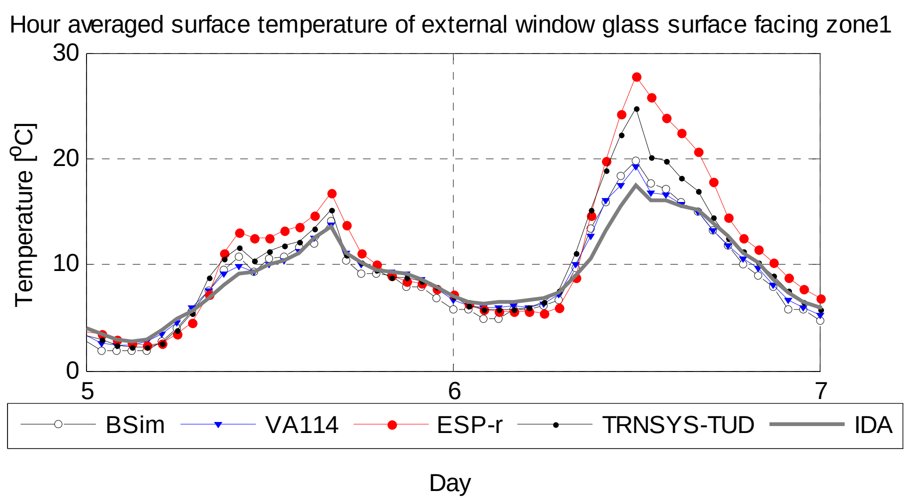


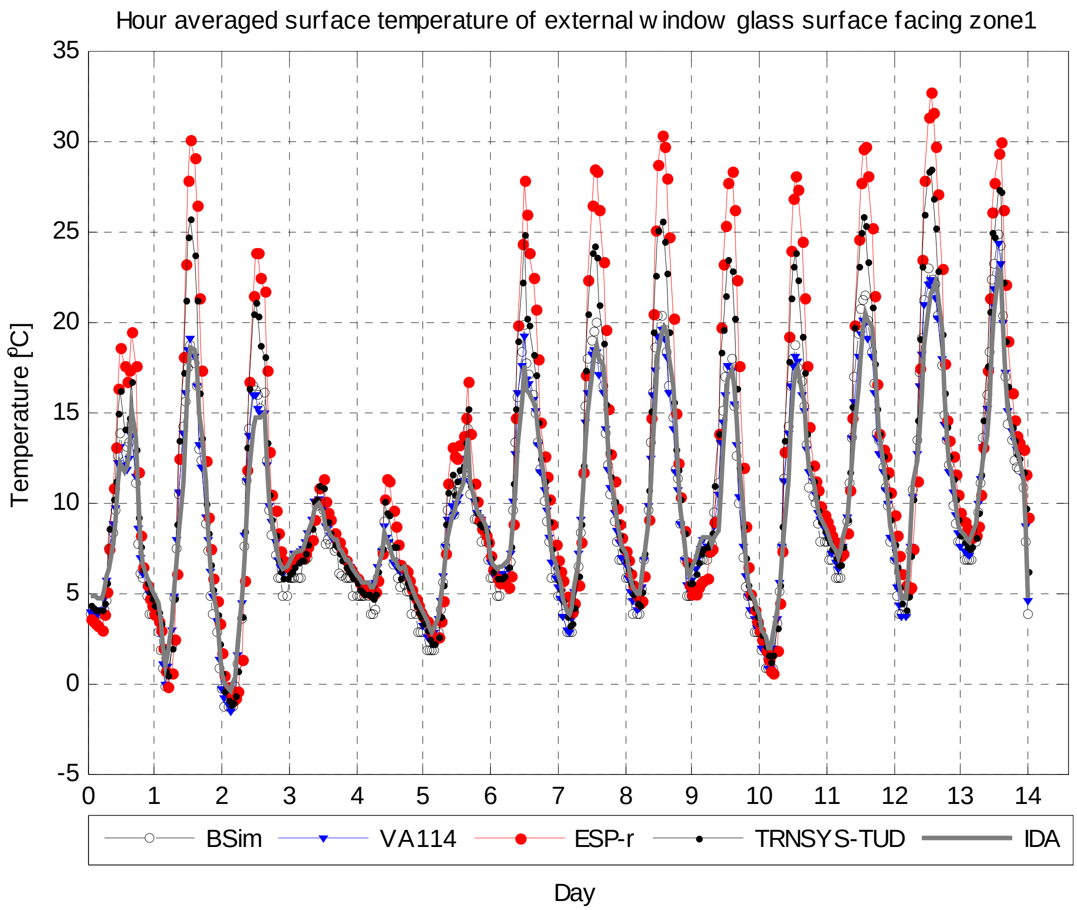


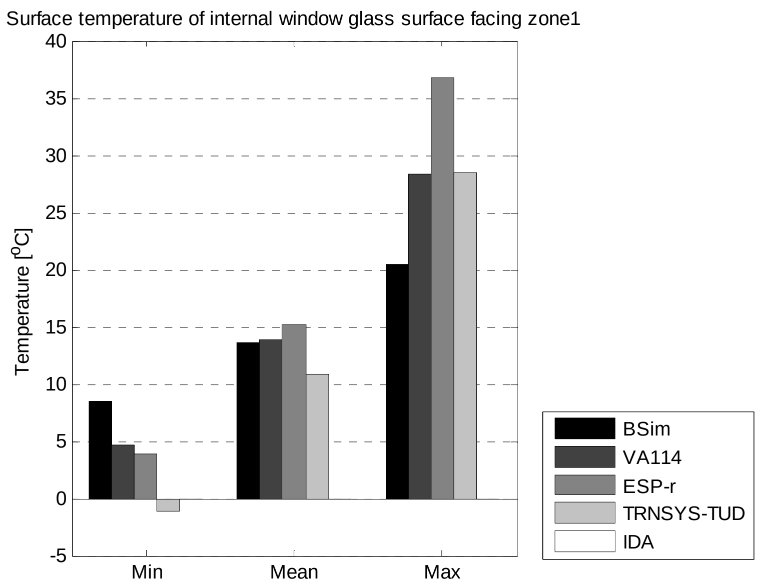
Hour averaged surface temperature of external w indow glass surface facing external
Temperature [ºC]
40
35
30
25
20
15
10
5
0
-5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day



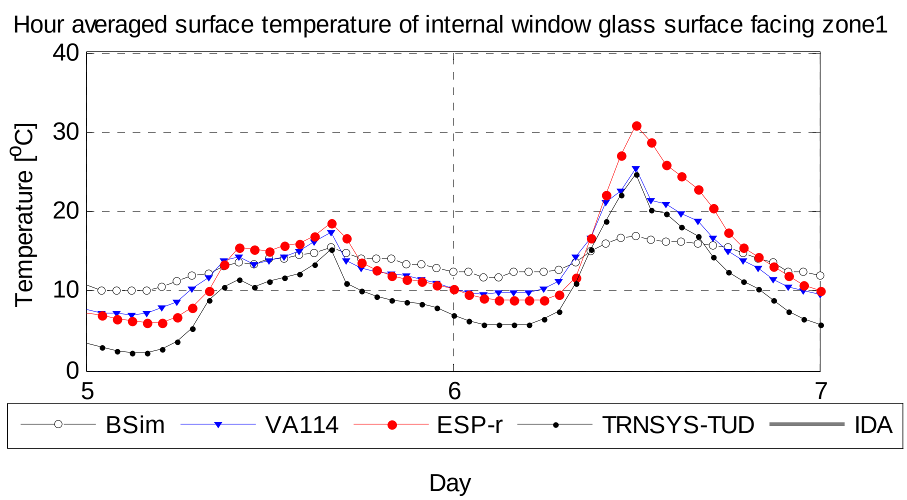
Surface temperature of external window glass surface facing zone 1	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	-1.3	-1.5	-0.9	-1.2	-0.4
Max, °C	24.9	24.3	32.7	28.5	22.8
Average, °C	9.3	9.6	11.9	10.8	9.7

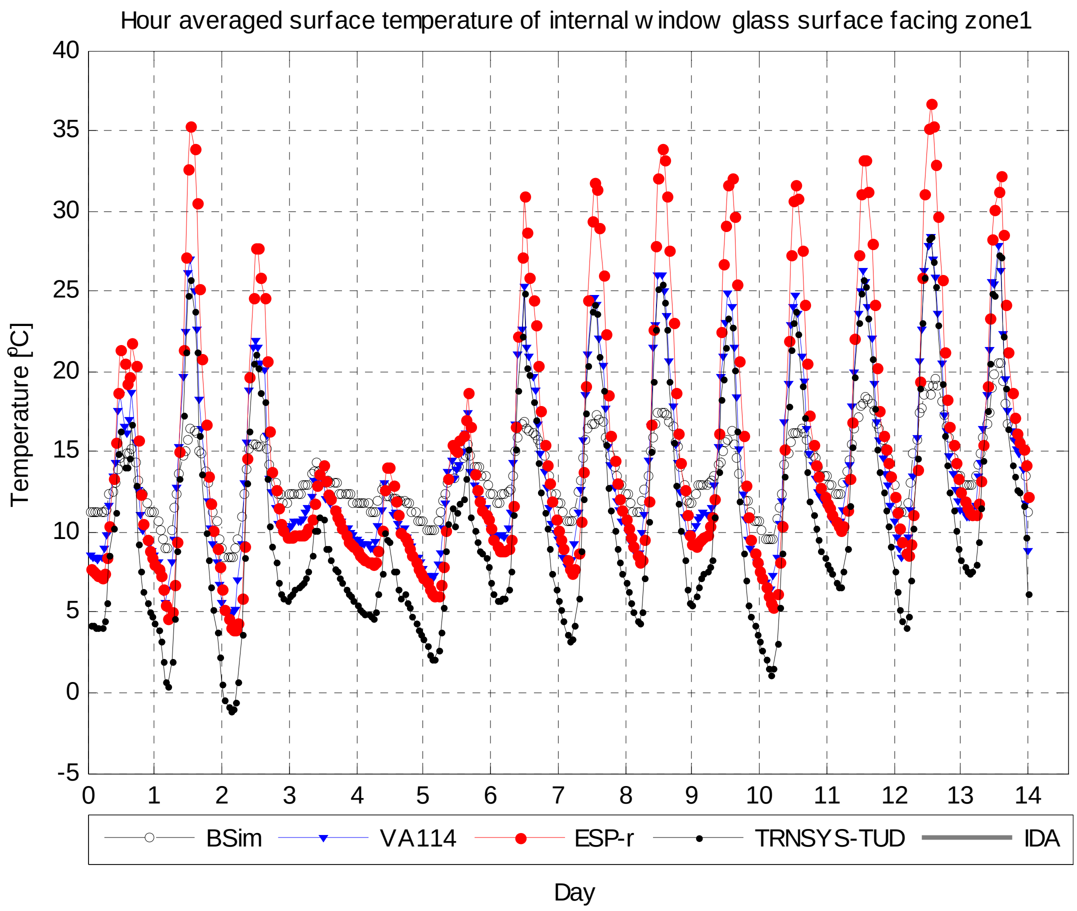



Hour averaged surface temperature of external window glass surface facing zone1
Temperature [ºC]
Day
BSim
VA114
ESP-r
TRNSYS-TUD
IDA

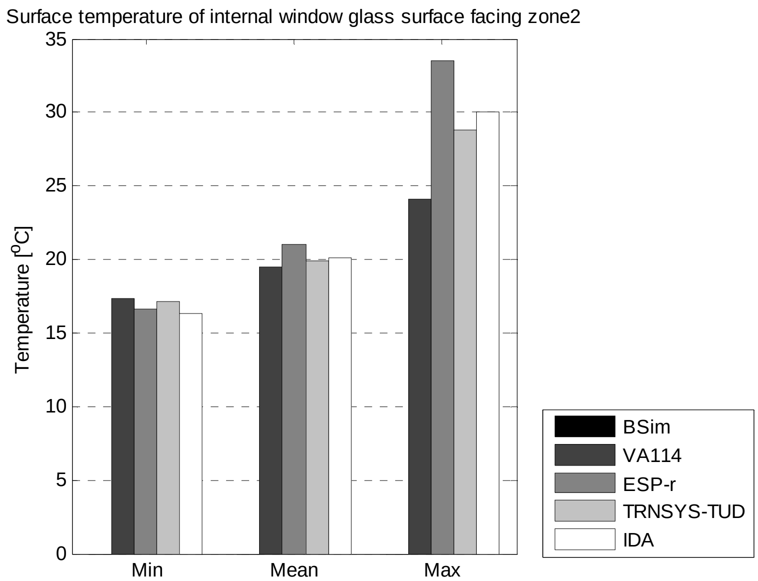


Surface temperature f internal window glass surface facing zone 1	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	8.4	4.7	3.9	-1.2	-
Max, °C	20.5	28.4	36.7	28.5	-
Average, °C	13.6	13.9	15.2	10.8	-

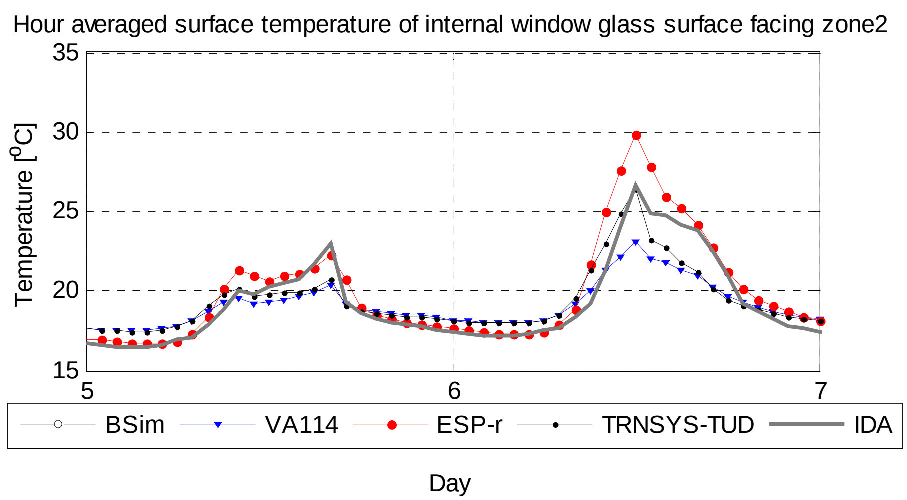


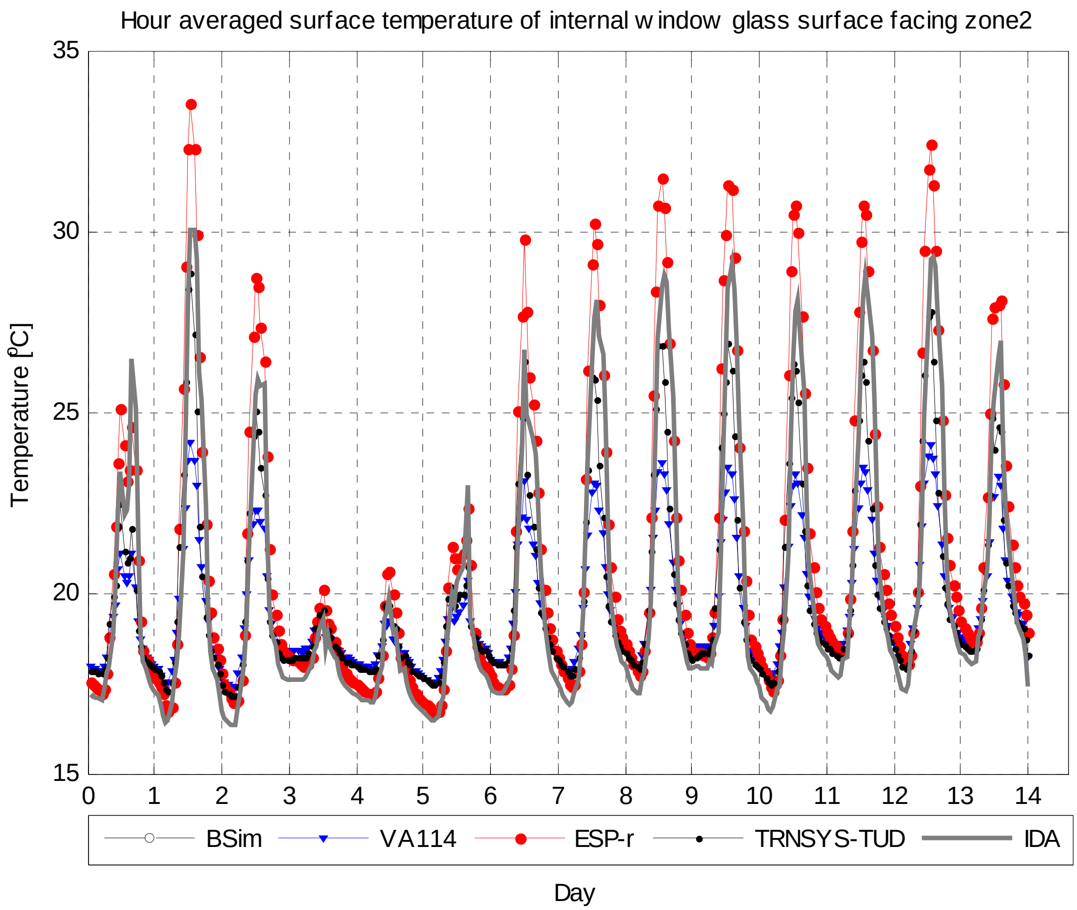


Hour averaged surface temperature of internal window glass surface facing zone1
Temperature [ºC]
40
35
30
25
20
15
10
5
0
-5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day



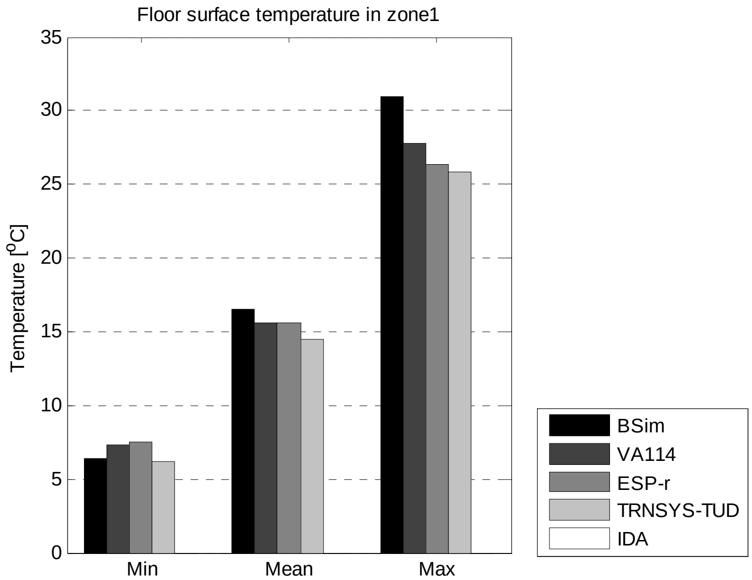
Surface temperature of internal window glass surface facing zone 2	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	12.2	17.4	16.7	17.1	16.3
Max, °C	20.3	24.1	33.6	28.8	30.0
Average, °C	15.7	19.5	21.0	19.9	20.1



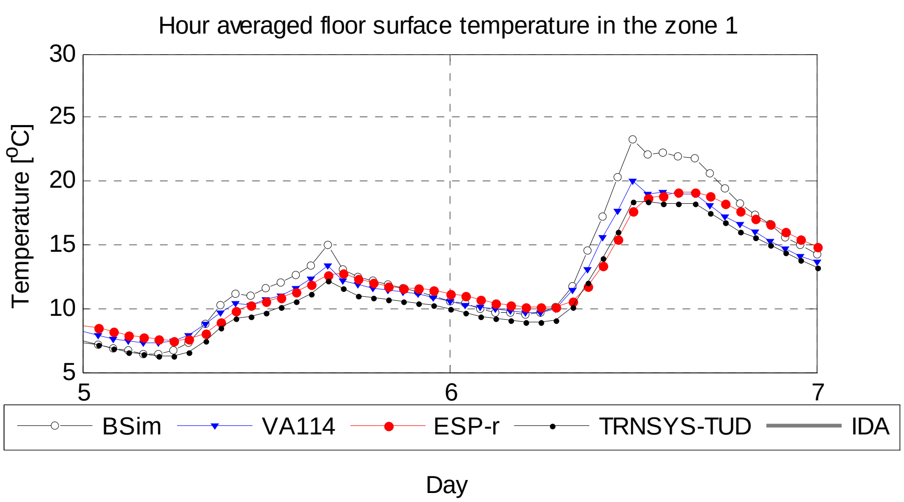


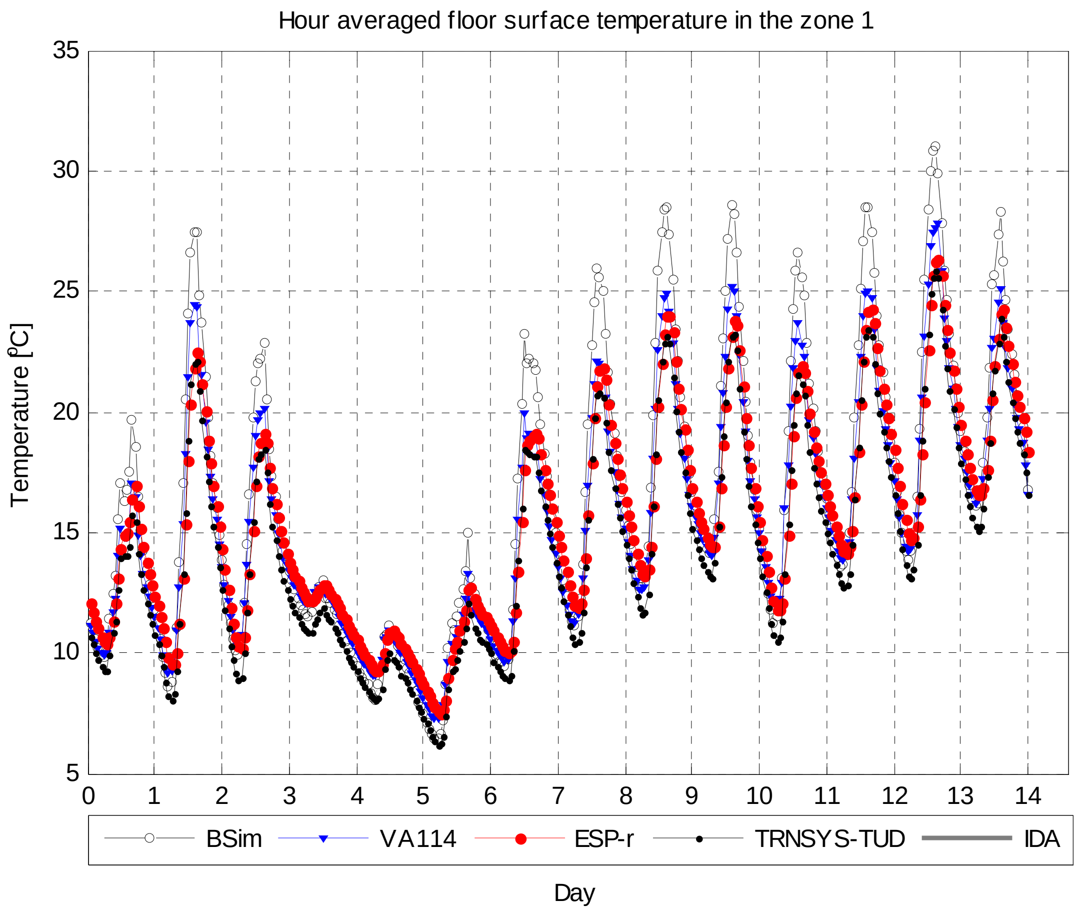
Hour averaged surface temperature of internal window glass surface facing zone2
Temperature [ºC]
Day
BSim
VA114
ESP-r
TRNSYS-TUD
IDA

Floor and ceiling surface temperature

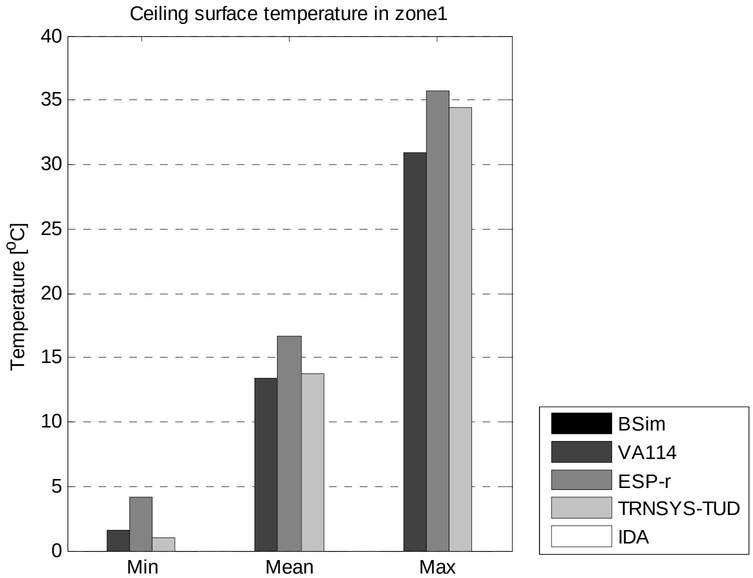


Floor surface temperature in zone 1	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	6.4	7.3	7.5	6.2	-
Max, °C	31.0	27.8	26.3	25.8	-
Average, °C	16.5	15.6	15.6	14.5	-

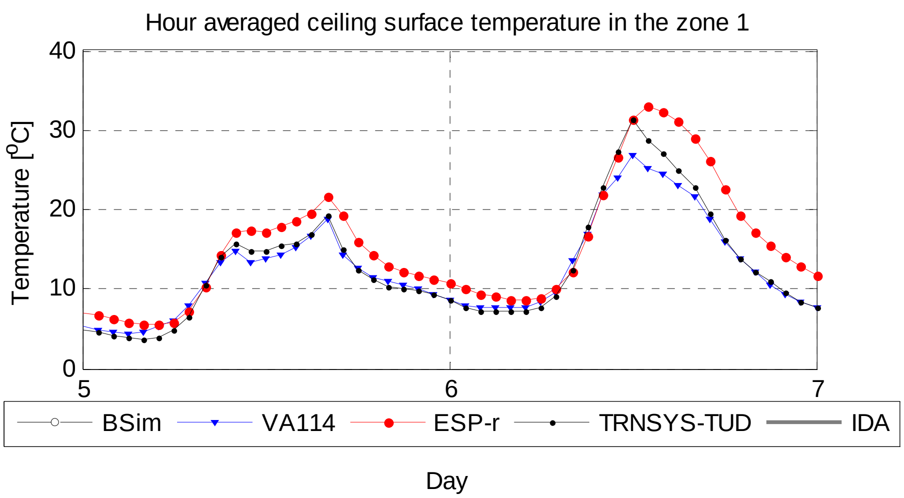


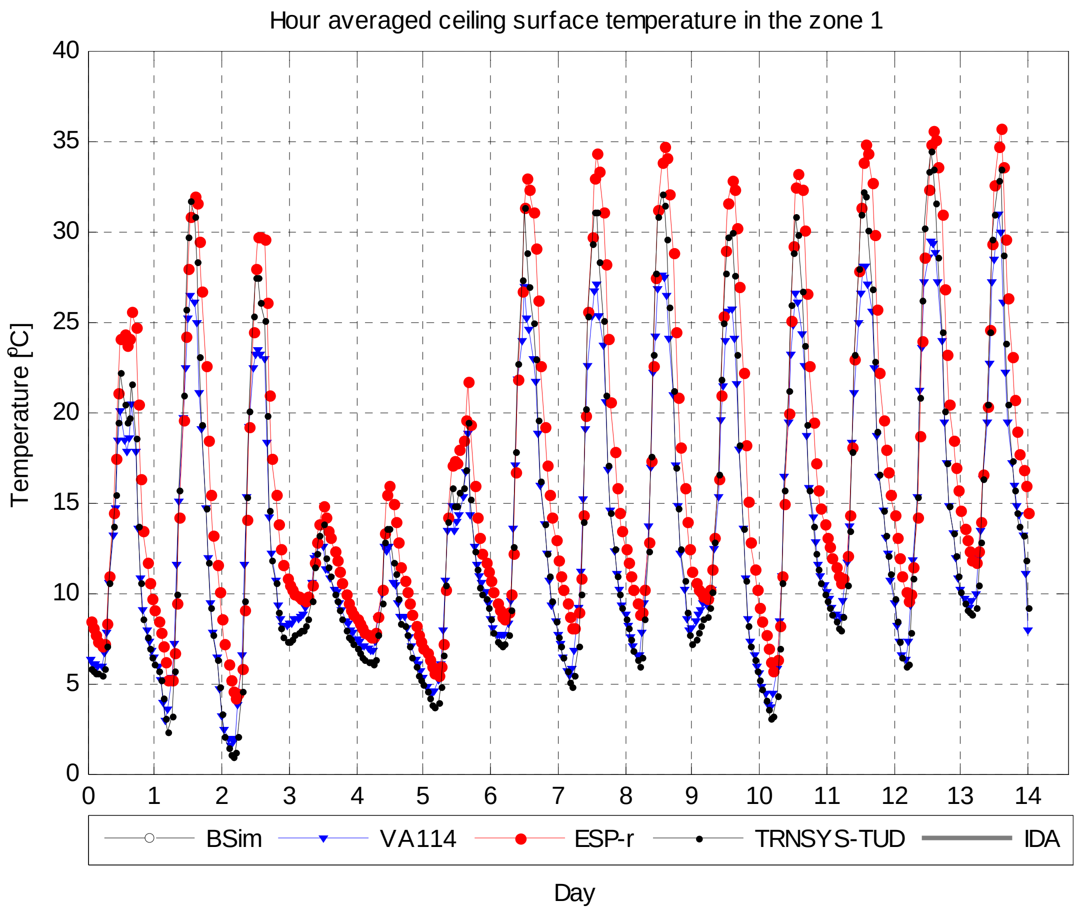


Hour averaged floor surface temperature in the zone 1
Temperature [°C]
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day

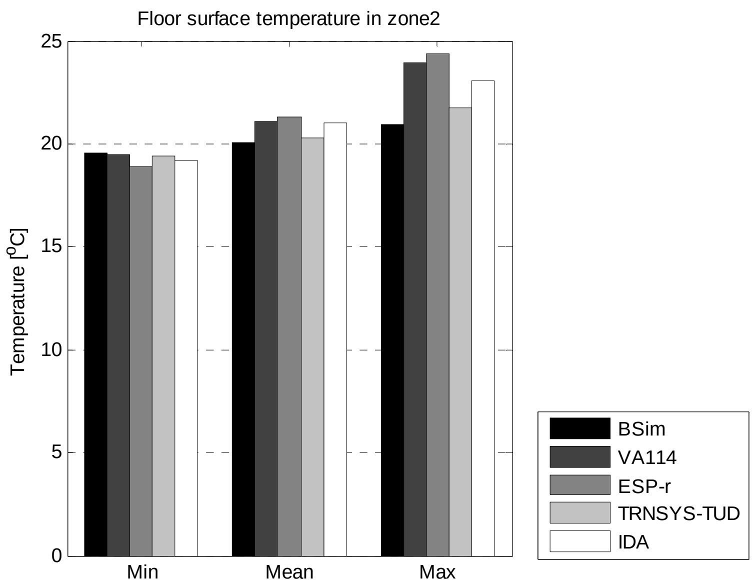


Ceiling surface temperature in zone 1	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	1.9	1.6	4.2	0.9	-
Max, °C	85.2	30.9	35.7	34.5	-
Average, °C	24.1	13.4	16.7	13.8	-

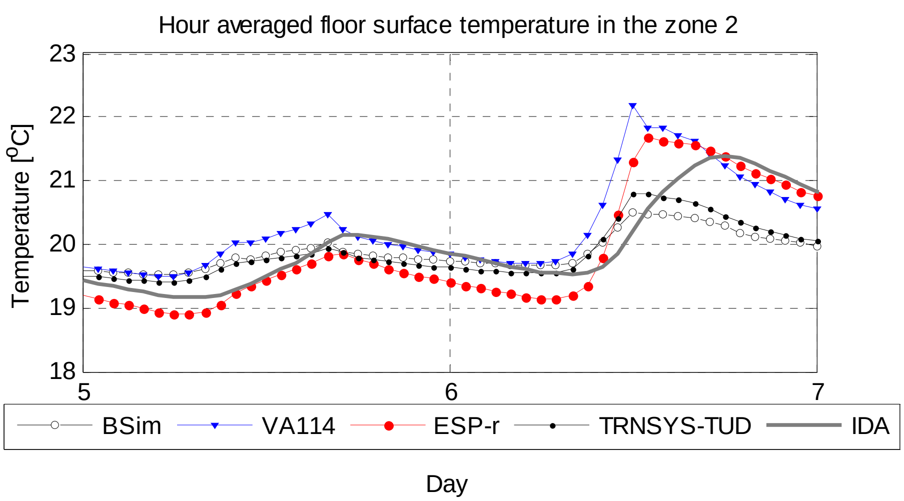


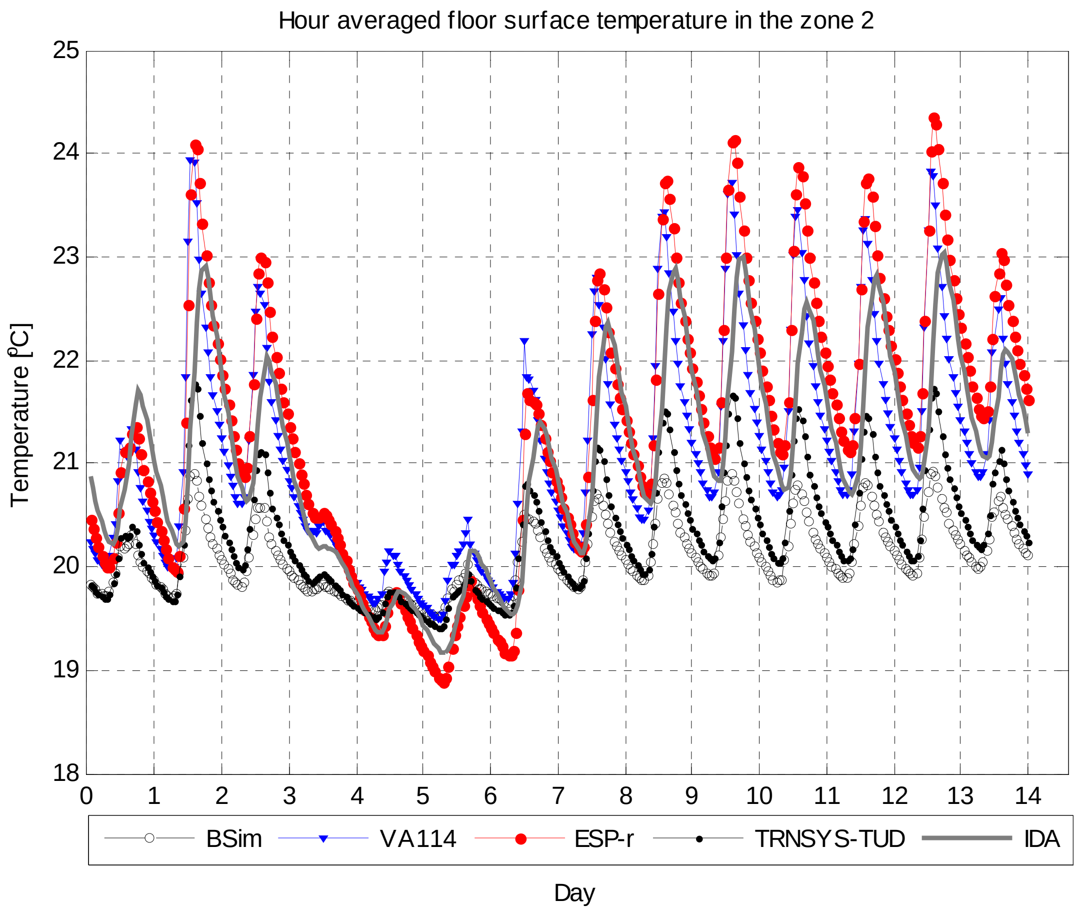


Hour averaged ceiling surface temperature in the zone 1
Temperature [ºC]
40
35
30
25
20
15
10
5
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day

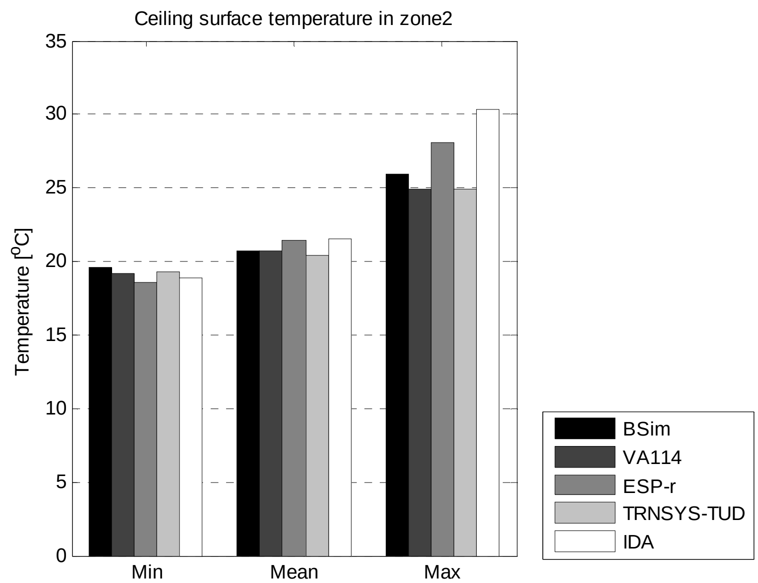


Floor surface temperature in zone 2	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	19.5	19.5	18.9	19.4	19.2
Max, °C	20.9	24.0	24.4	21.8	23.0
Average, °C	20.1	21.1	21.3	20.3	21.0

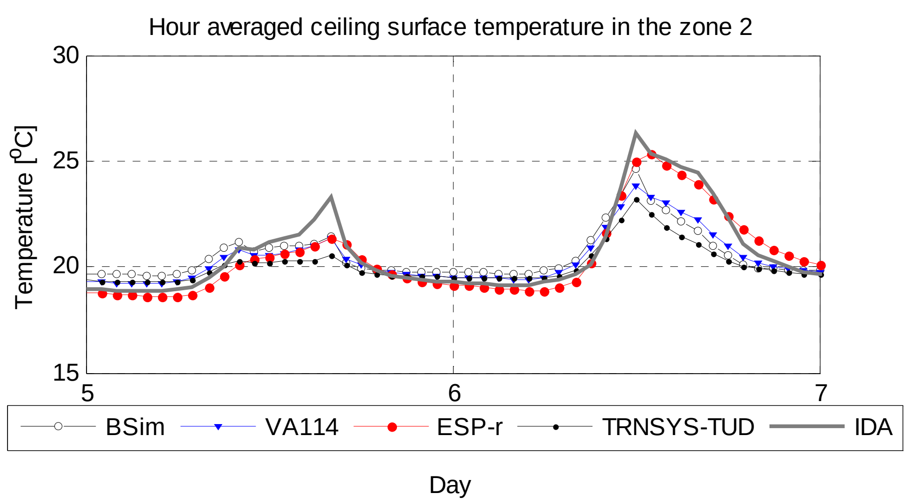


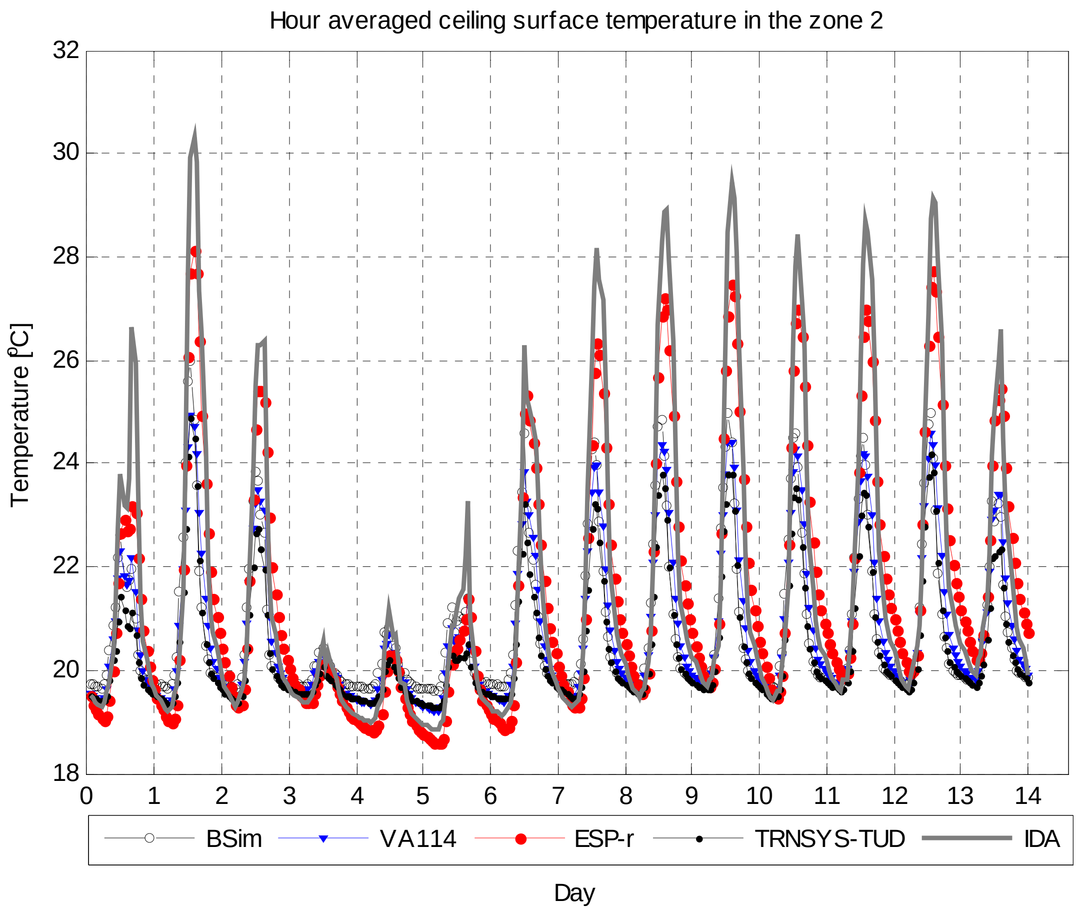


Hour averaged floor surface temperature in the zone 2
Temperature [ºC]
Day
25
24
23
22
21
20
19
18
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA



Ceiling surface temperature in zone 2	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min	19.6	19.2	18.6	19.3	18.8
Max	26.0	24.9	28.1	24.9	30.3
Average	20.8	20.8	21.5	20.4	21.6

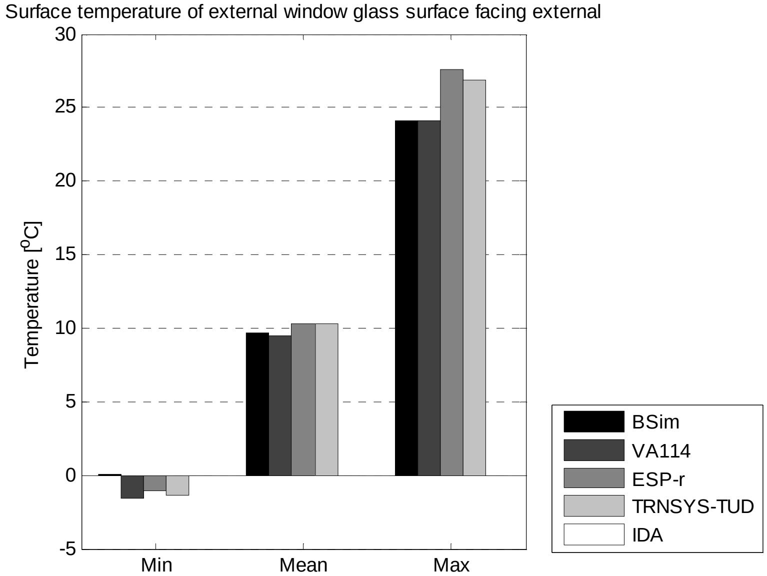




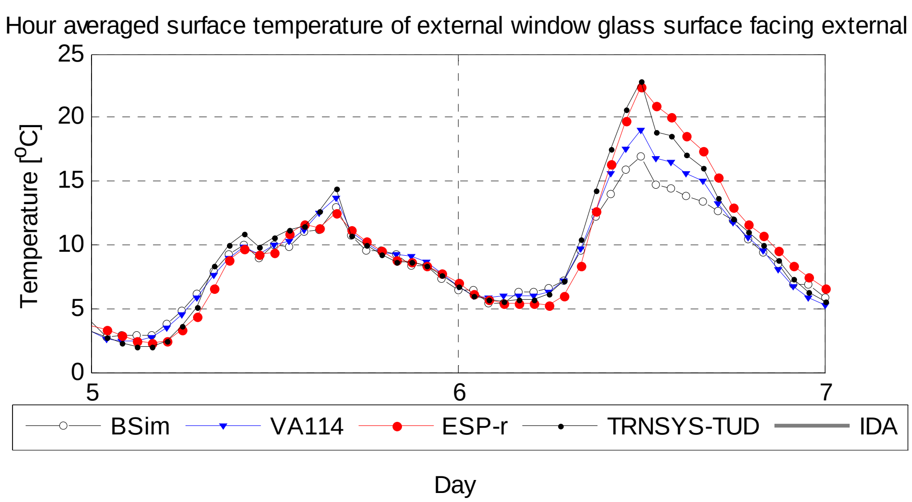
Hour averaged ceiling surface temperature in the zone 2
Temperature [ºC]
32
30
28
26
24
22
20
18
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day

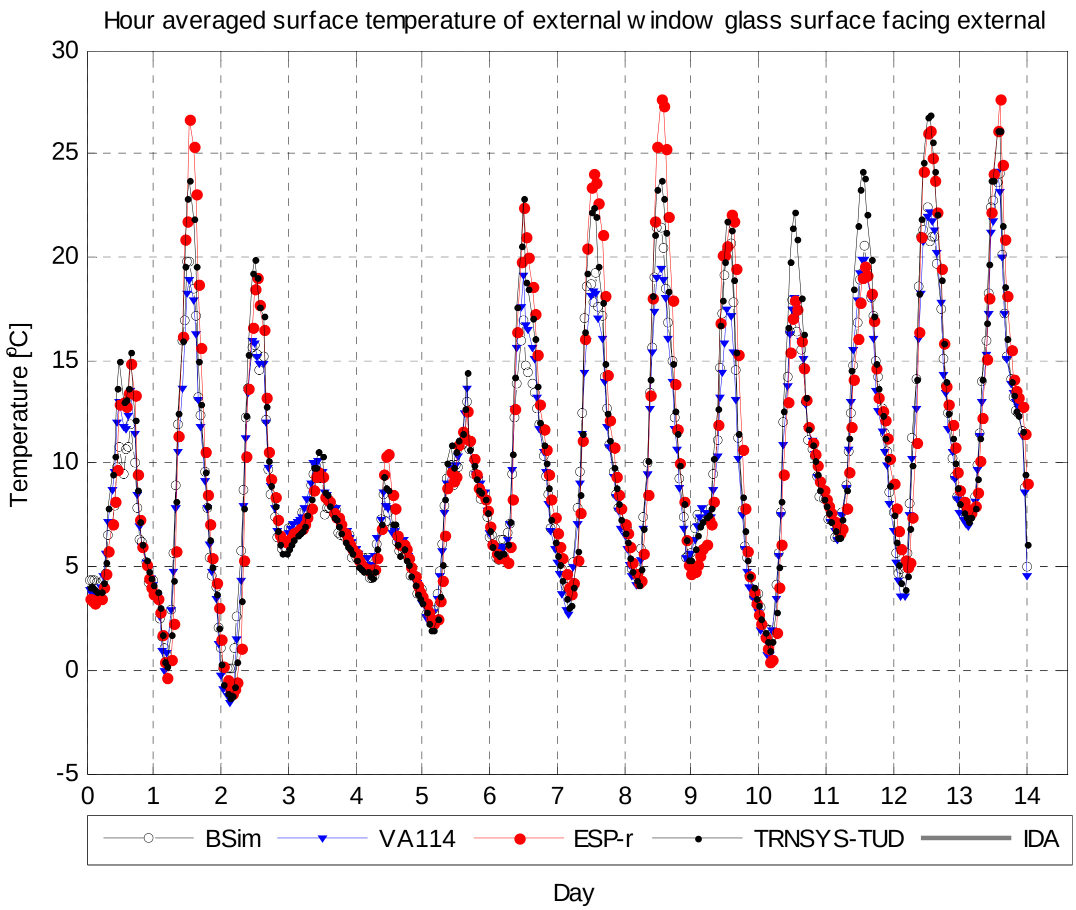
DSF200_4

Surface temperatures of the glazing

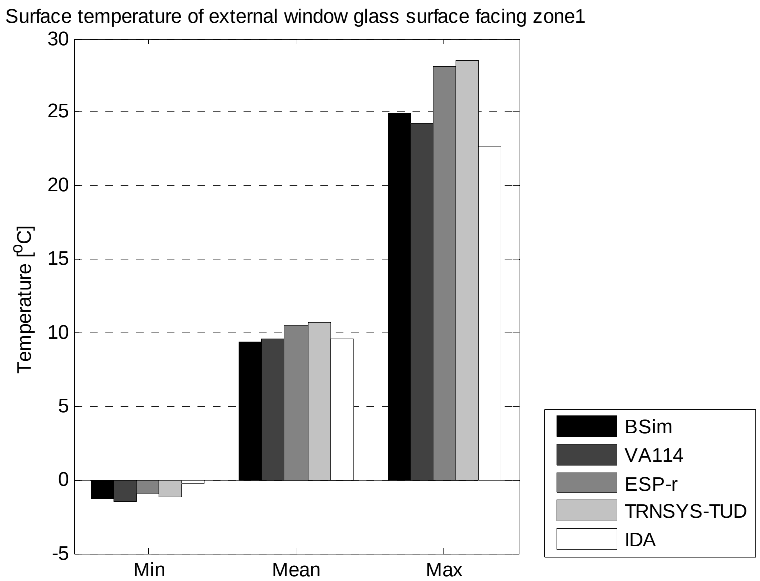


Surface temperature of external window glass surface facing external	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	0.1	-1.6	-1.1	-1.4	-
Max, °C	24.1	24.1	27.6	26.9	-
Average, °C	9.7	9.5	10.3	10.3	-

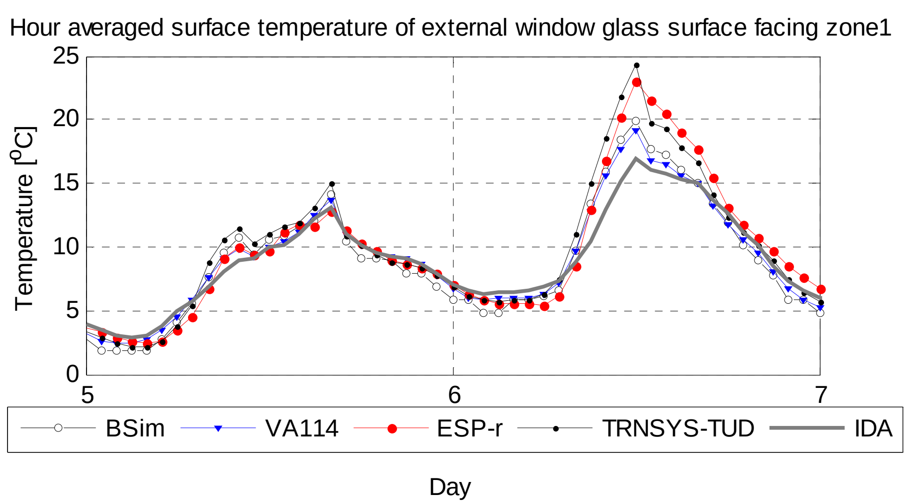


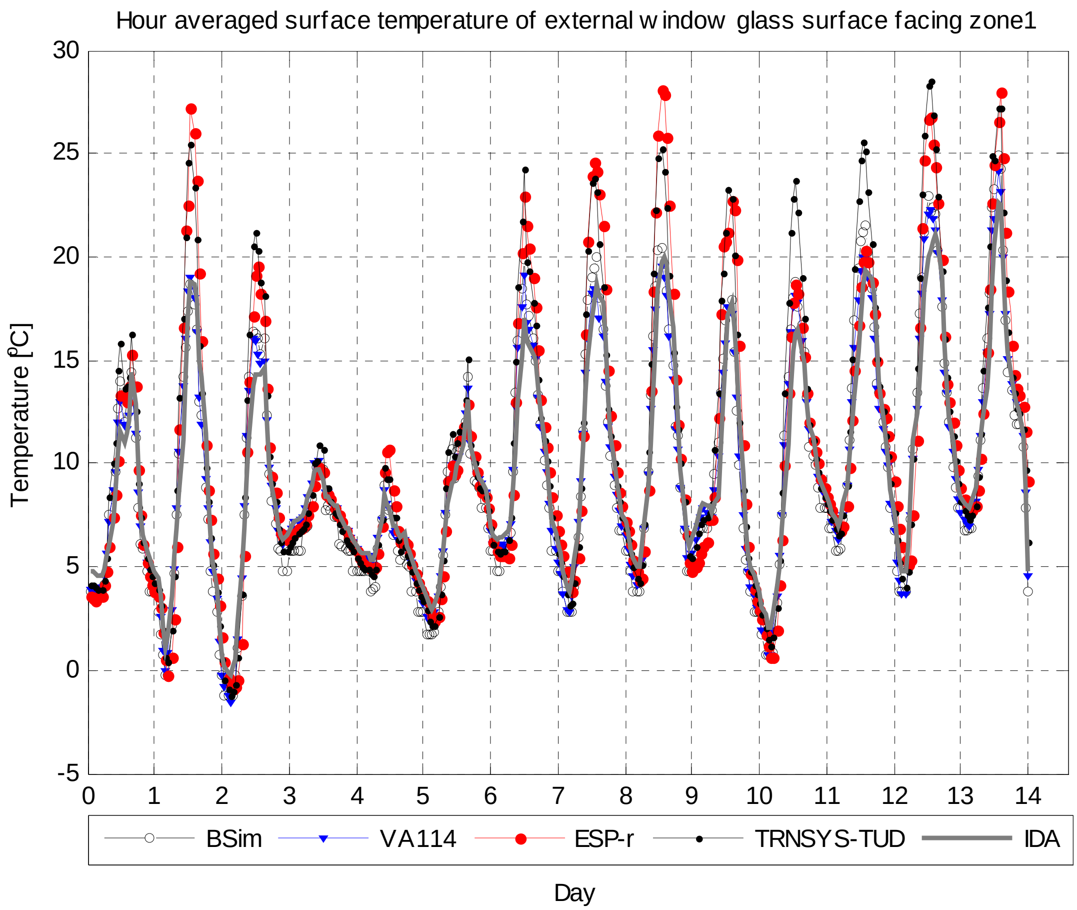


Hour averaged surface temperature of external w indow glass surface facing external
Temperature [°C]
30
25
20
15
10
5
0
-5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day

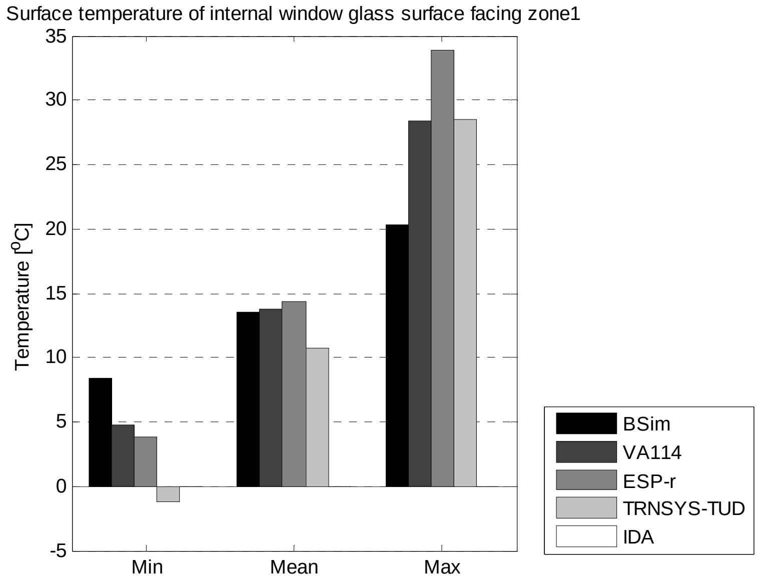


Surface temperature of external window glass surface facing zone 1	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	-1.3	-1.5	-0.9	-1.2	-0.2
Max, °C	24.9	24.2	28.1	28.5	22.7
Average, °C	9.4	9.5	10.5	10.7	9.6

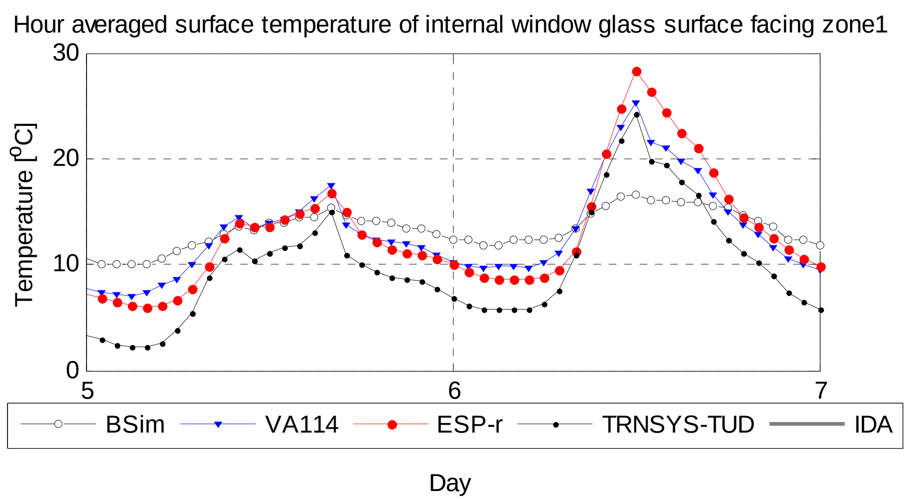


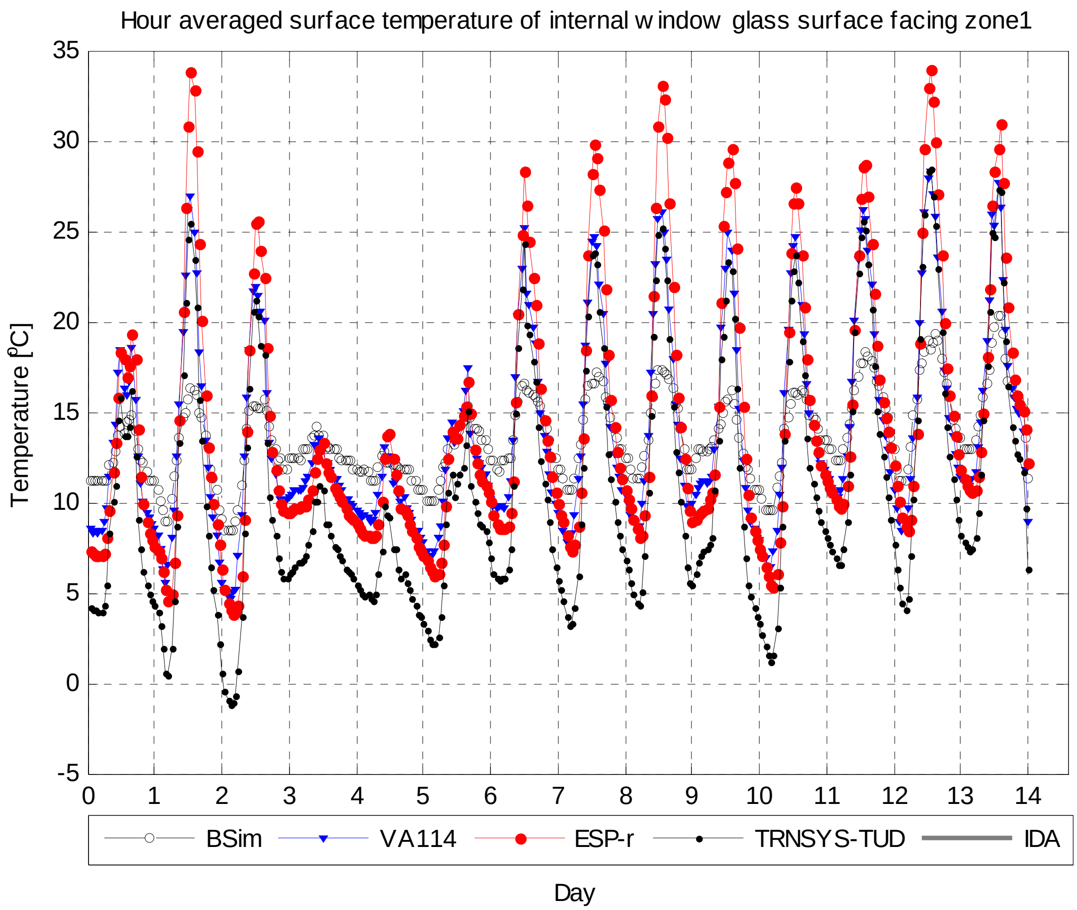


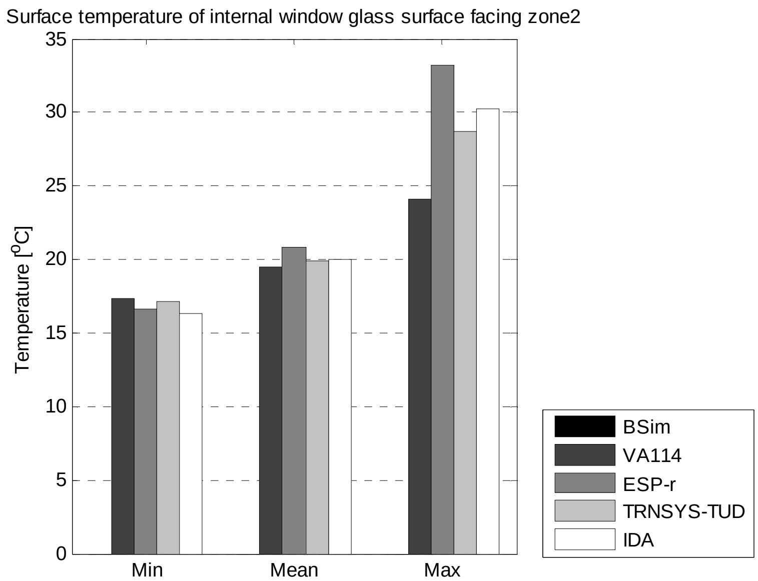
Hour averaged surface temperature of external window glass surface facing zone1
Temperature [°C]
Day
30
25
20
15
10
5
0
-5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA



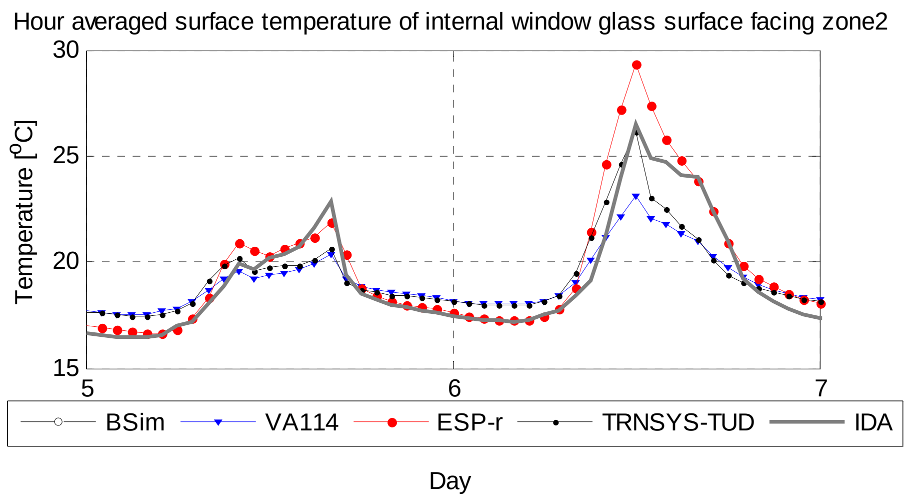
Surface temperature of internal window glass surface facing zone 1	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min	8.4	4.7	3.9	-1.2	-
Max	20.4	28.4	33.9	28.5	-
Average	13.5	13.8	14.3	10.7	-

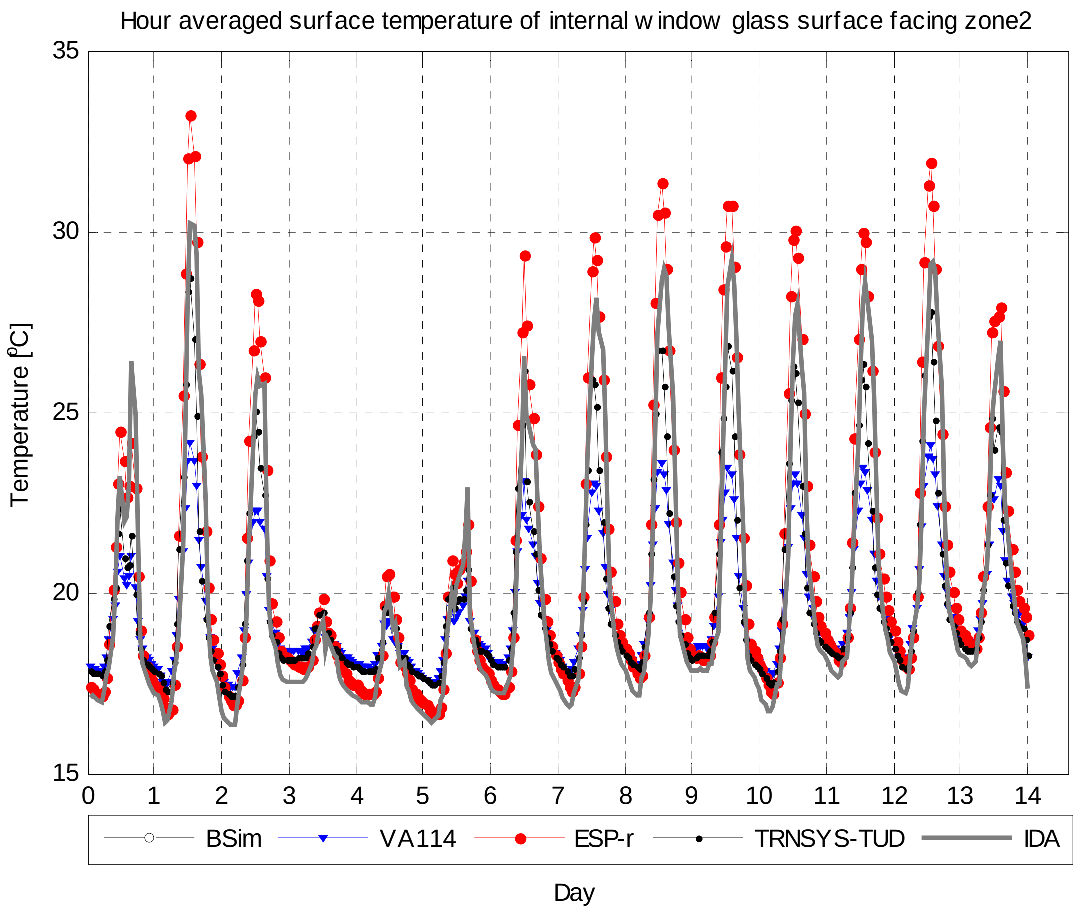



Hour averaged surface temperature of internal window glass surface facing zone1
Temperature [ºC]
Day
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
35
30
25
20
15
10
5
0
-5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14



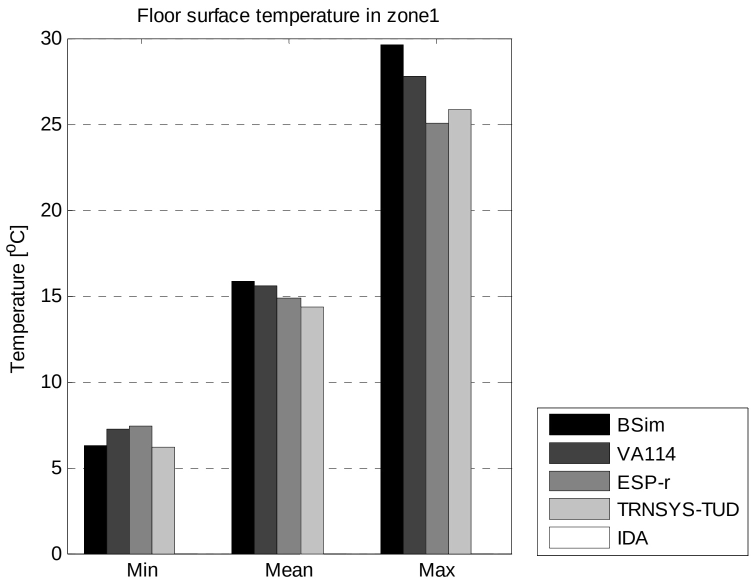
Surface temperature of internal window glass surface facing zone 2	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	12.2	17.4	16.6	17.1	16.3
Max, °C	20.2	24.1	33.2	28.7	30.2
Average, °C	15.7	19.5	20.8	19.9	20.1



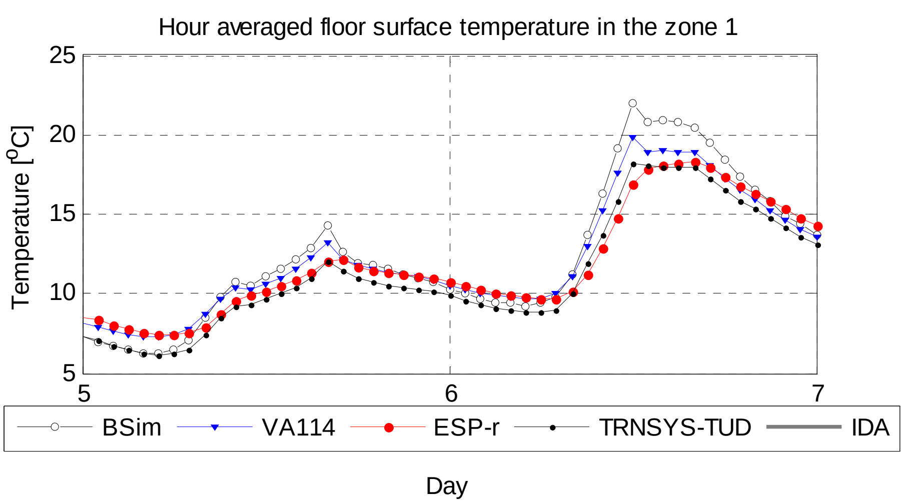


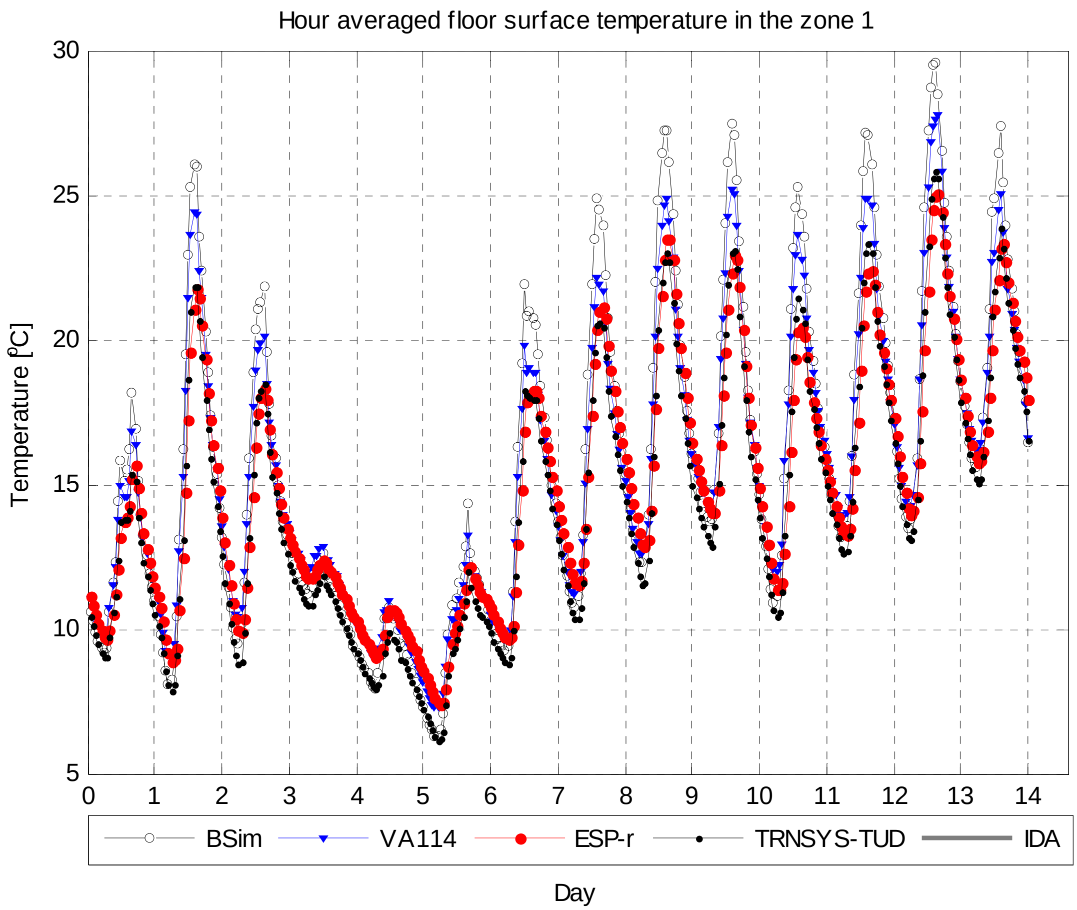
Hour averaged surface temperature of internal window glass surface facing zone2
Temperature [ºC]
35
30
25
20
15
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day

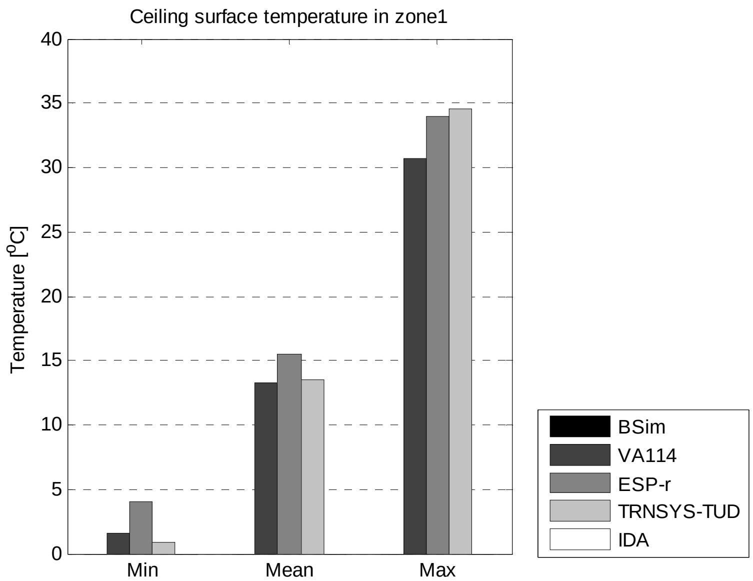
Floor and ceiling surface temperature



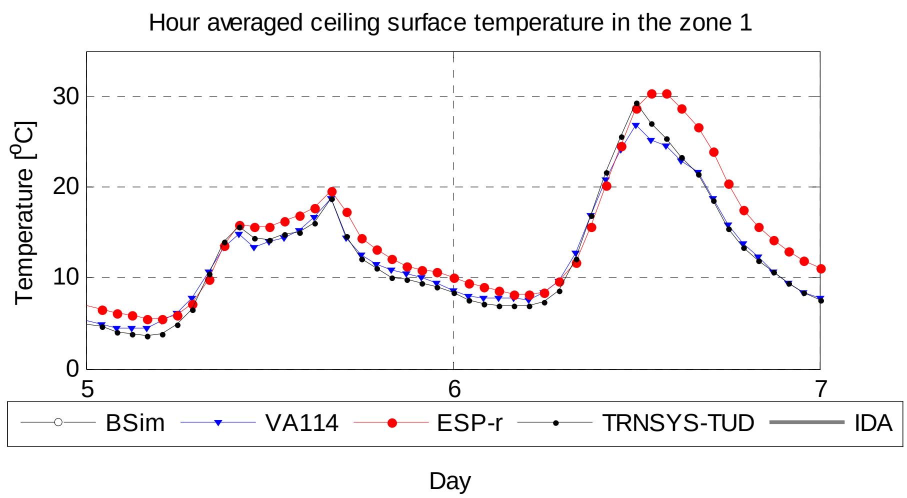
Floor surface temperature in zone 1	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	6.3	7.3	7.4	6.1	-
Max, °C	29.6	27.8	25.1	25.8	-
Average, °C	15.8	15.5	14.9	14.3	-

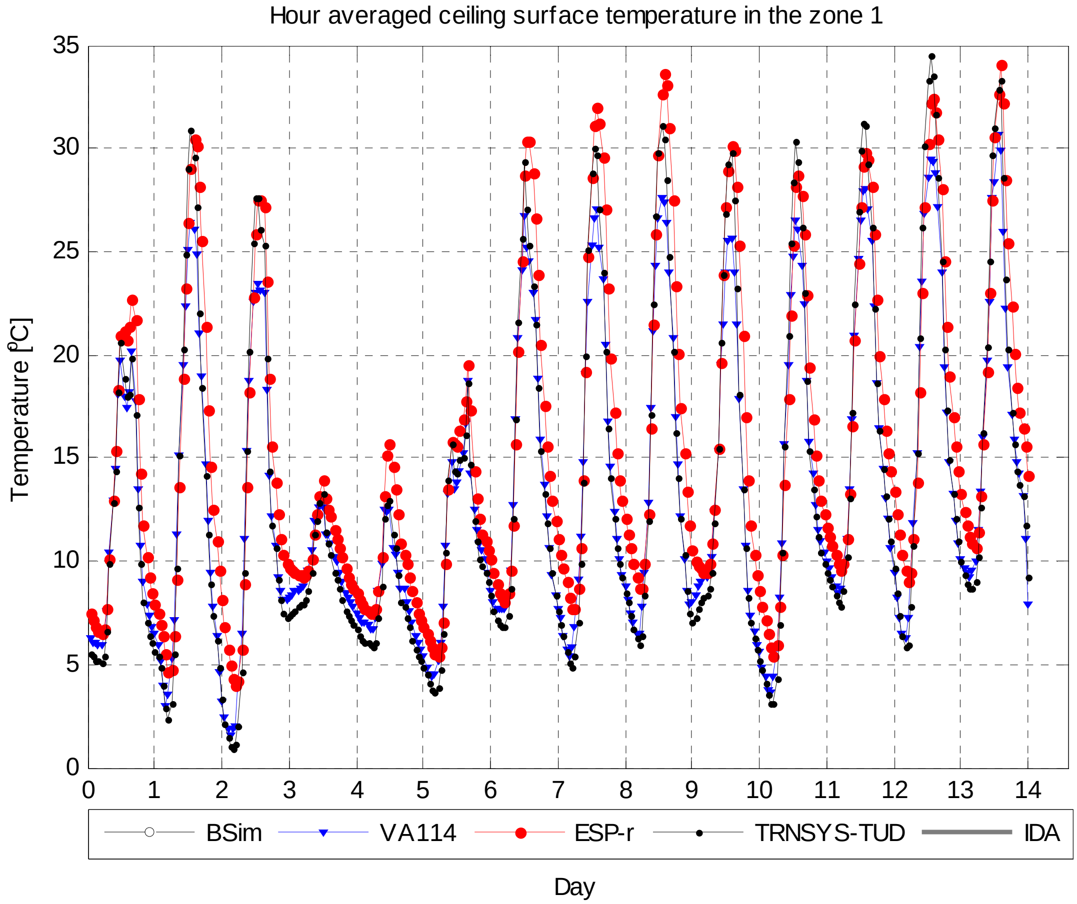



Hour averaged floor surface temperature in the zone 1
Temperature [ºC]
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day

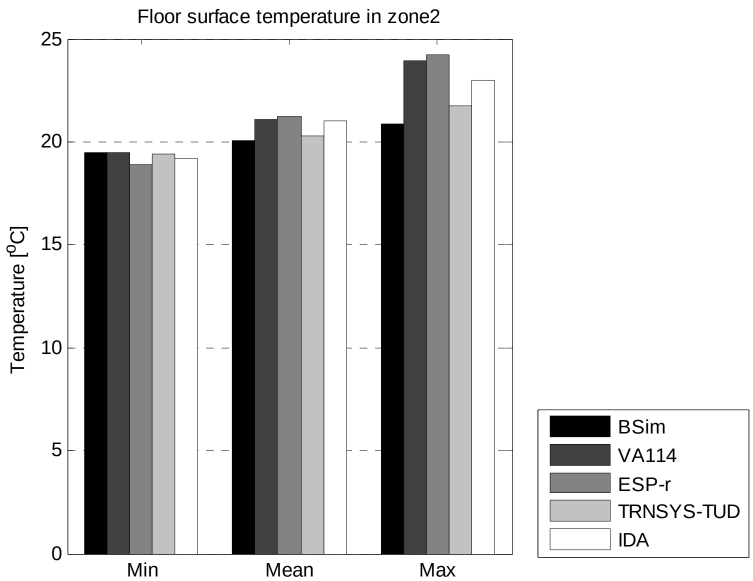


Ceiling surface temperature in zone 1	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	1.8	1.6	4.0	0.9	-
Max, °C	83.4	30.7	34.0	34.5	-
Average, °C	23.5	13.3	15.5	13.5	-

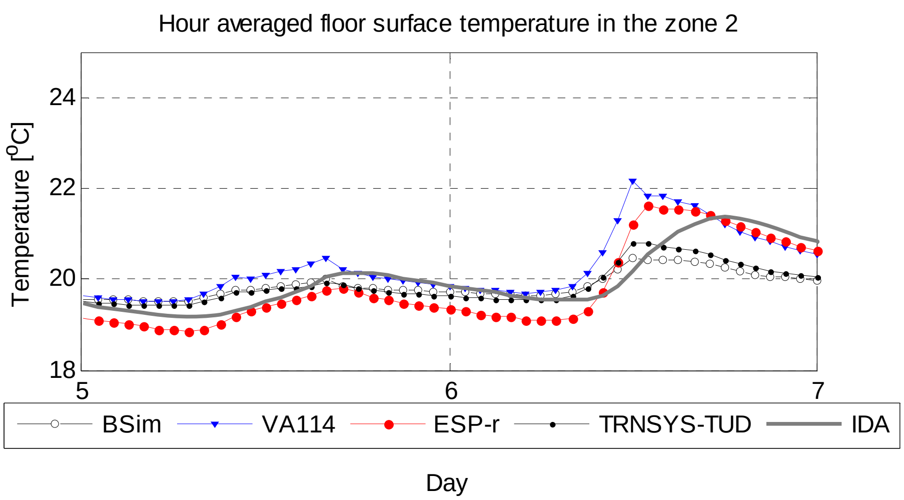


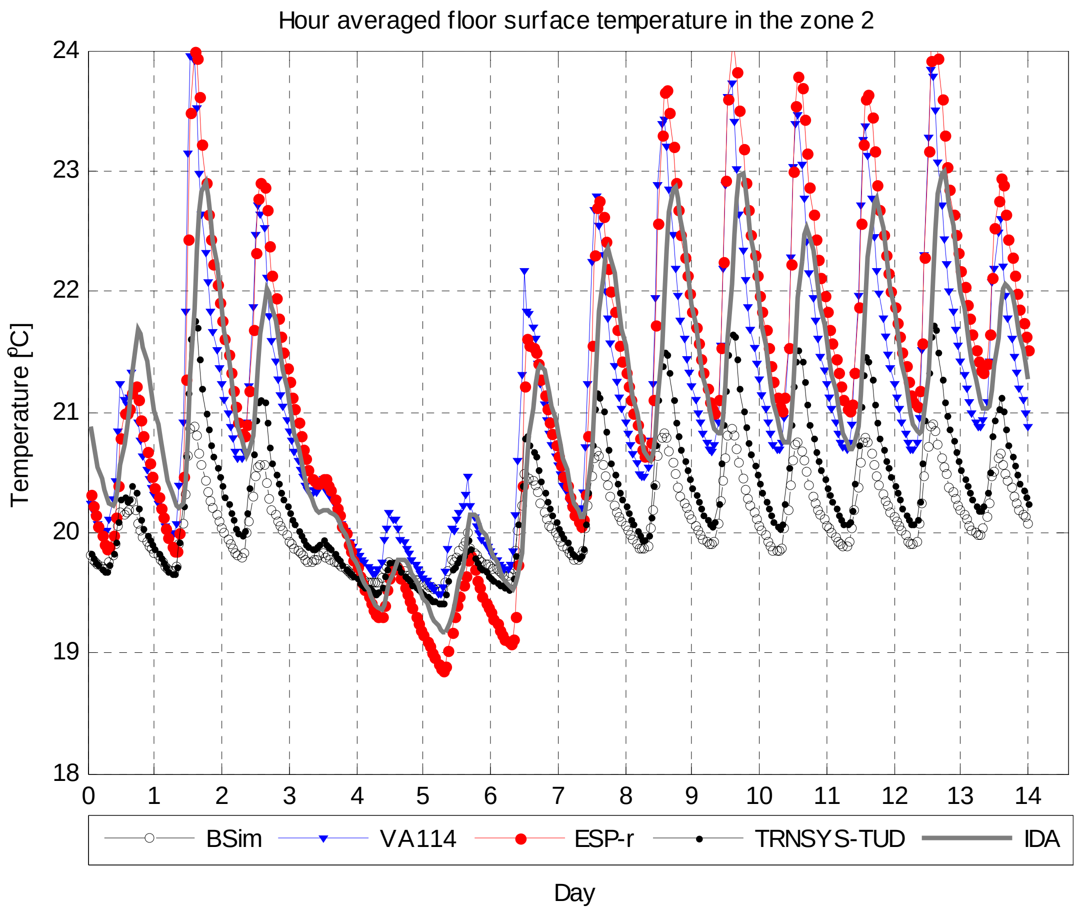


Hour averaged ceiling surface temperature in the zone 1
Temperature [ºC]
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day

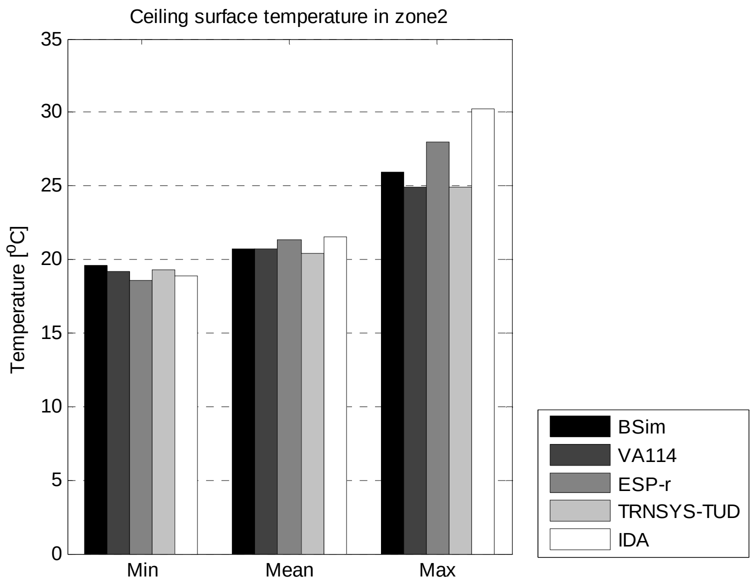


Floor surface temperature in zone 2	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	19.5	19.5	18.9	19.4	19.2
Max, °C	20.9	24.0	24.2	21.8	23.0
Average, °C	20.1	21.1	21.2	20.3	21.0

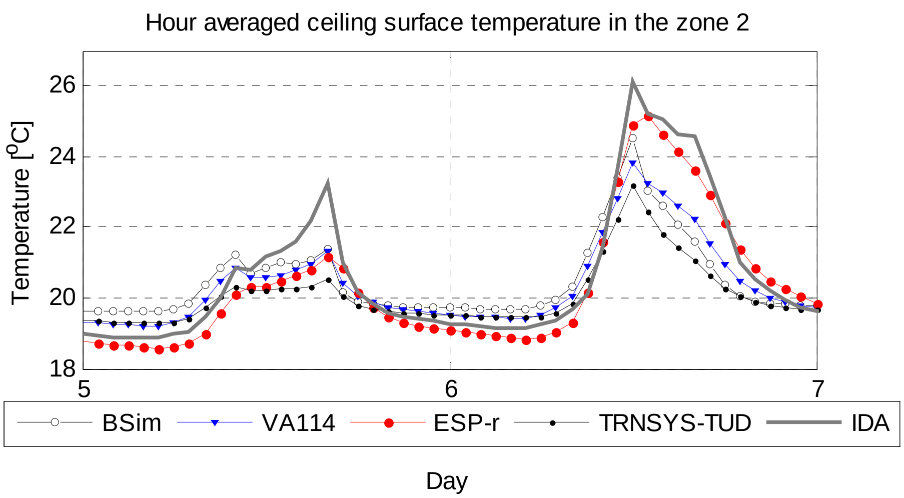


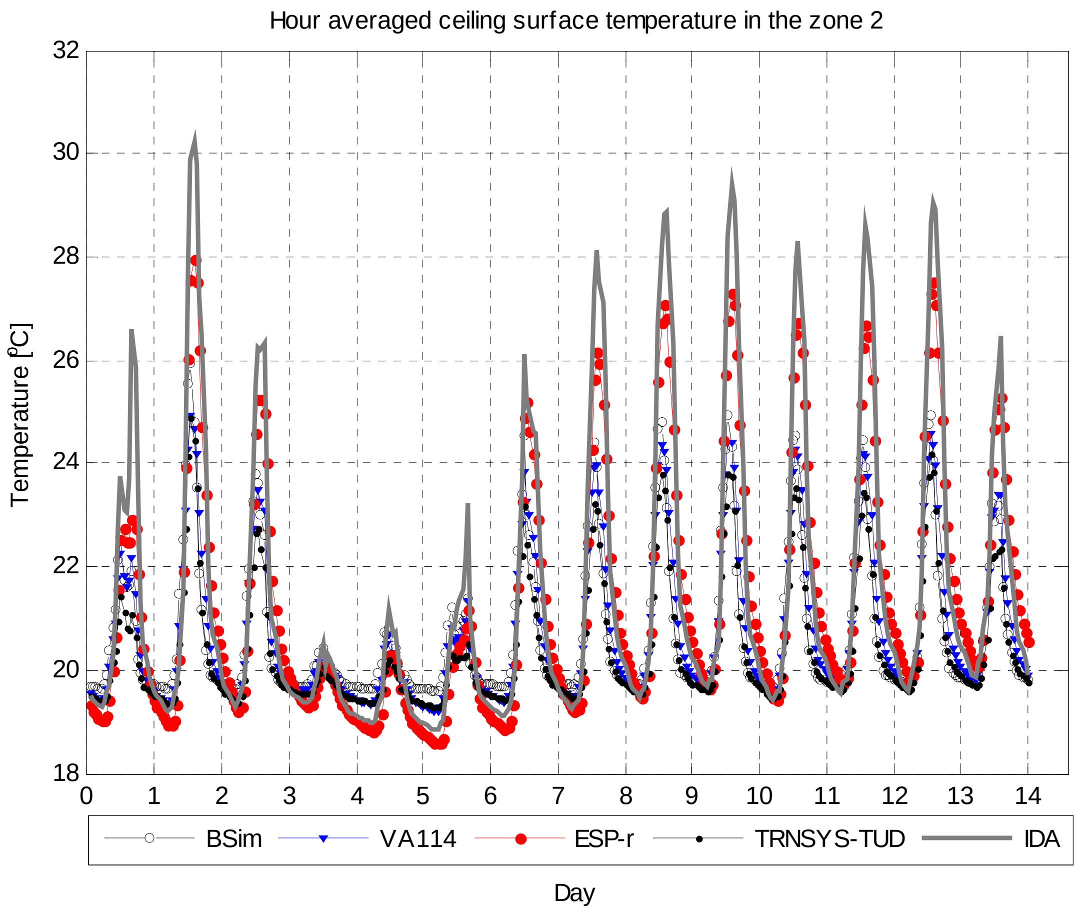


Hour averaged floor surface temperature in the zone 2
Temperature [ºC]
24
23
22
21
20
19
18
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day



Ceiling surface temperature in zone 2	BSim	VA114	ESP-r	TRNSYS-TUD	IDA
Min, °C	19.6	19.2	18.6	19.3	18.9
Max, °C	25.9	24.9	28.0	24.9	30.2
Average, °C	20.7	20.8	21.3	20.4	21.6





Hour averaged ceiling surface temperature in the zone 2
Temperature [ºC]
32
30
28
26
24
22
20
18
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BSim
VA114
ESP-r
TRNSYS-TUD
IDA
Day

APPENDIX: Questionnaires

GENERAL

1 **Program name and version number** — **BSim 4.7.1.18**

2 **Name of organization performed the simulations** — **Aalborg University**

3 **Name of person performed simulations and contact information** —
Olena Kalyanova
Ph.D. student,
Aalborg University
Sohngaardsholmsvej 57 DK-9000 tel. +45 9635 8587
ok@civil.aau.dk

4 **Program status**

☐ Freeware
☒ Commercial
☐ Other, please specify

5 **Time convention for weather data: first interval in the weather input lasts 00:00-01:00, climate is assumed constant over the sampling interval**

☒ Yes
☐ No, please specify

CALCULATION OF BOUNDARY CONDITIONS

6 **Please specify the solar model for calculation of incident solar radiation**
Perez

7 **Transmission of the direct solar radiation into zone 1**

☐ Calculated with the constant solar heat gain coefficient (g-value)
☐ Calculated with the g-value as a function of incidence (function of incidence is fixed within code)
☒ Calculated with the g-value as a function of incidence (function of incidence is user defined)
☐ Other, please specify

8 **Transmission of the direct solar radiation into zone 2**

☐ Treated as diffuse solar radiation and calculated with the constant g-value
☐ Calculated with the g-value as a function of incidence (function of incidence is fixed within code)
☒ Calculated with the g-value as a function of incidence (function of incidence is user defined)
☐ Other, please specify

9 **Transmission of the diffuse solar radiation into zone 1**

☒ Calculated with the solar heat gain coefficient at the solar incidence 60^o
☐ Other, please specify

10 **Distribution of solar radiation to the surfaces in the zone 1**

☐ Distributed equally to all surfaces
☐ Calculated according surface area weighting
☐ Calculated according to solar path and view factors
☐ Other, please specify: direct solar radiation is distributed according to the solar path, the diffuse solar radiation is area weighted

11 **Distribution of solar radiation to the surfaces in the zone 2**

☐ Distributed equally to all surfaces

☐ Calculated according surface area weighting
☐ Calculated according to solar path and view factors
☐ Other, please specify: direct solar radiation is distributed according to the solar path, the diffuse solar radiation is area weighted

<u>MODEL DEFINITIONS</u>

12 Air temperature in the zone 1 is calculated as:

☒ One node temperature
☐ Few zones are stacked on the top of each other and the air temperature in each of zones is calculated, please specify number of stacked zones
☐ Other, please specify

13 Air temperature in the zone 2 is calculated as:

☒ One node temperature
☐ Few zones are stacked on the top of each other and the air temperature in each of zones is calculated, please specify number of stacked zones
☐ Other, please specify

<u>HEAT EXCHANGE WITH EXTERIOR</u>

14 External heat transfer coefficients

☒ Split radiative/convective
☐ Combined radiative/ convective
☐ Other, please specify

15 External heat transfer coefficients are calculated with identical assumptions for all surfaces (window frame, window glazing, walls etc.)

☒ Yes
☐ No, please specify

16 External convection

☐ Constant coefficients fixed within code
☐ User-specified constant coefficients
☐ Calculated within code as a function of orientation
☒ Calculated within code as a function of wind speed
☐ Calculated within code as a function of wind speed and direction
☐ Other, please specify

17 External radiative heat exchange

☐ Assumed to be ambient temperature
☒ Assumed to be sky temperature
☐ Other, please specify

<u>HEAT TRANSFER WITHIN ZONES</u>

18 Internal heat transfer coefficients

☒ Split radiative/convection
☐ Combined radiative/ convective
☐ Other, please specify

19 Internal heat transfer coefficients are calculated with identical assumptions in all zones and for all surfaces (window frame, window glazing, walls etc.)

☒ Yes
☐ No, please specify

20 Internal convection

☐ Constant coefficients fixed within code
☐ User-specified constant coefficients
☒ Calculated within code as a function of orientation (vertical/horizontal)
☒ Calculated within code as a function of temperature difference
☐ Calculated within code as a function of air velocity in the zone
☐ Calculated within code as a function of surface finishes
☐ Other, please specify

21 Longwave radiation exchange within zone

☐ Constant linearized coefficients
☒ Linearized coefficients based on view factors
☐ Linearized coefficients based on surface emissivities
☐ Nonlinear treatment of radiation heat exchange
☐ Other, please specify

<u>WINDOW</u>

22 Window

☐ Window frame and glazing are modeled as separate elements of construction
☐ Window frame and glazing are modeled as separate elements of construction, but the total U-value is calculated within the code
☐ Window frame and glazing are modeled as separate elements of construction, but the total U-value and g-value are calculated within the code
☒ Other, please specify : Window frame and glazing are modelled as separate elements of construction, but the total U-value is calculated within the code, but the g-value is calculated in the code on the basis of user defined solar transmission

23 Glazing temperature

☐ Calculated for 1 nodal point on the basis of fixed resistance
☐ Calculated dynamically, using the same scheme as for opaque elements
☒ Other, please specify: Calculated as a thermal ballance for the surface, depending on ammount of absorbed/reflected solar radiation and air temperature in the neighbouring zones

<u>AIRFLOW MODEL</u>

24 Discharge coefficient

☒ Fixed within the code
☐ User-specified fixed value
☐ Calculated by code, please specify what are the parameters involved in code calculations
☐ Other, please specify

25 Pressure difference coefficients

☒ Fixed within the code, identical for all openings sharing the same surface
☐ User-specified, identical for all openings sharing the same surface
☐ User-specified for every opening
☐ Other, please specify

26 Calculated mass flow rate in the model is a function of

☒ Buoyancy force
☒ Wind pressure
☐ Wind turbulence
☐ Other, please specify

GENERAL

1 **Program name and version number** **VA114 – version 2.25**

2 **Name of organization performed the simulations** **VABI Software bv**

3 **Name of person performed simulations and contact information** **A. Wijsman**

Email: a.wijsman@vabi.nl

4 **Program status**

☐ Freeware
X Commercial
☐ Other, please specify

5 **Time convention for weather data: first interval in the weather input lasts 00:00-01:00, climate is assumed constant over the sampling interval**

X Yes
☐ No, please specify

CALCULATION OF BOUNDARY CONDITIONS

6 **Please specify the solar model for calculation of incident solar radiation**
See appendix D to this Modeler report

7 **Transmission of the direct solar radiation into zone 1**

☐ Calculated with the constant solar heat gain coefficient (g-value)
☐ Calculated with the g-value as a function of incidence (function of incidence is fixed within code)
☐ Calculated with the g-value as a function of incidence (function of incidence is user defined)
X Other, please specify: Calculated with Transmission (as a function of incidence – user defined) and Absorption in the pane;

8 **Transmission of the direct solar radiation into zone 2**

☐ Treated as diffuse solar radiation and calculated with the constant g-value
☐ Calculated with the g-value as a function of incidence (function of incidence is fixed within code)
☐ Calculated with the g-value as a function of incidence (function of incidence is user defined)
X Other, please specify: Calculated with Transmission and Absorption in the panes; properties at angle of incidence of 45 degree

9 **Transmission of the diffuse solar radiation into zone 1**

☐ Calculated with the solar heat gain coefficient at the solar incidence 60^{o}
X Other, please specify: Calculated with Transmission (at solar incidence of 58 ^{o}) and Absorption in the pane.

10 **Distribution of solar radiation to the surfaces in the zone 1**

☐ Distributed equally to all surfaces
☐ Calculated according surface area weighting
☐ Calculated according to solar path and view factors
X Other, please specify: Different treatment for Direct and Diffuse solar radiation. Distribution of Direct

solar is calculated by solar path; partly absorbed and partly diffuse reflected at surfaces that are hit. Distribution of Diffuse solar and Diffuse reflected Direct solar is calculated by absorption factors (based on view factors and absorption coefficients of the surfaces that are hit)

11 Distribution of solar radiation to the surfaces in the zone 2

☐ Distributed equally to all surfaces
☐ Calculated according surface area weighting
☐ Calculated according to solar path and view factors
X Other, please specify: same as distribution in zone 1

MODEL DEFINITIONS

12 Air temperature in the zone 1 is calculated as:

X One node temperature
☐ Few zones are stacked on the top of each other and the air temperature in each of zones is calculated, please specify number of stacked zones
☐ Other, please specify

13 Air temperature in the zone 2 is calculated as:

X One node temperature
☐ Few zones are stacked on the top of each other and the air temperature in each of zones is calculated, please specify number of stacked zones
☐ Other, please specify

HEAT EXCHANGE WITH EXTERIOR

14 External heat transfer coefficients

X Split radiative/convective
☐ Combined radiative/ convective
☐ Other, please specify

15 External heat transfer coefficients are calculated with identical assumptions for all surfaces (window frame, window glazing, walls etc.)

☐ Yes
X No, please specify : External heat transfer coefficients are not calculated (see external convection and external radiative heat exchange)

16 External convection

☐ Constant coefficients fixed within code
X User-specified constant coefficients
☐ Calculated within code as a function of orientation
☐ Calculated within code as a function of wind speed
☐ Calculated within code as a function of wind speed and direction
☐ Other, please specify

External radiative heat exchange

17 ☐ Assumed to be ambient temperature
X Assumed to be sky temperature
☐ Other, please specify

HEAT TRANSFER WITHIN ZONES

18 Internal heat transfer coefficients

X Split radiative/convection
☐ Combined radiative/ convective
☐ Other, please specify

19 Internal heat transfer coefficients are calculated with identical assumptions in all zones and for all surfaces (window frame, window glazing, walls etc.)

☐ Yes
☐ No, please specify : Ixternal heat transfer coefficients are not calculated (see internal convection and internal radiative heat exchange)

20 Internal convection

☐ Constant coefficients fixed within code
X User-specified constant coefficients
☐ Calculated within code as a function of orientation (vertical/horizontal)
☐ Calculated within code as a function of temperature difference
☐ Calculated within code as a function of air velocity in the zone
☐ Calculated within code as a function of surface finishes
☐ Other, please specify

21 Longwave radiation exchange within zone

☐ Constant linearized coefficients
☐ Linearized coefficients based on view factors
X Linearized coefficients based on view factors and surface emissivities
☐ Nonlinear treatment of radiation heat exchange
☐ Other, please specify

WINDOW

22 Window

X Window frame and glazing are modeled as separate elements of construction; properties are user defined
☐ Window frame and glazing are modeled as separate elements of construction, but the total U-value is calculated within the code
☐ Window frame and glazing are modeled as separate elements of construction, but the total U-value and g-value are calculated within the code
☐ Other, please specify

23 Glazing temperature

☐ Calculated for 1 nodal point on the basis of fixed resistance
X Calculated dynamically, using the same scheme as for opaque elements
☐ Other, please specify

AIRFLOW MODEL

24 Discharge coefficient

X Fixed within the code
☐ User-specified fixed value

☐ Calculated by code, please specify what are the parameters involved in code calculations
☐ Other, please specify

25 Pressure difference coefficients

☐ Fixed within the code, identical for all openings sharing the same surface
X User-specified, identical for all openings sharing the same surface
☐ User-specified for every opening
☐ Other, please specify

26 Calculated mass flow rate in the model is a function of

X Buoyancy force
X Wind pressure
X Wind fluctuations
☐ Other, please specify

GENERAL

1 Program name and version number **ESP-r 11.3**

2 Name of organization performed the simulations **ESRU, University of Strathclyde**

3 Name of person performed simulations and contact information **Paul Strachan**
paul@esru.strath.ac.uk
tel: +44 141 548 2041

4 Program status

☒ Freeware (Open Source)
☐ Commercial
☐ Other, please specify

5 Time convention for weather data: first interval in the weather input lasts 00:00-01:00, climate is assumed constant over the sampling interval

☐ Yes
☒ No, please specify: Solar data is hour centred (i.e. covers period 00:00-01:00) in these simulations. Linear interpolation is carried out for sub-hourly simulations

CALCULATION OF BOUNDARY CONDITIONS

6 Please specify the solar model for calculation of incident solar radiation
See report. Perez 1990 is used for the anisotropic diffuse sky model.

7 Transmission of the direct solar radiation into zone 1

☐ Calculated with the constant solar heat gain coefficient (g-value)
☐ Calculated with the g-value as a function of incidence (function of incidence is fixed within code)
☐ Calculated with the g-value as a function of incidence (function of incidence is user defined)
☒ Other, please specify See report - transmittance is an input optical property as are layer absorptances. The convection and radiation are calculated explicitly at the glazing system boundaries. g-values are not used.

8 Transmission of the direct solar radiation into zone 2

☐ Treated as diffuse solar radiation and calculated with the constant g-value
☐ Calculated with the g-value as a function of incidence (function of incidence is fixed within code)
☐ Calculated with the g-value as a function of incidence (function of incidence is user defined)
☒ Other, please specify As above

9 Transmission of the diffuse solar radiation into zone 1

☐ Calculated with the solar heat gain coefficient at the solar incidence 60^{o}
☒ Other, please specify As above; incident angle assumed to be 51 degrees

10 Distribution of solar radiation to the surfaces in the zone 1

☐ Distributed equally to all surfaces
☐ Calculated according surface area weighting
☒ Calculated according to solar path and view factors
☐ Other, please specify

11 Distribution of solar radiation to the surfaces in the zone 2

☐ Distributed equally to all surfaces
☐ Calculated according surface area weighting

☒ Calculated according to solar path and view factors
☐ Other, please specify

MODEL DEFINITIONS

12 Air temperature in the zone 1 is calculated as:

☒ One node temperature (for DSF100 case only)
☒ Few zones are stacked on the top of each other and the air temperature in each of zones is calculated, please specify number of stacked zones 3
☐ Other, please specify

13 Air temperature in the zone 2 is calculated as:

☒ One node temperature
☐ Few zones are stacked on the top of each other and the air temperature in each of zones is calculated, please specify number of stacked zones
☐ Other, please specify

HEAT EXCHANGE WITH EXTERIOR

14 External heat transfer coefficients

☒ Split radiative/convective
☐ Combined radiative/ convective
☐ Other, please specify

15 External heat transfer coefficients are calculated with identical assumptions for all surfaces (window frame, window glazing, walls etc.)

☒ Yes
☐ No, please specify

16 External convection

☐ Constant coefficients fixed within code
☐ User-specified constant coefficients
☐ Calculated within code as a function of orientation
☐ Calculated within code as a function of wind speed
☒ Calculated within code as a function of wind speed and direction
☐ Other, please specify

17 External radiative heat exchange

☐ Assumed to be ambient temperature
☐ Assumed to be sky temperature
☒ Other, please specify Sky and ground surface temperatures, depending on viewfactors

HEAT TRANSFER WITHIN ZONES

18 Internal heat transfer coefficients

☒ Split radiative/convection
☐ Combined radiative/ convective
☐ Other, please specify

19 Internal heat transfer coefficients are calculated with identical assumptions in all zones and for all surfaces (window frame, window glazing, walls etc.)

- ☒ Yes (with exception of mechanically ventilated case – see report)
- ☐ No, please specify

20 Internal convection

- ☐ Constant coefficients fixed within code
- ☐ User-specified constant coefficients
- ☐ Calculated within code as a function of orientation (vertical/horizontal)
- ☒ Calculated within code as a function of temperature difference
- ☐ Calculated within code as a function of air velocity in the zone
- ☐ Calculated within code as a function of surface finishes
- ☐ Other, please specify

21 Longwave radiation exchange within zone

- ☐ Constant linearized coefficients
- ☒ Linearized coefficients based on view factors
- ☒ Linearized coefficients based on surface emissivities
- ☐ Nonlinear treatment of radiation heat exchange
- ☐ Other, please specify

WINDOW

22 Window

- ☒ Window frame and glazing are modeled as separate elements of construction
- ☐ Window frame and glazing are modeled as separate elements of construction, but the total U-value is calculated within the code
- ☐ Window frame and glazing are modeled as separate elements of construction, but the total U-value and g-value are calculated within the code
- ☐ Other, please specify

23 Glazing temperature

- ☐ Calculated for 1 nodal point on the basis of fixed resistance
- ☒ Calculated dynamically, using the same scheme as for opaque elements
- ☐ Other, please specify

AIRFLOW MODEL

24 Discharge coefficient

- ☐ Fixed within the code
- ☒ User-specified fixed value
- ☐ Calculated by code, please specify what are the parameters involved in code calculations
- ☐ Other, please specify

25 Pressure difference coefficients

- ☐ Fixed within the code, identical for all openings sharing the same surface
- ☐ User-specified, identical for all openings sharing the same surface

☒ User-specified for every opening
☐ Other, please specify

26 Calculated mass flow rate in the model is a function of

☒ Buoyancy force
☒ Wind pressure
☐ Wind turbulence
☐ Other, please specify

GENERAL

1 **Program name and version number** **TRNSYS-TUD**

2 **Name of organization performed the simulations** **Technical University of Dresden**

3 **Name of person performed simulations and contact information**

Clemens Felsmann
felsmann@tga.tu-dresden.de

Program status

☐ Freeware
☐ Commercial
ξ Other: The code was developed based on commercial TRNSYS for research purposes

5 **Time convention for weather data: first interval in the weather input lasts 00:00-01:00, climate is assumed constant over the sampling interval**

☐ Yes
ξ No: normally inputs change linearly but solar radiation is calculated using a special smoothing function..

CALCULATION OF BOUNDARY CONDITIONS

6 **Please specify the solar model for calculation of incident solar radiation**
Perez model

7 **Transmission of the direct solar radiation into zone 1**

☐ Calculated with the constant solar heat gain coefficient (g-value)
☐ Calculated with the g-value as a function of incidence (function of incidence is fixed within code)
☐ Calculated with the g-value as a function of incidence (function of incidence is user defined)
ξ Other: Calculated with the g-value as a function of incidence (function of incidence was calculated by WINFOW5 Software)

8 **Transmission of the direct solar radiation into zone 2**

ξ Treated as diffuse solar radiation and calculated with the constant g-value
☐ Calculated with the g-value as a function of incidence (function of incidence is fixed within code)
☐ Calculated with the g-value as a function of incidence (function of incidence is user defined)
☐ Other, please specify

9 **Transmission of the diffuse solar radiation into zone 1**

☐ Calculated with the solar heat gain coefficient at the solar incidence 60^{o}
ξ Other: Calculated with the solar heat gain coefficient was calculated by WINFOW5 Software

10 **Distribution of solar radiation to the surfaces in the zone 1**

ξ Distributed equally to all surfaces: diffuse radiation
☐ Calculated according surface area weighting
ξ Calculated according to solar path and view factors: direct radiation
☐ Other, please specify

11 **Distribution of solar radiation to the surfaces in the zone 2**

ξ Distributed equally to all surfaces because all radiation was treated as diffuse radiation
☐ Calculated according surface area weighting

☐ Calculated according to solar path and view factors
☐ Other, please specify

MODEL DEFINITIONS

12 Air temperature in the zone 1 is calculated as:

ξ One node temperature was reported but…
ξ Few zones are stacked on the top of each other and the air temperature in each of zones is calculated, please specify number of stacked zones 4
☐ Other, please specify

13 Air temperature in the zone 2 is calculated as:

ξ One node temperature was reported but …
ξ Few zones are stacked on the top of each other and the air temperature in each of zones is calculated, please specify number of stacked zones 4
☐ Other, please specify

HEAT EXCHANGE WITH EXTERIOR

14 External heat transfer coefficients

ξ Split radiative/convective
☐ Combined radiative/ convective
☐ Other, please specify

15 External heat transfer coefficients are calculated with identical assumptions for all surfaces (window frame, window glazing, walls etc.)

ξ Yes
☐ No, please specify

16 External convection

☐ Constant coefficients fixed within code
ξ User-specified constant coefficients
☐ Calculated within code as a function of orientation
☐ Calculated within code as a function of wind speed
☐ Calculated within code as a function of wind speed and direction
☐ Other, please specify

17 External radiative heat exchange

☐ Assumed to be ambient temperature
☐ Assumed to be sky temperature
ξ Other: it depends on the orientation whether ambient or sky temperature will be used

HEAT TRANSFER WITHIN ZONES

18 Internal heat transfer coefficients

ξ Split radiative/convection
☐ Combined radiative/ convective
☐ Other, please specify

19 **Internal heat transfer coefficients are calculated with identical assumptions in all zones and for all surfaces (window frame, window glazing, walls etc.)**

ξ Yes
☐ No, please specify

20 **Internal convection**

☐ Constant coefficients fixed within code
ξ User-specified constant coefficients
☐ Calculated within code as a function of orientation (vertical/horizontal)
☐ Calculated within code as a function of temperature difference
☐ Calculated within code as a function of air velocity in the zone
☐ Calculated within code as a function of surface finishes
☐ Other, please specify

21 **Longwave radiation exchange within zone**

☐ Constant linearized coefficients
☐ Linearized coefficients based on view factors
☐ Linearized coefficients based on surface emissivities
ξ Nonlinear treatment of radiation heat exchange
☐ Other, please specify

WINDOW

22 **Window**

☐ Window frame and glazing are modeled as separate elements of construction
☐ Window frame and glazing are modeled as separate elements of construction, but the total U-value is calculated within the code
ξ Window frame and glazing are modeled as separate elements of construction, but the total U-value and g-value are calculated within the code
☐ Other, please specify

23 **Glazing temperature**

ξ Calculated for 1 nodal point on the basis of fixed resistance
☐ Calculated dynamically, using the same scheme as for opaque elements
☐ Other, please specify

AIRFLOW MODEL

24 **Discharge coefficient**

☐ Fixed within the code
ξ User-specified fixed value
☐ Calculated by code, please specify what are the parameters involved in code calculations
☐ Other, please specify

25 **Pressure difference coefficients**

☐ Fixed within the code, identical for all openings sharing the same surface
☐ User-specified, identical for all openings sharing the same surface
ξ User-specified for every opening
☐ Other, please specify

26 Calculated mass flow rate in the model is a function of

ξ Buoyancy force
ξ Wind pressure
☐ Wind turbulence
ξ Other: mass flow rate also depends on mechanical ventilation systems available in the building

GENERAL

1	**Program name and version number**	**IDA ICE 3.0**
2	**Name of organization performed the simulations**	**EBD, LTH, Sweden**
3	**Name of person performed simulations and contact information**	Harris Poirazis Lund University harris.poirazis@ebd.lth.se

4 Program status

☐ Freeware
☒ Commercial
☐ Other, please specify

5 Time convention for weather data: first interval in the weather input lasts 00:00-01:00, climate is assumed constant over the sampling interval

☒ Yes
☐ No, please specify

CALCULATION OF BOUNDARY CONDITIONS

6 Please specify the solar model for calculation of incident solar radiation
Model by Perez (1990)

7 Transmission of the direct solar radiation into zone 1

☐ Calculated with the constant solar heat gain coefficient (g-value)
☒ Calculated with the g-value as a function of incidence (function of incidence is fixed within code)
☐ Calculated with the g-value as a function of incidence (function of incidence is user defined)
☐ Other, please specify

8 Transmission of the direct solar radiation into zone 2

☐ Treated as diffuse solar radiation and calculated with the constant g-value
☒ Calculated with the g-value as a function of incidence (function of incidence is fixed within code)
☐ Calculated with the g-value as a function of incidence (function of incidence is user defined)
☐ Other, please specify

9 Transmission of the diffuse solar radiation into zone 1

☐ Calculated with the solar heat gain coefficient at the solar incidence 60^o
☒ Other, please specify Calculated as 0.77/0.87*T-normal

10 Distribution of solar radiation to the surfaces in the zone 1

☐ Distributed equally to all surfaces
☐ Calculated according surface area weighting
☒ Calculated according to solar path and view factors
☐ Other, please specify

11 Distribution of solar radiation to the surfaces in the zone 2

☐ Distributed equally to all surfaces
☐ Calculated according surface area weighting
☐ Calculated according to solar path and view factors
☒ Other, please specify Calculated according to view factors and surface reflectance values

MODEL DEFINITIONS

12 Air temperature in the zone 1 is calculated as:

☒ One node temperature
☐ Few zones are stacked on the top of each other and the air temperature in each of zones is calculated, please specify number of stacked zones
☐ Other, please specify

13 Air temperature in the zone 2 is calculated as:

☒ One node temperature
☐ Few zones are stacked on the top of each other and the air temperature in each of zones is calculated, please specify number of stacked zones
☐ Other, please specify

HEAT EXCHANGE WITH EXTERIOR

14 External heat transfer coefficients

☒ Split radiative/convective
☐ Combined radiative/ convective
☐ Other, please specify

15 External heat transfer coefficients are calculated with identical assumptions for all surfaces (window frame, window glazing, walls etc.)

☒ Yes
☐ No, please specify

16 External convection

☐ Constant coefficients fixed within code
☐ User-specified constant coefficients
☐ Calculated within code as a function of orientation

☐ Calculated within code as a function of wind speed
☒ Calculated within code as a function of wind speed and direction
☐ Other, please specify

17 External radiative heat exchange

☐ Assumed to be ambient temperature
☐ Assumed to be sky temperature
☒ Other, please specify Sky/ambient temperatures according to view factors for sky/ground. Sky temperature is calculated as ambient temperature minus 5°C

HEAT TRANSFER WITHIN ZONES

18 Internal heat transfer coefficients

☒ Split radiative/convection
☐ Combined radiative/ convective
☐ Other, please specify

19 Internal heat transfer coefficients are calculated with identical assumptions in all zones and for all surfaces (window frame, window glazing, walls etc.)

☒ Yes
☐ No, please specify

20 Internal convection

☐ Constant coefficients fixed within code
☐ User-specified constant coefficients
☒ Calculated within code as a function of orientation (vertical/horizontal)
☒ Calculated within code as a function of temperature difference
☐ Calculated within code as a function of air velocity in the zone
☐ Calculated within code as a function of surface finishes
☐ Other, please specify

21 Longwave radiation exchange within zone

☐ Constant linearized coefficients
☒ Linearized coefficients based on view factors
☒ Linearized coefficients based on surface emissivities
☐ Nonlinear treatment of radiation heat exchange
☐ Other, please specify

WINDOW

22 Window

☒ Window frame and glazing are modeled as separate elements of construction
☐ Window frame and glazing are modeled as separate elements of construction, but the total U-value is calculated within the code
☐ Window frame and glazing are modeled as separate elements of construction, but the total U-value and g-value are calculated within the code
☐ Other, please specify

23 Glazing temperature

☒ Calculated for 1 nodal point on the basis of fixed resistance
☐ Calculated dynamically, using the same scheme as for opaque elements
☐ Other, please specify

<u>AIRFLOW MODEL</u>

24 Discharge coefficient

☐ Fixed within the code
☒ User-specified fixed value
☐ Calculated by code, please specify what are the parameters involved in code calculations
☐ Other, please specify

25 Pressure difference coefficients

☐ Fixed within the code, identical for all openings sharing the same surface
☒ User-specified, identical for all openings sharing the same surface
☐ User-specified for every opening
☐ Other, please specify

26 Calculated mass flow rate in the model is a function of

☒ Buoyancy force
☒ Wind pressure
☐ Wind turbulence
☐ Other, please specify

APPENDIX: Modeler reports

BSim Modeler Report

Comparative Validation of Building Simulation Software

Technical Report

IEA ECBCS Annex43 / SHC Task 34
Validation of Building Energy Simulation Tools

Subtask E

O. Kalyanova
P. Heiselberg

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AALBORG UNIVERSITY
Department of Civil Engineering

Aalborg University
Department of Civil Engineering
Indoor Environmental Engineering Research Group

DCE Technical Report No. 025

BSim Modeler Report
Comparative Validation of Building Simulation Software

by

O. Kalyanova
P. Heiselberg

august 2007

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INDEX

1. Introduction

Test cases DSF100_2, DSF200_3, DSF200_4 and DSF400_3 were simulated with the Danish Building simulating software BSim, version 4.7.1.18.

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http://www.dbur.dk (English)
http://www.bsim.dk (BSim homepage)

BSim (Building Simulation) is the integrated tool for projecting buildings and installations. The software consists of seven modules:

- SimView - Graphic user interface
- Tsbi5 - Indoor climate, thermal and moisture conditions
- Xsun - Sunlight and shadows
- SimLight - Daylight calculations
- BV98 - Danish Building regulations compliance checker
- SimDXF - Importing CAD drawings
- SimDB - Database with constructions and materials

Moreover there few advanced options available, these are:

- Advanced simulations of moisture transport in buildings and constructions
- Calculations of electrical energy yield from a building integrated solar cell (PV) system
- Simulation of indoor climate with natural ventilation in the building

2. Modelling approaches in BSim

Calculations in BSim performed in a steady state condition for the each time step. The software contains also accumulation of heat and moisture calculations. There are two or more time steps per hour.

Zones

A building consists of an arbitrary number of zones, which are limited by an arbitrary number of surfaces.

The zone air is represented in the building description as a nodal point, for which air temperature and water vapour content are calculated. It is assumed that the air in a zone is fully mixed. However, the temperature stratification in a zone can be modeled by means of Kappa-model, which is highly dependent on user assumptions/inputs.

External environment

This is so-called virtual zone, e.g. the outside air, the condition of which is not to be calculated, but is given by data from a file or a timetable, defined by user.

Transmission of solar radiation to the zone

XSun, which forms a part of the BSim software suite, can be used for the detailed analyses of the path of direct solar radiation through a building. It is possible to see where and when the sun strikes any face in the model. The direct solar radiation through the external and internal window will be distributed geometrically correct according to the solar path, while the diffuse solar radiation will be distributed according to surface area weighting.

Solar radiation

From the values given in the weather data file BSim is able to calculate the solar incidence on an arbitrarily orientated surface. Petersen's model is the default one for calculation of solar incidence in BSim. Available models for calculation of solar incidence in BSim are: Petersen's, Munier's, Lund's and Perez's.

Longwave radiation exchange between the model and ambient

Only the radiative exchange to the sky takes part in the simulation. There is thus no radiative exchange with eventual other buildings in the model and nor with eventual advanced parts of the building itself. The radiative heat exchange is thus only dependant on the temperature difference between any surface and the sky, respectively the ground and the tilt of the surface.

Internal longwave radiation exchange

It is only possible to simulate long-wave radiative exchange in tsbi5 in those rooms, which are convex, in order to enable calculation of view factors in BSim. When the internal longwave radiation exchange is to be calculated then the convective heat transfer coefficients are calculated separately for each surface, otherwise a combined value of convection and radiation is used.

The longwave radiation exchange from the surfaces of the glass and the surrounding surfaces with average emission coefficient (e = 0.94) is used for all surfaces made of glass.

Outdoor surface convection coefficient

Next to calculating the long wave radiation effects, the heat transfers coefficient between the outdoor air and the first node point on the exterior side of the construction is calculated as a function of wind speed.

Convective heat transfer coefficients

For vertical surfaces:

Laminar conditions, small surfaces ($\Delta T \leq 9.5/L^3$):

Equation 2-1

$$\alpha_c = 1.43\left(\frac{\Delta T}{L}\right)^{0.25} \text{ W/m}^2\text{K}$$

Turbulent conditions, large surfaces ($\Delta T > 9.5/L^3$):

Equation 2-2

$$\alpha_c = 1.31(\Delta T)^{0.33} \text{ W/m}^2\text{K}$$

For horizontal surfaces with upward heat flow (warm floors or cold ceilings):

Laminar conditions, small surfaces ($\Delta T \leq 0.19/L^3$):

Equation 2-3

$$\alpha_c = 1.32\left(\frac{\Delta T}{L}\right)^{0.25} \text{ W/m}^2\text{K}$$

Turbulent conditions, large surfaces ($\Delta T > 0.19/L^3$):

Equation 2-4

$$\alpha_c = 1.52(\Delta T)^{0.33} \text{ W/m}^2\text{K}$$

For horizontal surfaces with downward heat flow (cold floors or warm ceilings), only laminar conditions:

Equation 2-5

$$\alpha_c = 0.59\left(\frac{\Delta T}{L}\right)^{0.25} \text{ W/m}^2\text{K}$$

Glass temperature

In the model, different absorption and reflection at the two glass faces are used in the calculation of the absorbed amount of radiation in the glass. Then the temperature for the glass surfaces is calculated as a heat balance to the air temperature next to the glass surface, including the amount of absorbed energy in the glass face.

Heat balance for the zone air

The heat balance for the air in a zone does not make allowance for the heat capacity of the air which means that the air momentarily adjusts itself to alterations in the surroundings, includes:

-heat flows from adjoining constructions
-heat flows through windoors
-solar radiation through windoors (of which only a limited amount is assumed to be induced to the air)
-thermal contribution from various heat loads and systems
-air penetration from outdoor air (infiltration, venting)
-air supplied from ventilation systems
-air transferred by from other zones (mixing)

Heat transmission in the constructions

The constructions consist of one or more layers, which are assumed to be homogeneous, consisting of one material, which is characterized by thermal material values. The heat transmission internally in the constructions is described non-stationary, i.e. by making allowance for each individual layer's thermal capacity. Thick material layers are divided into several thinner layers (control volumes).

Heat transfer coefficients at the window surfaces are calculated in the same way as the heat transfer coefficients for the wall containing the window.

Air mass balance

If an un-balanced air-stream is introduced in any thermal zone, this will automatically be balanced with in- or exfiltration of air from the outdoors in the tsbi5 simulations. This happens even if the thermal zone has no direct connection (faces) to the outdoors.

Control

All systems in BSim are controlled on the basis of an operative temperature in the thermal zone to which they are attached. However, it is possible to adjust the control system for application of the air temperature instead for the operative air temperature.

3. Modelling assumptions

General

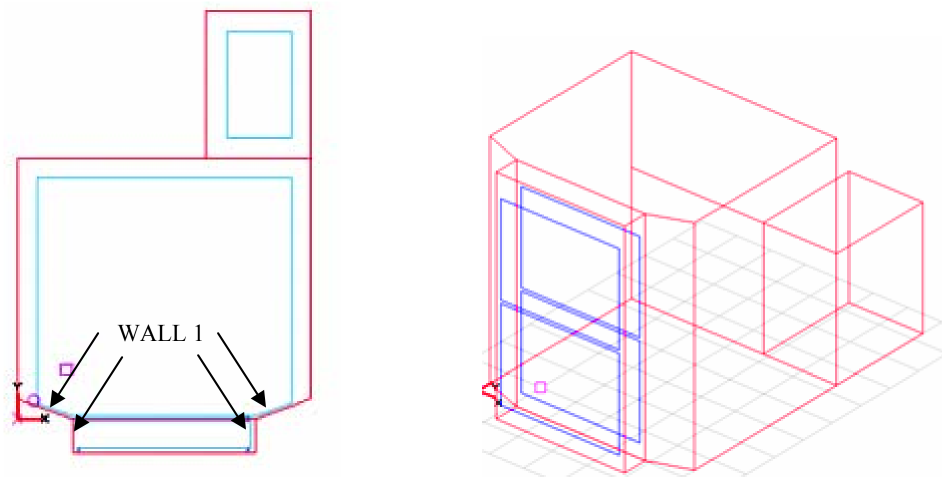
Weather data

The climate data is provided together with the specification, where it is advised to use global and diffuse solar radiation on the horizontal surface as input parameters. BSim is not able to use these parameters as inputs, therefore the Normal direct solar radiation and diffuse solar radiation were used instead for.

Model geometry

Thermal zones in the model are defined according to the specification, thus zone 1 represents the DSF and zone 2 represents the room adjacent to the DSF.

WALL 1, shared by zone 1 and zone 2 was modeled as an adiabatic and relatively thin wall for each of the zones, see Figure 1a. The internal dimensions of the zone 1were kept unchanged according to the specification. Internal dimensions and shape of the zone 2 were changed, as following: left and right WALL 1 in the zone 2 was given a slope in order to activate the longwave radiation calculations (BSim limitation for the concave spaces). The length of the WALL 2 was changed to attain the same internal zone volume as in the specification (Figure 1) .



a. b.

Figure 1. Geometry of BSim model. Plan (a). Model in 3D (b).

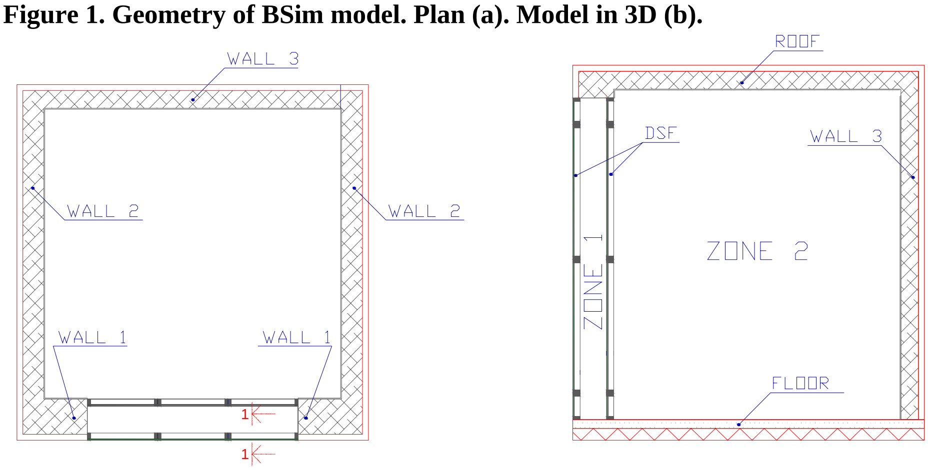


Figure 2. Definition of zones and walls in the specification. Plan (left) and section1-1 (right).

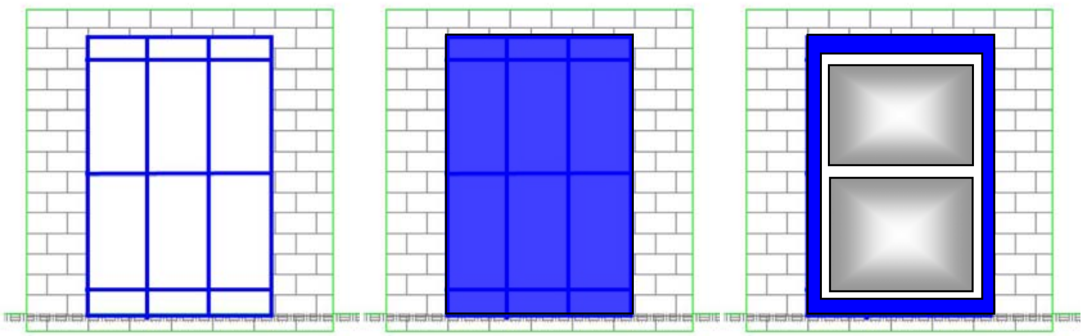
Opaque constructions

U-values for the constructions are calculated by BSim when the material properties of the constructions are defined by user. The U-value is calculated according to the Danish Norms DS 418. Material properties were defined according to the specification.

Transparent constructions (Windoors)

Following Figure 3 is included in the report to explain the modelling procedure for the DSF. Figure 3a corresponds to the original geometry definition in the test specification. First, all windows and wall of the external façade are replaced by a separate construction with the U-value equal to the U-value of the window frame (U= 3.86 W/m^2, Figure 3b). Then windows are added to the new construction (Figure 3c). Six sections of the external windows are replaced by 2 sections with the corresponding area of glazing.

It is necessary to leave some distance between the window frame and the edge of the construction in BSim. In the Figure 3c is shown area of 1.236 m^2, left around the windows (blue color), this area has the same U-value as the window frame. Total frame area of windows is 3.216 m^2.
Remaining frame area will be:
A=3.216-1.236=1.98 m^2
This area 1.98m^2 was equally distributed between 2 windows (Figure 3c.)



a. b. c.

Figure 3. South façade, defined in the test case specification and in the model

Same steps were repeated for the internal window sections.

These changes require adjustments in U-value of the windows, to fulfill a condition:

Equation 3-1

$$A_w \cdot U_w \cdot 6 \approx A_c \cdot U_f + A_w^* \cdot U_w^* \cdot 2$$

A_w – area of window section defined in the specification, m^2
U_w – U-value of the window section defined in the specification, W/m^2
6 – number of window sections
A_c – area (of new construction) left around the window, m^2
U_f – U-value of the frame defined in the specification, W/m^2
A_w^* – area of 1 out of 2 window sections (Figure 3c), m^2
U_w^* – adjusted U-value of window sections in Figure 3c, m^2
2 – number of window sections (Figure 3c)

There is a slight discrepancy in fulfilling the above condition with the software used, as BSim automatically calculates the U-value for windows. Thus, the U-value for the glass had to be adjusted and therefore it differs from the values in the specification.

Results for the external window sections:
Ac=1.236 m^2
A_w^*=9.069 m^2
U_w^*=5.76 W/m^2
U_{glass}=5.91 W/m^2

Results for the internal window sections:
Ac=1.236 m^2
A_w^*=9.069 m^2
U_w^*=2.01 W/m^2
U_{glass}=1.69 W/m^2

Incident solar radiation

Perez model was used for the calculations

Transmission of solar radiation
According to the specification, given IGDB- number was used for the estimation of the optical properties of the glazing. The transmission of solar radiation as a function of angle of incidence was estimated according to the Window 5 software for the given in the specification IGDB number, as following.

For the external window partitions:

α, deg	0	10	20	30	40	50	60	70	80	90
τ	0.726	0.725	0.721	0.714	0.702	0.679	0.633	0.532	0.318	0

For internal window partitions:

α, deg	0	10	20	30	40	50	60	70	80	90
τ	0.56	0.559	0.555	0.549	0.539	0.516	0.459	0.344	0.167	0

Solar heat transmittance (g-value) for the solar radiation normal to the glass surface is calculated f by BSim on the basis of glazing transmittance properties. Values used in simulations are:
0.74 for the external window partitions and 0.56 for the internal ones.

Program assumes heat transmittance for diffuse solar radiation (reflected from surroundings, i.e. neighbor buildings, ground, clouds etc.) equal to the transmittance for direct radiation at an angle of incidence of 60°.

Absorption/reflection properties of the glazing

Absorption and reflection properties of the glazing were used in the BSim models, these values were calculated together with the calculations of glazing solar transmission as a function of angle of incidence with the help of Window5 software. Following values were used in the models:

External window partitions:

Direct solar radiation transmittance 0.73
Front reflectance (side facing outside) 0.07
Back reflectance (side facing inside) 0.07
Front absorptance 0.21
Back absorptance 0.21

Internal window partitions

Direct solar radiation transmittance 0.55
Front reflectance (side facing outside) 0.16
Back reflectance (side facing inside) 0.14
Front absorptance 0.12
Back absorptance 0.16

Surface finishes

Solar radiation sticking the opaque external surfaces is absorbed according to the defined surface absorption property, however solar radiation sticking on the opaque internal surfaces is fully absorbed by the surface.

Glazing Surface temperatures

In BSim the model for calculation of the glazing surface temperatures is simplified, it accounts for the absorbed solar radiation in the glazing pan and the air temperature in the neighboring zones. However there it has a limitation: it is assumed that there are always two layers of glass and this model is not applicable for the glass with coatings. And therefore it can not be directly applied for the constructions defined in the specification.

Glazing emissivity

This is the default value in the BSim and equals 0.84

Air flow modelling

The airflow model for the case defined in the specification is described as 'Single Sided in Different Levels'**.** It is used when several pairs of openings in one face are located in different vertical levels with the uniform temperature distribution in the thermal zone. The airflow through the zone is described by general expression in Equation 3-2.

Equation 3-2

$$q = \left| \pm q_v^2 \pm q_t^2 \right|^{1/2} = \left| \frac{c_v}{|c_v|} \cdot (c_v \cdot V_{10})^2 + \frac{\Delta T}{|\Delta T|} \cdot (c_t \cdot |\Delta T|)^2 \right|^{1/2}$$

Equation 3-3

$$c_t = \sum_{j=1}^{n} c_{D,j} \cdot A_j \cdot \left(\frac{2 \cdot (H_o - H_j) \cdot g}{T_i} \right)^{1/2}$$

Equation 3-4

$$c_v = 0.03 \cdot A$$

q	- air flow rate in the zone
q_v, q_t	- airflow rate caused by wind forces and buoyancy correspondingly
c_v, c_t	- coefficient for the wind force and buoyancy correspondingly
V_{10}	- the reference wind velocity at the height 10m
ΔT	- temperature difference between two environments
n	- number of openings
j	- opening number
c_D	- the discharge coefficient
A_j	- area of the opening 'j'
H_o	- height of the neutral plan
H_j	- height of the opening 'j'
g	- gravity force

Wind pressure coefficients

In BSim the wind pressure coefficients are the default values, determined as average values for the surfaces at the different wind incidence angles. BSim chooses the Cp-values from these standards based on the geometry of the building model. Comparison of the Cp values given in the specification and BSim-values is performed in Figure 4.
However, the BSim approach means that every surface is given only 1 value independently on number of openings in the surface and as consequence there is no pressure difference between the openings on the same surface caused by wind.

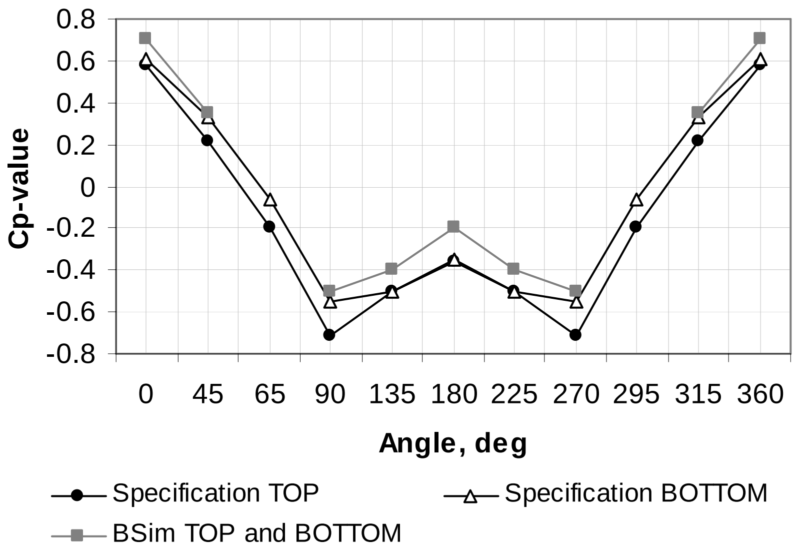


Figure 4. Comparison between Cp -values in the specification and BSim default.

Wind profile

The default function is used to describe the wind velocity profile. A function for the open flat country was used in the calculations and can be described as in Figure 5.

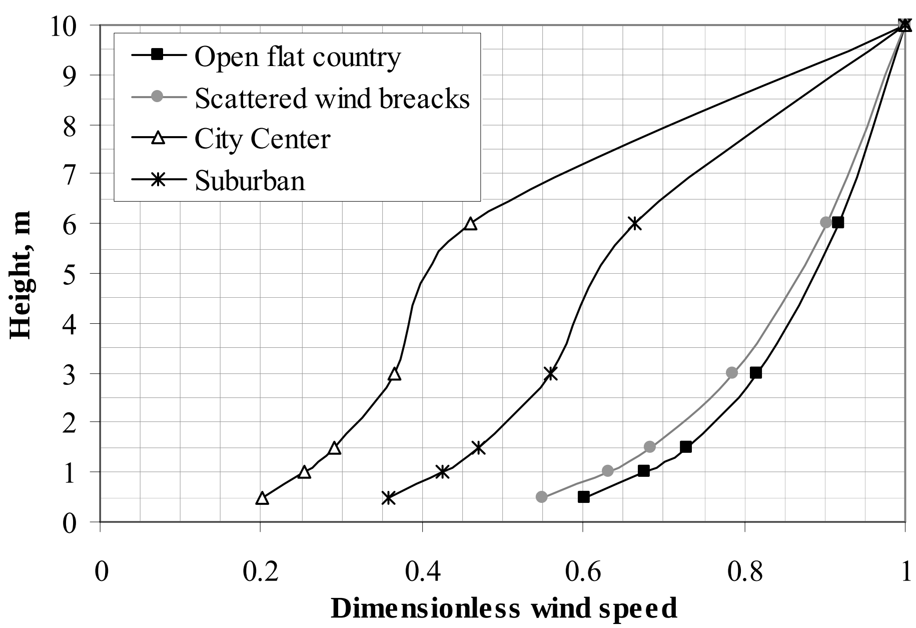


Figure 5. Wind profiles available in BSim.

Discharge coefficient

The discharge coefficient in BSim is the default value of 0.65

Thermal bridges

Thermal bridges were not included into the calculations according to the test specification.

Infiltration

Infiltration was not activated for the test cases

Control and air temperature

In BSim systems are controlled according to the operative air temperature, however in the specification the control is performed true the air temperature only. I order to follow the requirements in the specification the longwave radiation contribution on the calculations of the operative air temperature were deactivated.

Remaining parameters

Remaining parameters were modeled according to the test case specification

DSF100_2

Heating/cooling

Heating/Cooling system is introduced to *Zone 2*. The set point temperature for cooling is set to 20.0^{o}C and 19.9^{o}C for heating.
The proportion of the cooling output that is reckoned to be given off to the room air by convection is equal to 1. Heating/Cooling power provided to the *Zone 2* is unlimited to maintain the set point temperature of the room.

DSF200_3, DSF 200_4

Heating/cooling

Heating/Cooling system is introduced to *Zone 2*. The set point temperature for cooling is set to 20.1^{o}C and 19.9^{o}C for heating.
The proportion of the cooling output that is reckoned to be given off to the room air by convection is equal to 1. Heating/Cooling power provided to the *Zone 2* is unlimited to maintain the set point temperature of the room.

Natural ventilation

The natural ventilation is activated and calculated as described above

DSF400_3

Heating/cooling

The set point temperature for cooling is set to 20.1^{o}C and 19.9^{o}C for heating.

Ventilation (Mechanical)

Air is supplied into the *Zone 2* in amount of 0.60m^3/s that corresponds to air change rate 15.5 1/h in the zone. The temperature of the inlet air is the same as the air temperature in the *Zone 1*. Same amount of air is supplied to the DSF from the external environment.

4. Results

All results are given in tables:
Output results DSF100_2.xls
Output results DSF400_3.xls

5. Remarks

Glass surface temperature needs investigations

6. Corrected errors

Calculation of view factors for the large opposing glazed surfaces on a short distance from each other.

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IEA SHC Task 34 / ECBCS Annex 43
Subtask E: Double Skin Facade

Double Skin Facade - Modeler Report

Comparative Testcases

VA114

VABI Software BV
P.O. Box 29
2600 AA Delft
The Netherlands

June 26, 2007 (fourth draft)
April 23, 2007 (third draft)
November 30, 2006 (second draft)
March 27, 2006 (first draft)

Report by A. Wijsman

<u>Remark:</u>
In March 2006 a first draft was made: a description of the model and its assumptions was given. The simulation program, that in earlier times passed the BESTEST [1],[2],[3], was subjected to the IEA-34/43 tests[4] (DSF100_2 and DSF400_3). Results for these runs were given.
In November 2006 reruns were done: specs changed, assumptions changed. Also tests DSF200_3 and DSF200_4 were done. The second draft contains information about this work.
In April 2007 again reruns were done: specs had minor changes, the VA114-model for the internal window was improved. The third draft contains information about this work.
Now, in June 2007, a fourth (the final draft) is ready. Two descriptions have been added: a description of the VA114-submodel for air flow by wind fluctuations and a description of VA114's solar processor. A completed questionnaire for the program VA114 has been added. Final runs were done and results are reported.

Heat exchange within a Zone and between Zones

1. Introduction

The Building simulation program VA114 is developed and distributed by VABI Software BV. The current version is 2.25.

The program calculates the Demand, the Supply, the Distribution and the Generation of heat and cold for a building with its energy supply system. Moreover the internal comfort temperature and overheating are calculated.

VA114 is a multi-zone program (up to 30). The time step applied in VA114 is 1 hour.

The boundary conditions, which are possible in VA114 are:
- bounded to ambient
- bounded to a neighbour zone
- bounded to a mirror zone
- bounded to the underground

The current program VA114 models:
- heat exchange within a zone
- heat exchange between zones by conduction
- heat exchange between zones by airflow (ventilation)
- solar gain and solar exchange between zones
- solar shading
- and other processes

The simulation program VA114 passed the BESTEST [1],[2],[3]. Last year (2005) the simulation program was subjected to the new IEA-34/43 tests of subtask B (Multi-zone Non air – tests MZ320, MZ340, MZ350, MZ355 and MZ360).

In March 2006 the program was subjected to the new IEA-34/43 tests of subtask E (Double Skin Façade). A start was made with the tests DSF100_2 and DSF400_3. Information can be found in the first draft of this report.

Tests are under development, specs and required output are still changing.

In November 2006 reruns were done: specs changed, assumptions changed. Also tests DSF200_3 and DSF200_4 were done. The second draft contains information about this work.

In April 2007 again reruns were done: specs had minor changes, the VA114-model for the internal window was improved. The third draft contains information about this work.

Now, in June 2007, a fourth (the final draft) is ready. Two descriptions have been added: a description of the VA114-submodel for air flow by wind fluctuations and a description of VA114's solar processor (Appendix D). A completed questionnaire for the program VA114 has been added (Appendix E). Final runs were done and results are reported.

<u>Remark:</u>
VABI Software bv is developing the simulation program VA114. A new version of VA114 was distributed to its users (about 200) in February 2006. Before the distribution of this new version it was tested extensively: by running the Bestest cases (1995), by running the Dutch EDR-tests and by running the new IEA-34/43-MZ-tests.

2. Model description

The current program VA114 models:

- heat exchange within a zone
- heat exchange between zones by conduction
- heat exchange between zones by airflow (ventilation)
- solar gain and solar exchange between zones
- solar shading
- and other processes

In more detail:

- heat exchange within a zone

The zone air is described by one node. Between this zone air node and the internal surfaces heat exchange takes place by convection. The convection coefficient is user given and can be specific for each surface.
Heat exchange between the surfaces happens by long wave radiation. This heat exchange is dependent on the view factors and emittance factor of the internal surfaces.
Remark: there is an option in the model the value of the convection coefficient can switch between two values.

- heat exchange between zones by conduction

Internal and external walls are simulated by a number of nodes. Each with a heat capacity and with heat resistances in between.

- heat exchange between zones by airflow (ventilation)

Air exchange takes place between ambient and the zone and between neighbouring zones. This air exchange can be user given or calculated according to a network node model.
In Appendix A detailed information is given about the modelling aspects of this process.

- solar gain and solar exchange between zones

Solar radiation enters a zone by windows. This solar radiation is absorbed in the zone or can leave the zone through windows, to ambient or to a neighbouring zone.
In Appendix B detailed information is given about the modelling aspects of this process. Incident solar radiation is calculated by VA114's solar processor (see Appendix D).

- solar shading

Solar shading happens by surrounding buildings, by external façade parts, by own buildings parts and by setback of the window.
In Appendix C detailed information is given about the modelling aspects of this process.

- and other processes

Like: internal heat production (by persons, equipment and lighting), mechanical ventilation, ….

3. Modeling Assumptions

In this chapter the modeling assumptions are discussed. First in general and then specific per test case. See the corresponding paragraphs of the Test case specification [4]

Comments/assumptions with respect to the General information

DSF test cases
The DSF test cases are subdivided into 5 groups:

- DSF100: All openings are closed
- DSF200: Openings are open to the outside
- DSF300: Openings are open to the inside
- DSF400: Bottom opening is open to the outside and the top opening is open to the inside (pre-heating mode)
- DSF500: Top opening is open to the outside and the bottom opening is open to the inside (chimney/exhaust mode).

Geography, site location
Varlose, Copenhagen, Denmark:

- latitude 55,77 degree North
- longitude 12,32 degree East
- Altitude: 27 m above sea level

Weather data
The time on the tape is "standard local time". It is a pity the format of the file is not close to the format of the TMY-files.
Total solar radiation on the horizontal and diffuse solar radiation on the horizontal are given; direct normal solar radiation is calculated from the 2 given components.
Wind velocity on the tape is the velocity in the open field at a height of 10 m.

Geometry
Four zones are specified:

- zone 1, the DSF
- zone 2, the zone behind the DSF
- zone 3, the left back zone
- zone 4, the right back zone

The inner dimensions were used to get the right volume. The depth of the zones 3 and 4 is 3,00 m. It is assumed the wall in between zone 2 and 3 is adiabatical; so is the wall in between zone 3 and 4.

The external and the internal window have an area of 19,37 m^2 (6 * 3,229 m^2): 16,16 m^2 is glazing (83,4%), 3,21 m^2 is frame.

Window properties

The <u>external window</u> has the following properties:

U-value = 5,36 W/(m^2.K) (glazing = 5,70 and frame = 3,86)
g-value = 0,667 (glazing = 0,80 and frame = 0,00)
C_f-value=0,017 (glazing = 0,020 and frame = 0,00)

Angular Modifier (AM) of this single glazing:

```
Angle=    0.     15.     30.    40.     45.     50.     60.     70.     80.     90.
AM=    1.032  1.029  1.024  1.012  1.000  0.985  0.921  0.776  0.480  0.000
```

For diffuse solar radiation an incidence angle of 58^o is applied.

<u>Remark:</u> above g-value is for perpendicular incident radiation (incident angle is 0^o); AM is a multiplier for g-value at 45^o incident angle. So as input g-45 has to be used:

g-45 = 0,667 /1,032 = 0,646 (glazing = 0,775 and frame = 0,00)

The <u>internal window</u> has the following properties:

U-value = 1,60 W/(m^2K) (glazing = 1,20 and frame = 3,86)
g-value = 0,525 (glazing = 0,63 and frame = 0,00)
C_f-value=0,057 (glazing = 0,068 and frame = 0,00)

Angular Modifier (AM) of this double glazing:

```
Angle=    0.     15.     30.    40.     45.     50.     60.     70.     80.     90.
AM=    1.054  1.051  1.041  1.021  1.000  0.973  0.866  0.661  0.338  0.000
```

For diffuse solar radiation an incidence angle of 58^o is applied.

<u>Remark:</u> above g-value is for perpendicular incident radiation (incident angle is 0^o); AM is a multiplier for g-value at 45^o incident angle. So as input g-45 has to be used:

g-45 = 0,525 /1,054 = 0,498 (glazing = 0,598 and frame = 0,00)

The emissivity of the glazing is 0,84 on both the side to external and the side to internal.

<u>Remark:</u> C_f-value is determined by simulation and interpolation – at what C_f-value is for the given g-value the transmission as prescribed.

<u>Remark:</u> the standard AM's available in the VA114-input were used (for single glazing and for double glazing). Both AM's are given above.

Solar gain

It is assumed the solar gain is for 100% sensible (0% latent) and for 100% radiative (convective part Czon= 0%).

Properties of the constructions

The properties are as specified.

The constructions have an infrared emittance (emissivity) of 0,88 and a solar absorptance of 0,40 (this value is estimated; a realistic value for a white surface).

Heat loss through the floor

The heat loss through the floor (in W/m^2): the ground resistance to the heat transmission is prescribed - 1,5 m^2.K/W (according to the DS 418).
For the given floor construction this results in an overall U-value of 0,15 W/(m^2.K); so a heat loss of 1,5 W/m^2 (temperature difference is 20 – 10 = 10 K)

Remark: this value is about the same as the heat loss calculated based on ISO-13370

According to ISO-13370 (slab on ground)
The floor has the prescribed construction and is assumed to be above a 0,50 m layer of soil. The properties of the soil are not specified. Taken is:

- thermal conductivity = 1,75 W/(m.K)
- Specific mass = 1500 kg/m^3
- Specific heat = 1500 J/(kg.K)

Assumption for the heat loss:
Internal zone temperature = 20 ^oC - constant during the year
External temperature during the year = 9,1 ^oC with minimum 0,6 ^oC and maximum 16,8 ^oC.

Calculated heat loss through the floor according to ISO-13370 (slab on ground):

Q_{floor} = 1,76 + 0,86 cos (arg)

With

Arg = argument, that is a function of time of the year.

Soil properties have some influence on this heat loss [5].

Convective Surface Coefficients

The internal convective surface coefficients are assumed to be 3,0 W/(m^2.K); the external convective surface coefficients are assumed to be 18,0 W/(m^2.K).

Radiative Surface Coefficients

The radiative surface coefficients are calculated based on mean temperature, view factors and infrared emittance.
External sky radiation is calculated based on clouds cover, vapour pressure (location Arnhem – the Netherlands)

Pre-conditioning period

A weather file of 14 days is available: April 17, 2005 till April 30. VA114 works with a pre-conditioning period of 42 days. Normally 42 days before the starting date is taken. Now this is not possible, therefore 42 times the first day (April 17) is taken.

Comments/assumptions with respect to test case DSF100

The zones 2, 3 and 4 are equipped with a 100% convective heating and cooling device. The capacity of these devices are assumed to be infinite.

The control temperature is the air temperature.

The set point of this device is:

- heating set point 20 °C
- cooling set point 20 °C

Comments/assumptions with respect to test case DSF400

The volume of zone 2 is 143,68 m^3; the exhaust air flow rate corresponds to an air exchange rate of 15,0 (=0,5987 m^3/s = 2155 m^3/h).

The internal convective surface coefficients in zone 1 are unchanged: 3,0 W/(m^2.K).

Comments/assumptions with respect to test case DSF200

The size of the top and bottom openings is 0,75 m^2 each:

3 x free opening area (0,20 m^2) + 2 x side area of opening (0,075 m^2)

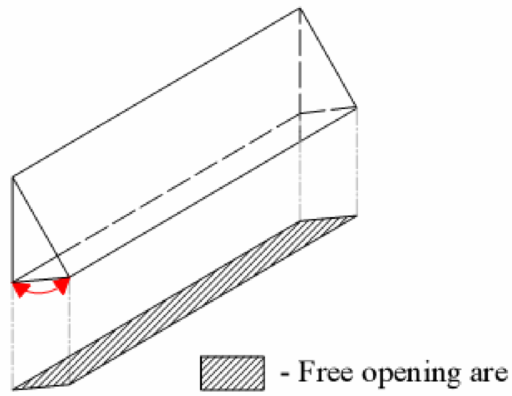


Figure 3. Free opening area

Wind pressure coefficients differ from the specs: the VA114-table is applied (source AIVC) . Moreover VA114 assumes coefficients for top and bottom openings are the same (see chapter 5); the specs prescribe different coefficients for top and bottom

The internal convective surface coefficients in zone 1 are unchanged: 3,0 W/(m^2.K).

4. Modelling Options

Applied modelling options.

Infrared heat exchange (see chapter 2)
Infrared heat exchange within a zone works with view factors between the internal surfaces and with emittances of that internal surfaces. The view factors are calculated with a detailed Ray-tracing method, which is applicable for all shapes of zones

Heat exchange between zone by airflow - ventilation (see chapter 2)
Air exchange takes place between ambient and the zone and between neighbouring zones. This air exchange is calculated according to a network node model (model vent2). Air flow by thermal buoyancy, wind pressure and wind fluctuations. Calculation is based on properties of openings (cracks, open windows, …), actual temperatures, wind velocity and wind direction.

Solar distribution over the internal surfaces (see chapter 2)
Direct radiation and diffuse radiation are treated separately.
For the direct radiation it is calculated which internal surfaces are hit; such a surface absorbs a part of that direct radiation and reflects the rest diffusely.
The direct solar distribution is calculated with a detailed Ray-tracing method, which is applicable for all shapes of zones
The distribution of the diffuse radiation (through windows and the reflected direct radiation by internal surfaces) is calculated by the view factors (see above) and by the reflections (= 1,0 – absorptance) of the internal surfaces.

Solar shading (see chapter 2)
External façade parts, own building parts and set back of window cause both shading of the direct solar radiation and shading of the diffuse solar radiation. The direct shading is calculated by a detailed Ray-tracing method, which is again applicable for all shapes of zones.
Surrounding buildings can be submitted (input) to the program as external façade parts too. In that way both shading of the direct solar radiation and shading of the diffuse solar radiation is calculated.
For the diffuse shading a detailed Ray-tracing method is applied.

5. Modeling Difficulties

Window modelling (all DSF-cases)

The window can be modelled in several ways:

- as one construction (glazing and frame combined - method fg0)
- as two constructions (glazing and frame separately); 3 ways are distinguished:
    - frame one part, each of the 12 glazing parts separately (method fg1)
    - frame one part, glazing one part – both height and width of glazing smaller than window dimensions (method fg2)
    - frame one part, glazing one part – height of glazing same as window height, width of glazing smaller than window width (method fg3).

Each method has its advantages and disadvantages:

- method fg0 is easy to model, but window surface temperature (= mix of glazing and frame temperature) differs from the glazing temperature (a required output result)
- method fg1, fg2, fg3 require more detailed input, but give the right glazing temperatures
- method fg3 has the window openings at the right height; important in modelling thermal buoyancy.
- …..

Method fg3 was selected

Figure 1: : frame (f) and glazing (g) separated

```
 ----------------------------
|     |                |     |
|     |                |     |
|     |                |     |
|     |                |     |
|frame|    Glazing     | frame|
|     |                |     |
|     |                |     |
|     |                |     |
 -----------------------------
```

Modelling of internal window (all DSF-cases)

The internal window model used by VA114 was improved since the former tests: the real optical properties of the glazing part (the real transmission and the real absorption in the panes) are taken into account :

- transmission of solar radiation = Trsm
- absorption in the glazing panes = Abs,i
- reflection of solar radiation = 1 – Trsm – Sum(Abs,i)
- Angular Modifier (AM) = 1,0

The transmission Trsm and the absorptions Abs,i are derived from the g-value, the C_f-value and the U-value.

Modelling of window openings (DSF200-cases)

In VA114 per window 2 openings can be defined, each with their own dimensions and position within the glazing area.

Figure 2: : Window can have 2 openings

```
 ----------------------------
|   ------                   |
|  |      |                  |
|   ------                   |
|                            |
|                ----        |
|               |    |       |
|                ----        |
 -----------------------------
```

In test case DSF200 the bottom openings have the same size as the top openings:
0,75 m^2 (3 x 0,20 m^2 + 2 x 0,075 m^2)

In figure 2 the glazing dimensions and the position of both openings are given.

Figure 2: Glazing dimensions and position of both openings

```
  -----.-----2,965-----.------
 |     | ============= |      |
 |     | | 2,50*0,30 | |      | Height 5,060 - 5,360
 |     | ============= |      |
 |     |               |      |    ^
 |     |               |      |    | difference 4,990
 |Frame|   Glazing     |Frame |    |
 |     |               |      |    v
5,450  |               |      |
 |     | ============= |      |
 |     | |           | |      | Height 0,080 - 0,038
 |     | ============= |      |
  -----.---------------.------
 <- - - - - - 3,555 - - - - - >
```

Each of the two openings is modelled by two “cracks”:
Length of cracks = width of opening
Height of crack1 = 0,28 * height of opening
Height of crack2 = 0,72 * height of opening
C-value of cracks = 0,40 * height of opening
Discharge coefficient used in the determination of C-value is 0,61 in stead of the prescribed 0,65. Discharge coefficients for supply and exhaust openings are the same.

Window openings are fully open and not controlled. All restrictions (window is not allowed to open) are excluded, so the window is open 24 hours a day.

Modelling of airflow

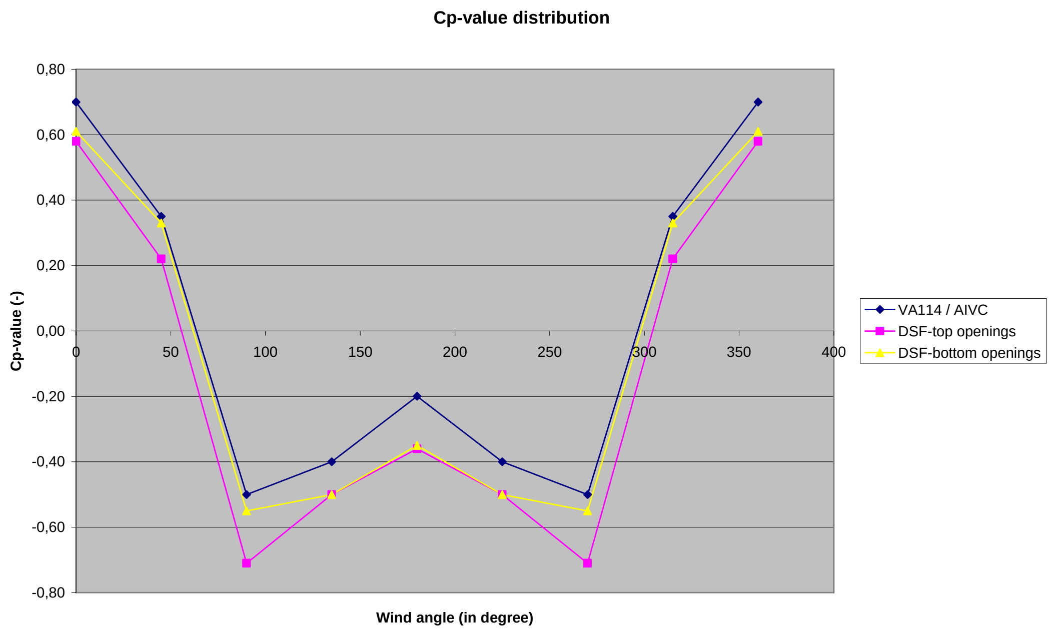
Air flow is calculated based on actual wind speed and wind direction, the actual ambient temperature and the zone temperature of the former time step (Tzone (hour-1))

Calculation of air flow is only possible in case cracks are present in all zones. So very small cracks (negligible small) were introduced in each zone.

Wind pressure coefficients

In the DSF-test specifications the Cp-values of the top openings are different from those of the bottom openings. VA114 have one Cp-value on a façade, so Cp-values for top and bottom openings are the same.
VA114 makes use of the AIVC-table; values in that table are different from the DSF-table (See figure 3). Cp-values are available for each 45 degrees; rather rough. Interpolation between these values was done.

Figure 3: Wind pressure coefficients according to specs and according to VA114-table



Downward and upward flow separate in the output

How to distinguish? Driving forces are buoyancy and wind. Wind by pressure drop and by wind fluctuations. In the VA114-model the wind pressure difference = 0,0: openings are on the same façade (so wind pressure coefficients are independent on the height).

Observed air flows:

- Air flow in occurs at the bottom openings (through both “cracks”) and air flow out at the top openings (through both “cracks”) – see figure 4a.
- In some cases in- and outflow occurs both at the bottom and top openings (one “crack” in, second “crack” out) - see figure 4b.
- It also happens air flow in occurs at the top openings and air flow out at the bottom openings – see figure 4c.

Figure 4a: In- and outflow, upward flow

```
    -------------
   |             |
 /  ⇓ 630       |
   | ⇓ 600       |
   |             |
   |     ^       |
   |     |  1230 |
   |             |
   |             |
 /  ◊ 600       |
   | ◊ 630 kg/h |
    -------------
```

Figure 4b: In- and outflow, upward and downward flow

```
    -------------              -------------
   |             |            |             |
 /  ⇓ 400       |           /  ◊ 400       |
   | ◊ 200       |            | ⇓ 200       |
   |             |            |             |
   |     | ^     |            |     | ^     |
   |200? v | 400?|            |400? v | 200?|
   |             |            |             |
   |             |            |             |
 /  ⇓ 200       |           /  ◊ 200       |
   | ◊ 400 kg/h |             | ⇓ 400 kg/h |
    -------------              -------------
```

Figure 4c: In- and outflow, downward flow

```
    -------------
   |             |
 /  ◊ 210       |
   | ◊ 200       |
   |             |
   |     |       |
   |     v   410 |
   |             |
   |             |
 /  ⇓ 200       |
   | ⇓ 210 kg/h |
    -------------
```

In situation 4a there is a resulting upward flow (+) and in situation 4c a resulting downward flow (-). In both situations the resulting flow is equal to the amount of fresh ambient air that is entering. In situation 4b the resulting flow is upward (+200 kg/h) in the left figure and down ward in the right figure (-200 kg/h); but both different from the amount of fresh air that is entering (600 kg/h).

In the results the fresh air amount should be given, but giving that amount with a '+' or '-' sign to indicate upward or downward flow results in a jump from + to – in the air flow plot.

So it is not easy to give upward and downward flow separately in the output.

<u>Remark:</u> in the DSF the real air flows can/will be higher than the fresh air amount because of recirculation in the DSF.

6. Software errors discovered and/or Comparison between different versions of the same software.

The following software errors were discovered and corrected.

The internal window model

It was found the internal window model was too simple:

- transmission = g-value
- absorption in the panes = 0,0
- reflection of the window = 1,0 – g-value
- Angular Modifier = 1,0

The internal window model used by VA114 was improved: the real optical properties of the glazing part (the real transmission and the real absorption in the panes) are taken into account :

- transmission of solar radiation = Trsm
- absorption in the glazing panes = Abs,i
- reflection of solar radiation = 1 – Trsm – Sum(Abs,i)
- Angular Modifier (AM) = 1,0

The transmission Trsm and the absorptions Abs,i are derived from the g-value, the C_f-value and the U-value.

The sub model for air flow by wind fluctuations

In Appendix AA this model is described.

In the original version the wind coefficient C_1 was 0,01 and the wind velocity was the wind velocity at roof height. The way of sheltering had no influence on the velocity in the window opening.

After studying literature it was found the C_1 is dependent on the way of sheltering (exposed C_1= 0,004 , semi-exposed C_1= 0,002 , sheltered C_1 =0,001) and the wind velocity should be the wind at a local weather station. The model was revised for those points.

7. Results

DSF100_2

The results of test case DSF100_2 are given in file "Output Results DSF100_2-20070625.xls": 14 days with hourly results for the specified output parameters.

Totals during the 14-day's period:

Heating	25 kWh
Cooling	-164 kWh

Peak power used:

Heating	0,43 kW
Cooling	-2,54 kW

Net solar gain:

Incident on the DSF	905 kWh
Solar transmitted to zone 1	614 kWh
Solar transmitted to zone 2	257 kWh
Absorption by internal window	130 kWh

Extreme temperatures:

Maximum zone 1	31,0 ^{o}C
Minimum zone 1	4,3 ^{o}C
Mean zone 1	14,6 ^{o}C

DSF400_3

The results of test case DSF400_3 are given in file "Output Results DSF400_3-20070625.xls": 14 days with hourly results for the specified output parameters.

Totals during the 14-day's period:

Heating	2678 kWh
Cooling	- 4 kWh

Peak power used:

Heating	15,43 kW
Cooling	-1,67 kW

Net solar gain:

Incident on the DSF	905 kWh
Solar transmitted to zone 1	614 kWh
Solar transmitted to zone 2	257 kWh
Absorption by internal window	130 kWh

Extreme temperatures:

Maximum zone 1	20,1 ^{o}C
Minimum zone 1	-0,9 ^{o}C
Mean zone 1	8,6 ^{o}C

DSF200_3

The results of test case DSF200_3 are given in file "Output Results DSF200_3-20070625.xls": 14 days with hourly results for the specified output parameters.

Totals during the 14-day's period:

Heating	33 kWh
Cooling	- 147 kWh

Peak power used:

Heating	0,48 kW
Cooling	-2,36 kW

Net solar gain:

Incident on the DSF	905 kWh
Solar transmitted to zone 1	614 kWh
Solar transmitted to zone 2	257 kWh
Absorption by internal window	130 kWh

Extreme temperatures:

Maximum zone 1	22,7 ^{o}C
Minimum zone 1	-0,2 ^{o}C
Mean zone 1	9,5 ^{o}C

DSF200_4

The results of test case DSF200_4 are given in file "Output Results DSF200_4-20070625.xls": 14 days with hourly results for the specified output parameters.

Totals during the 14-day's period:

Heating	33 kWh
Cooling	- 147 kWh

Peak power used:

Heating	0,48 kW
Cooling	-2,36 kW

Net solar gain:

Incident on the DSF	905 kWh
Solar transmitted to zone 1	614 kWh
Solar transmitted to zone 2	257 kWh
Absorption by internal window	130 kWh

Extreme temperatures:

Maximum zone 1	22,3 ^{o}C
Minimum zone 1	-0,2 ^{o}C
Mean zone 1	9,3 ^{o}C

8. **Other** (optional)

Solar on a clear sky

During the former tests it was observed the solar intensity on the horizontal and the solar height have their maximum not at the same time. See figure 8.1. There was a shift of about 10 minutes.

Our question was: Is the time during the measurements OK??

At the meeting in Golden (March 2007) it was mentioned the solar data was not for the location Aalborg (57,05 degree North and 9,93 degree East), but for the location Varlose, Copenhagen (55,77 degree North and 12,32 degree East). Calculations are done now for the right location (Copenhagen). Figure 8.2 shows no shift between solar intensity and solar height.

Figure 8.1: Solar intensity on the horizontal and solar height on a clear day - normalized
Calculations for the location Aalborg, the wrong location

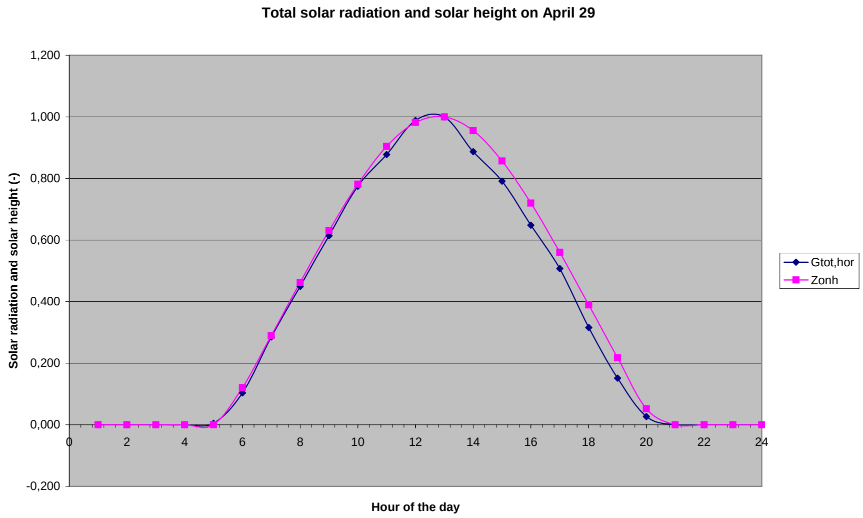
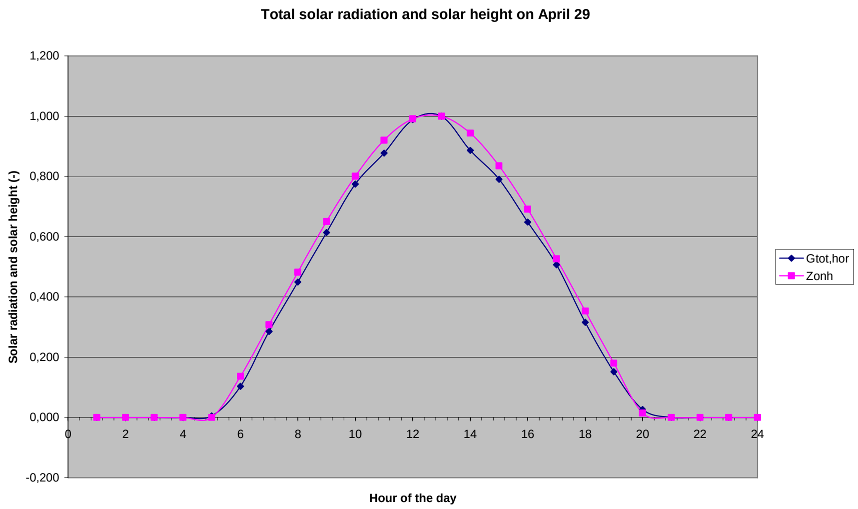


Figure 8.2: Solar intensity on the horizontal and solar height on a clear day
Calculations for the location Varlose, Copenhagen, the right location



Window modelling: glazing and frame combined or separated

The window can be modelled in several ways:

- as one construction (glazing and frame combined - method fg0)
- as two constructions (glazing and frame separately); 3 ways are distinguished:
  - frame one part, each of the 12 glazing parts separately (method fg1)
  - frame one part, glazing one part – both height and width of glazing smaller than window dimensions (method fg2)
  - frame one part, glazing one part – height of glazing same as window height, width of glazing smaller than window width (method fg3).

- Method fg0: glazing and frame combined

```
 ----------------------------
|                            |
|                            |
|                            |
|                            |
|                            |
|                            |
|                            |
|                            |
|                            |
 ----------------------------
```

- Method fg1: glazing and frame separately – 12 glazing parts separately

```
 ============================
||        |  |       |  |        ||
|============================|
||        |  |       |  |        ||
||        |  |       |  |        ||
|============================|
||        |  |       |  |        ||
||        |  |       |  |        ||
|============================|
||        |  |       |  |        ||
 ============================
```

- Method fg2: glazing and frame separately – shape 1

```
 ----------------------------
|                            |
|   ---------------------    |
|  |                     |   |
|  |                     |   |
|  |                     |   |
|  |                     |   |
|  |                     |   |
|   ---------------------    |
|                            |
 ----------------------------
```

- Method fg3: glazing and frame separately – shape 2

```
 ----------------------------
|     |               |      |
|     |               |      |
|     |               |      |
|     |               |      |
|     |               |      |
|     |               |      |
|     |               |      |
|     |               |      |
|     |               |      |
 ----------------------------
```

Sensitivity was determined for case DSF100_2. Results can be found in the table below.

Table 2: Influence window model on heating/cooling in zone 2

Window model used	Heating load	Cooling load
Fg0	35 kWh	144 kWh
Fg1	28 kWh	153 kWh
Fg2	25 kWh	164 kWh
Fg3	25 kWh	164 kWh

Conclusion: Influence is not negligible

Discussion:

Model Fg0 is too rough; in the output surface temperatures of window are not glazing temperatures, but a mix between temperature of glazing temperature and frame temperature.

Model Fg1 is very detailed (12 glazing parts in a frame); in the output surface temperatures are glazing temperatures of each of the 12 parts. Shading and internal distribution of solar radiation is calculated all right. The simulation takes considerable more calculation time.

Model Fg2 and Fg3 are of sufficient detail; in the output temperatures are glazing temperatures of the one glazing part. Shading and internal distribution of solar radiation is calculated (we think) sufficient good.

In the further tests model Fg3 was taken, but we should keep in mind the difference between model Fg3 and Fg1.

Diffuse circum solar treated as beam or treated as diffuse radiation

In VA114 diffuse circum solar radiation, impinging on a window is treated as beam radiation, whereas other models treat this component as diffuse radiation. This assumption has influence on the shading, the transmitted solar, the distribution of the solar radiation in the zones, the exchange of solar radiation through internal windows.

With VA114 the influence of this assumption on the results has been studied for case DSF100_2. Table 3 gives the results.

Table 3: Influence of the treatment of diffuse circum solar radiation

Diffuse circum solar treated as	Heating load	Cooling load
Beam	24 kWh	162 kWh
Diffuse	25 kWh	164 kWh

Conclusion: Influence on the heating/cooling load is not so big.

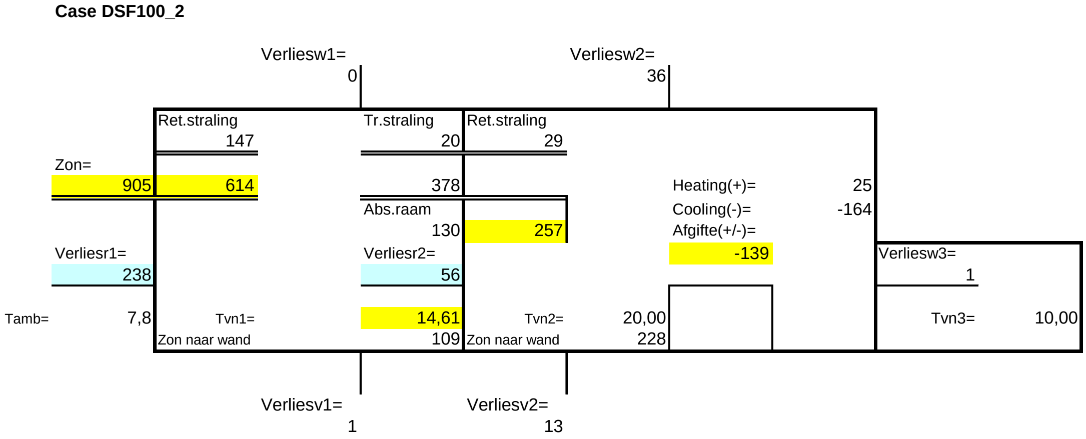
In the rest of this study the diffuse circumsolar will be treated as diffuse, because solar radiation outputs (beam totals and diffuse totals) will then be compatible with the outputs of the other programs.

DSF100_2

A spreadsheet was made to check the heat balance of the entire test cell.

In figure 8.3 an impression is given. The temperatures in this figure are average values over the entire period.

Figure 8.3: Heat fluxes in the test cell over the entire period (14 days) – case DSF100_2



Final remark:

VA114 has an option to simulate the DSF not as separate zone, but as a single, ventilated component. Ventilation can be done in all thinkable ways. These simulations are not done yet, but can be done in future.

9. Conclusions and Recommendations

VABI Software BV does developments on the Building simulation program VA114. The program was subjected to the new IEA34/43 DSF-tests [4].

In this modeller report information about the program, about the tests and about the results are given.

Last month 3 iterations (run, present results, compare results, draw conclusions, modify model and/or specs, run again, …) were done.

These results should be considered as final results. They will be discussed at the next meeting in Glasgow – UK (October 2007)

10. References

[1] Judkoff, R and Neymark, J
"International Energy Agency Building Energy Simulation Test (BESTEST) and Diagnostic Method", IEA: SHC Task 12 / ECBCS Annex 21, February 1995.

[2] Soethout, L. L.
"BESTEST Kwalificatietesten uitgevoerd aan het gebouwsimulatieprogramma VA114, versienummer 1.35". TNO-rapport 98-BBI-R0830, mei 1998.

[3] Wijsman, A.J.Th.M.; Plokker, W.
"Eerste thermische gebouwsimulatieprogramma's ondergingen de keurmerktest". TVVL Magazine, augustus 1999.

[4] Kalyanova, O. and Heiselberg, P.
"Comparative Test Case Specification – Test cases DSF100_2, DSF200_3, DSF200_4 and DSF400_3", IEA: SHC Task 34 / ECBCS Annex 43, April 2007.

[5] Wijsman, A. J. Th. M.
"Ground heat losses according to ISO-DIS-13370 – sensitivity for soil properties", Note November 28, 2006.

[6] Wijsman, A. J. Th. M.
"Double Skin Façade – Modeler Report; Empirical Test cases", Vabi Software bv, June 2007.

Appendix A: Heat exchange by airflow

Model description

Air exchange takes place between ambient and the zone and between neighbouring zones. Air exchange occurs through cracks and other openings in walls. Processes that are responsible for these airflows are:

- thermal buoyancy
- wind pressure and wind fluctuations
- mechanical imbalance over a zone

In figure A.1 this is given schematically

```
             M-In          M-Out         M-In
               |             ^             |
           ----|-------------|-------------|------
          |    |        |    |    |        |      |
        <-|-   v        |         |        v   -  | ->
          |             |         |               |
Wind      |             |         |               |
=== >     |             |         |               |
          |            <.-    <- - - -            |
          |             |         |               |
      - - | - >    - - -.->      -.>             <|-
v         |             |         |               |      vv
--------------------------------------------------------------
```

Figure A.1: Airflows in a building

In subroutine "VENT" the airflows are determined. Three models are available:

- subroutine "VENT1":
  In- and exfiltration flows are calculated based on an empirical relation for the air exchange rate. Interzonal flows are user given. In case of mechanical imbalance these in- and exfiltration flows and interzonal flows are adjusted to obtain balance.
- subroutine "VENT2":
  In- and exfiltration flows and interzonal flows are calculated with a nodal network. Thermal buoyancy, wind pressure, wind fluctuations and mechanical imbalance are taken into account.
- subroutine "VENT3":
  Airflows are calculated by interpolation between data from a database (depending on wind velocity and wind direction, ambient temperature and zone temperatures).

Some more information about the models will be given now. All models use as wind velocity the wind velocity at roof height.

Wind velocity at roof height

Available is the wind velocity from weather tape. That wind velocity is measured at a height of 10 m in a flat, open terrain. The wind velocity used in the models is the wind velocity at roof height. With the local circumstances (flat open terrain / woods, hilly terrain, villages, suburbs / town centre) and the relations of DAVENPORT the wind velocity at roof height is determined:

```
IWVELD = 1  A.    Flat, open terrain
                  Vwindh = Vwind6 * (Height/  6.)**0.16

IWVELD = 2  B.    Woods, hilly terrain, villages, suburbs
                  Vwindh = Vwind6 * (Height/ 46.)**0.28

IWVELD = 3  C.    Town centre
                  Vwindh = Vwind6 * (Height/104.)**0.40
```

In these relations is Vwind6 the wind velocity at a height of 6 m in flat, open terrain. With relation A:

```
                  Vwind6 = Vwind10 * (6./10)**0.16
                         = 0.922 * Vwind10
```

- subroutine "VENT1"

In- and exfiltration flows are calculated based on an empirical relation for the air exchange rate. Interzonal flows are user given. In case of mechanical imbalance these in- and exfiltration flows and interzonal flows are adjusted to maintain balance. The so-called SIMPLE model.

Relation for the infiltration rate Fv (in times per hour):

```
      Fv = Fva + Fvb*Vwind + Fvc*Vwind**2
```

Fva, Fvb and Fvc are given by user input. Vwind is wind velocity at roof height.

In- and exfiltration flows follow from multiplying the infiltration rate with the volume of the zone. In principle the infiltration flow is equal to the exfiltration flow

The interzonal airflows are given by user input. In principle the interzonal air flow from zone I to zone J is equal to the interzonal air flow from zone J to zone I.

In case of mechanical imbalance above mentioned airflows are adjusted based on the air balance for that zone

- **subroutine "VENT2"**

In- and exfiltration flows and interzonal flows are calculated with a nodal network. Thermal buoyancy, wind pressure, wind fluctuations and mechanical imbalance are taken into account.
Method uses zone temperatures at the end of the last time step and ambient temperature, wind velocity and wind direction of the present time step. The so-called DETAILED model

In general:
The airflow through a crack is given by

$$Flow = L \cdot C \cdot DP^{1/N}$$

width

```
L  =  crack length
C  =  air leakage coefficient of crack.
N  =  1/power coefficient
DP =  pressure difference across crack
```

A crack is characterized by its C and N. Common value for N = 1,5

Required input parameters:

- crack length L
- characteristics (C and N) of crack
- height at which crack is positioned

Crack height is important for calculation of thermal buoyancy. For calculation of airflows because of wind pressure differences are required:

- wind pressure coeffients CD
- wind velocity at roof height
- wind direction

In general:

Wind pressure = CD * Pthrust

with

CD	= wind pressure coefficient
Pthrust	= thrust = 0.5 * Rho * (Vwind)**2
Rho	= specific mass of ambient air
Vwind	= wind velocity at roof height

The wind pressure coefficients are available in table A.1 – source AIVC.

With the local circumstances (exposed, semi-exposed, sheltered) , the building height (< 3 storeys, 4-6 storeys, > 6 storeys), building shape (ratio length/width), wind direction and orientation of the façade in which the crack is present the CD-value is determined

<u>Remark:</u> a window opening is modelled by 2 cracks. After calculation of the airflows through that window the flows are corrected for wind fluctuations. By these fluctuations the in- and outflow through this window opening increase.

Calculation method

From the air balances for the several zones (sum of entering air flows = sum of leaving air flows) the pressure in each zone can be determined.
The relation between flow and pressure drop across a crack is not lineair, which makes the solution not so easy. Therefore the relation between flow and pressure drop

$$Flow = L \cdot C \cdot DP^{1/N}$$

is made linear

$$Flow = CLP \cdot DP$$

with

$$CLP = L \cdot C \cdot DP^{(1/N-1)}$$

The calculation process is iteratively:

- make a first estimation of the pressures in the zones
- calculate the coefficients CLP
- calculate the pressures in the zones: the air balances over the zones give N-equations (the number of zones) with N-unknowns (the pressures in each zone). By matrix solving all pressures are known.
- calculate the coefficients CLP again
- and so on

The airflow through each crack can now be calculated based on the known pressures.

Table A.1: Wind pressure coefficients CD

Igeval	IWbw	IWdim	IWbst	IWvlk	1	2	3	4	5	6	7	8	9
1	1	1	1	1	.70	.53	.35	-.08	-.50	-.45	-.40	-.30	-.20
2	1	1	1	2	.70	.53	.35	-.08	-.50	-.45	-.40	-.30	-.20
3	1	1	1	3	-.60	-.60	-.60	-.60	-.60	-.60	-.60	-.60	-.60
4	1	1	1	4	-.40	-.45	-.50	-.55	-.60	-.55	-.50	-.45	-.40
5	1	1	1	5	-.10	-.25	-.40	-.50	-.60	-.50	-.40	-.25	-.10
6	1	1	2	1	.40	.25	.10	-.10	-.30	-.33	-.35	-.28	-.20
7	1	1	2	2	.40	.25	.10	-.10	-.30	-.33	-.35	-.28	-.20
8	1	1	2	3	-.60	-.55	-.50	-.45	-.40	-.45	-.50	-.55	-.60
9	1	1	2	4	-.35	-.40	-.45	-.50	-.55	-.50	-.45	-.40	-.35
10	1	1	2	5	-.10	-.30	-.50	-.55	-.60	-.55	-.50	-.30	-.10
11	1	1	3	1	.20	.13	.05	-.10	-.25	-.28	-.30	-.28	-.25
12	1	1	3	2	.20	.13	.05	-.10	-.25	-.28	-.30	-.28	-.25
13	1	1	3	3	-.50	-.50	-.50	-.45	-.40	-.45	-.50	-.50	-.50
14	1	1	3	4	-.30	-.35	-.40	-.45	-.50	-.45	-.40	-.35	-.30
15	1	1	3	5	-.08	-.19	-.30	-.40	-.50	-.40	-.30	-.19	-.08
16	1	2	1	1	.50	.38	.25	-.13	-.50	-.65	-.80	-.75	-.70
17	1	2	1	2	.60	.40	.20	-.35	-.90	-.75	-.60	-.48	-.35
18	1	2	1	3	-.70	-.70	-.70	-.75	-.80	-.75	-.70	-.70	-.70
19	1	2	1	4	-.60	-.63	-.65	-.68	-.70	-.68	-.65	-.63	-.60
20	1	2	1	5	-.18	-.32	-.45	-.53	-.60	-.53	-.45	-.32	-.18
210	1	2	2	1	.28	.18	.07	-.15	-.35	-.47	-.59	-.55	-.50
220	1	2	2	2	.39	.29	.18	-.22	-.60	-.53	-.46	-.37	-.28
230	1	2	2	3	-.60	-.59	-.58	-.60	-.61	-.60	-.58	-.59	-.60
240	1	2	2	4	-.53	-.55	-.56	-.56	-.56	-.56	-.56	-.55	-.53
250	1	2	2	5	-.18	-.31	-.43	-.43	-.42	-.43	-.43	-.31	-.18
26	1	2	3	1	.06	-.03	-.12	-.16	-.20	-.29	-.38	-.34	-.30
27	1	2	3	2	.18	.17	.15	-.08	-.30	-.31	-.32	-.26	-.20
28	1	2	3	3	-.49	-.48	-.46	-.44	-.41	-.44	-.46	-.48	-.49
29	1	2	3	4	-.45	-.46	-.46	-.44	-.41	-.44	-.46	-.46	-.45
30	1	2	3	5	-.18	-.29	-.40	-.32	-.23	-.32	-.40	-.29	-.18

```
- IWbouw   = 1 : low buildings (\< 3 storeys)
             2 : middle high buildings ( 4 - 6 storeys)
             3 : high buildings (> 6 storeys)
- IWdim    = 1 : length/width    1 : 1
             2 :                 2 : 1
- IWbeschut= 1 : exposed
             2 : semi-exposed
             3 : sheltered
- IWvlak   = 1 : at the long side
             2 : at the short side
             3 : roof angle < 10 degree
             4 : 10 degree < roof angle < 30
             5 : roof angle > 30 degree
- IWricht  = 1 :   0.0 degree
             2 :  22.5 degree
             3 :  45.0 degree
             . :  .... degree
            17 : 360.0 degree
```

Remark: coefficients for IWbouw=2 and 3 (middle high and high buildings) are not available at the moment.. It is assumed they are equal to the coefficient for low buildings IWbouw=1

Source:

Air Infiltration and Ventilation Centre Handbook: 'Air infiltration Calculation Techniques - an Application Guide' (Liddament, 1986).

Open windows

Modelling can again be done in the simple way (air flow by open window is user given) or in the detailed way (air flow by open window is calculated).

The model user should specify each window to open in each zone. In figure A.2 this is given schematically

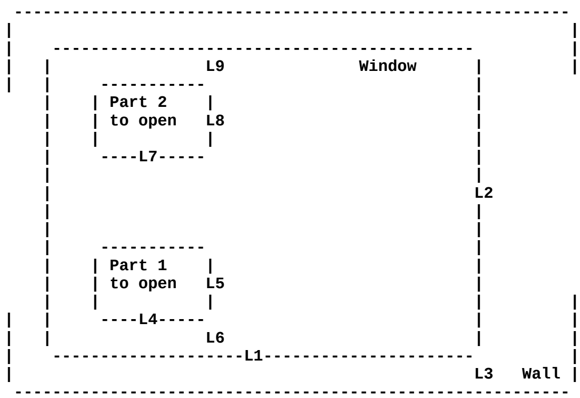


Figure A.2: Geometry of window parts to open

It should be specified what type of window opening it is:

- open it by moving in horizontal direction
- open it by moving in vertical direction
- …………

For each type of window opening in the model a translation is made to above shown geometry.

Each of the two openings is modelled as two cracks. Each crack has the following specs:

- crack length L
- characteristics (C and N) of crack
- height at which crack is positioned

And other …….

Control of window opening

Control of the window at day time operation and at night time operation can be selected independently.

General restrictions can be selected why windows are not allowed to be opened (danger for breaking in during weekend and night time, ambient noise during office hours). Also weather restrictions (too cold outdoors, too windy outdoors, ……) can be specified.

In case there are no restrictions windows open if indoor temperature Tzone comes above a given level (given by user input) and they close if temperature becomes below that temperature.

A window can have 5 opening positions between 0 % open (window is closed) and 100 % open (window at maximum position).

In time the position can be fixed (say for instance position 2) or variable (between position 1 and 5).

Variable window opening:

- if Tzone > Topen then window goes 1 position more open
- if Tzone < Topen then window goes 1 position more close.

Possible is for instance a fixed opening position at night time (people are not present) and a variable position at day time (people are present).

To prevent draught:
In case air velocity indoors comes above a certain level (given by user input) the window will go one position more close

<u>Remark:</u> Air flow by wind fluctuations through window openings is not modelled by other programs. Therefore in Appendix AA a description of the VA114-submodel is given.

Appendix AA: Air flow by wind fluctuations

Introduction

In IEA34/43 subtask E (DSF = Double Skin Facade) tests on Building Performance Simulations programs are conducted. One process that is tested is the ventilation of the DSF, i.e. the air flow through the DSF.

VA114's ventilation model takes 3 processes into account:

- air flow by thermal buoyancy
- air flow by wind pressure and by wind fluctuations
- air flow by mechanical imbalance over a zone

In appendix A all processes are described in short. Other participating programs take these processes also into account except air flow by wind fluctuations.

On request a short description of the sub-model for air flow by wind fluctuations is given in this memo.

Remark: VA114 works with one Cp-value for the entire façade, so in case there are no cracks or openings in one of the other walls the air flow by wind pressure will be 0,0.

The model for air flow by wind fluctuations

Wind on a single sided window opening, that is part of a further air tight zone, will cause an air flow through one half of the window opening the zone in and an air flow through the other half of the window opening the zone out. The mean velocity of the air is given by:

$$V_{oprm} = SQRT\ (C_1 * V_{wind}^2 + C_3) \qquad (1)$$

With

V_{oprm} = mean velocity of the air through the window opening to inside
V_{wind} = wind velocity at a local weather station

The coefficient C1 is depending on the sheltering:

- C_1 = 0,004 for exposed situations
- C_1 = 0,002 for semi-exposed situations
- C_1 = 0,001 for sheltered situations

The coefficient C_3 = 0,01; that means that in case there is no wind there is basic mean velocity of V_{oprm} = 0,1 m/s.

So at a wind of 0 m/s the V_{oprm} = 0,1 m/s; at a wind of 10 m/s the V_{oprm} = 0,33 m/s for a sheltered situation and 0,64 m/s.

During a gust of wind locally the wind will be higher: $V_{wind, max}$. And so the V_{oprm}:

$$V_{oprm,max} = SQRT\ (C_1*V_{wind,max}^2 + C_3) \qquad (2)$$

Moreover it is assumed:

$$V_{wind, max} = 2{,}0 * V_{wind} \qquad (3)$$

With the mean velocity V_{oprm} in the window opening the inflow and outflow can be calculated and in the same way the maximum inflow and outflow. Air flows by wind fluctuations.

In practice the window is not the only opening in the zone, so there will be a flow (an inflow or an outflow) through the window opening because of buoyancy, wind pressure and/or mechanical imbalance.

The air flow by wind fluctuations and the air flow by buoyancy, wind pressure and/or mechanical imbalance interact with each other. In case the latter is large with respect to the first the effect of the first (air flow by wind fluctuations) is negligible.

The model takes both air flows into account and calculates the resulting air flows. How that is done will not be discussed here.

Remark: The model is rather empirical and was set up by TNO from measurements in a rather (wind) shielded situation [1].

$$V_{oprm} = SQRT\ (C_1*V_{wind}^2 + C_2*H*dT + C_3) \qquad (4)$$

With

V_{oprm} = mean velocity of the air through the window opening to inside
V_{wind} = wind velocity at a local weather station
H = height of window opening
dT = temperature difference between inside and outside
C_1 = 0,001
C_2 = 0,0035
C_3 = 0,01

In VA114 the second term (buoyancy) is separately taken into account, so left out in formula.

The calculated air flow rates (by formula 4) act as 'guaranteed' minimum value for urban situations. These air flow rates will often be exceeded in more wind exposed situations. For those situations the wind coefficient C_1= 0,001 will be higher. On the analogy of Awbi [2], table 3.4, page 67, it was decided to take for exposed situations C_1=0,004 and for semi-exposed situations C_1=0,002.

Resume

This appendix describes the model of air flow by wind fluctuations. The model is rather simple and should be seen as a first step to take this effect into account.

[1] Phaff, J.C. , de Gids, W.F. et al
The ventilation of buildings. Investigation of the consequences of opening one window on the internal climate of the room, TNO report C448, March 1980.

[2] Awbi, H.B.
Ventilation of buildings. Air infiltration and natural ventilation (chapter 3), E & FN Spon, ISBN 0-419-15690-9.

Appendix B: Solar gain and solar exchange between zones

Model description

In subroutine "ZONINT" the solar gain and solar exchange between zones is simulated. In figure B.1 this is given very schematically.

```
          \                \              \
\   .----======----.------=======----.--=======---.
  \ |        \     |          \      |      \|    |
    ||         \   |            \|   |      -    ||
    ||\          \ ||           -   ||           ||
    ||  \|         ||               ||           ||
    |   -          ||\              ||            |
\   |              ||  \            ||            |
  \ |              ||    \|         ||            |
    ||             ||    -          ||           ||
    ||\            ||               ||           ||
    ||  \|         ||               ||           ||
    |   -          |                 |            |
    |              |                 |            |
    |              |                 |            |
    .--------------.-----------------.------------.
```

Figure B.1: Solar enters a zone by external windows and by internal windows. Windows can be present in the facades and in the roof.

It is calculated what fraction of the solar gain of a zone

- is used for the evaporation by plants
- comes sensible available to the air node
- comes sensible available to the walls; the distribution over all surfaces within the zone is calculated.

Direct and diffuse solar radiation are treated separately.

Steps in the calculation process:

. *calculation of the solar gain of a zone*

External windows:

```
SOMZON = Σ A(IV,IVLK)*TRANS(IV,IVLK)*
           (Amdir*Gdir(IV,IVLK)+Amdif*Gdif(IV,IVLK))
```

with

```
SOMZON      = solar gain
A           = area of the window
TRANS       = transmission of the window (incident angle 45°)
Amdir       = Angular Modifier-direct radiation (=1.000 at 45°)
Gdir        = intensity direct solar radiation on the window
Amdif       = Angular Modifier-diffuse radiation (at 58°)
Gdif        = intensity diffuse solar radiation on the window
```

Internal Windows:
The solar radiation, that enters the zone by internal windows is added to the solar gain SOMZON.

. *calculation of the latent and the sensible part of the solar gain*

Latent part (evaporation by plants)
```
SOMZONV     = VZON(IV) * SOMZON
```

Sensible part
```
SOMZONS     = (1.0 - VZON(IV)) * SOMZON
```

The fraction VZON is an input of the model.

. *calculation of the convective part and the radiative part*

Convective part (to the air node)
```
QZONL(IV) = CZON(IV)     * SOMZONS
```

Radiative part (to the wall surfaces)
```
QZONW(IV) = (1-CZON(IV)) * SOMZONS
```

The fraction CZON is an input of the model.

. *Calculation of the internal distribution of the radiative part.*

Many models are available here, from very simple ones (100% goes to the floor) to very detailed ones.
For the calculation of the exchange between zones a detailed model, that calculates the actual solar distribution (so each time step) is applied.

Detailed model for the internal solar distribution

The distribution of the solar radiation is separately done for direct and for diffuse radiation and is dependent on the solar position, the geometry of the zone, the absorption / reflection of the internal surfaces bounding that zone.

Each window is treated separately.

The solar entering the zone by a window has two components:
- a direct component
- a diffuse component

Remark: a fraction FDIFRM of the direct radiation is converted into diffuse when it passes the window. The fraction FDIFRM is an input of the model (at this moment FDIFRM=0.0).
Remark: the circumsolair diffuse radiation component is treated as direct solar radiation

The internal distribution is calculated in subroutine ZABSVLK: the fraction of the radiative part of the solar gain that is absorbed by each surface. The part absorbed by the surface of a window is assumed to pass that window (to outdoors or to a neighbouring zone) for 100 %.

The direct component

Subroutine PZONI2 calculates, based on the solar position, what internal surface(s) receive direct radiation, that enters the zone by a specific window. A fraction (= absorption coefficient) of this direct radiation is absorbed, the rest (1-absorption) is diffuse reflected.
Remark: in case the internal surface is an internal window PZONI2 calculates also what internal surface(s) of the neighbouring zone recieve this direct radiation.
Remark: PZONI2 uses a Ray-tracing method; shading by external facade parts, by own building parts and by window setback is integrated in this method.
Remark: for simpler cases (rectangular zones; no internal window) subroutine PZONI0 (100 % of the direct radiation hits the floor) and subroutine PZONI1 (a projection method, that calculates where the direct solar radiation hits the internal surfaces) are available.

The diffuse component

The calculation of the distribution of the diffuse radiation (diffuse entered by the windows + the diffuse reflected direct radiation) happens by exchange factors. These exchange factors FUFACA(IV,I,J) are derived from the view factors and the absorption coefficients of all internal surfaces.

Remark: the absorption coefficient of the surface of an internal window is assumed to be equal to the g_{value} of that window; so ($1-g_{value}$) is reflected by that window surface.
Remark: in case of internal windows the exchange between zones is calculated iteratively.

The result of this calculation is the solar absorbed by each internal surface.

Final Remark: as can be seen from figure 1 the following situations can occur:

- a beam of rays hits a part of an internal window
- a beam of rays hits more than one internal window
- several beams of rays hit the same internal window.

The model is able to handle these situations.

Appendix C: Solar shading

Model description

In subroutine "ZONEXT" the solar radiation on external surfaces is simulated. Based on the orientation of each surface and the known solar radiation on each orientation. Both the unshaded direct component (Gdir(IV,IVLK)) and the unshaded diffuse components (Gdif(IV,IVLK)) are known.

For solar shading a distinction is made between direct and diffuse solar shading

Direct solar shading
Direct solar shading happens by surrounding buildings (subroutine 'schaduw1'), by external facade parts, by own building parts and by setback of the window (subroutine 'schaduw2').

Shading factors:

Pschv1 (IV,IVLK)	surrounding buildings
Pschv2 (IV,IVLK)	external facade parts, own building parts, setback window

Remark: Factor = 0.0 is not shaded, factor = 1.0 is fully shaded
Remark: only windows have shading, shading of opaque walls is (until further notice) not taken into account

These factors are combined to one factor

Psch0(IV,IVLK) = 1. - (1.- Pschv1(IV,IVLK)) * (1. - Pschv2(IV,IVLK))

Diffuse solar shading
Diffuse solar shading by surrounding buildings is not taken into account; diffuse solar shading by external facade parts, by own building parts and by setback of the window is (subroutine 'schadw2d').

Shading factors:

Pschv1d (IV,IVLK)	surrounding buildings (is not taken into account, i.e. = 0.0)
Pschv2d (IV,IVLK)	external facade parts, own building parts, setback window

Remark: Factor = 0.0 is not shaded, factor = 1.0 is fully shaded
Remark: only windows have shading, shading of opaque walls is (until further notice) not taken into account

These factors are combined to one factor

Psch1(IV,IVLK) = 1. - (1.- Pschv1d(IV,IVLK)) * (1. - Pschv2d(IV,IVLK))

Solar radiation, shading included
The shaded solar radiation on external surfaces is given by:

Direct solar radiation	Gdir(IV,IVLK) = (1.0-Psch0(IV,IVLK)) * Gdir(IV,IVLK)
Diffuse solar radiation	Gdif(IV,IVLK) = (1.0-Psch1(IV,IVLK)) * Gdif(IV,IVLK)

Remark:
The circumsolar diffuse radiation component is treated as direct solar radiation.

More details about the mentioned models (subroutine Schaduw1, Schaduw2 and Schadw2d) is given below.

Direct solar shading by surrounding buildings
Direct solar shading by surrounding buildings is simulated in subroutine ‘schaduw1’.

<u>The method</u>
For a number of points on an external surface (see figure C.1.) the skyline is determined:
SKYH(IGR,IV,IPUNT)
This is done once and for each external surface.

```
5.----------------.4
 |                |
 |       .1       |
 |                |
2.----------------.3
```

Figure C.1: External surface with 5 points to determine shading

If the solar height at the given solar azimuth is below the skyline of a point then there is shading in that point (Psch = 1.0), if it is above there is no shading (Psch = 0.0).

The shading factor for that surface is the average shading factor of the 5 points.

Direct solar shading by external façade parts, own building parts and by setback of window
Direct solar shading by external facade parts, by own building parts and by setback of the window is simulated in subroutine ‘schaduw2’.

In figure C.2a and b the situation with obstructions is shown

```
 . . . . . . . . . . . . . . . . .
.                                .
.           Surface IVLK         .
.                                .
.           4.    1.-----------------------------.4  4.
.           /|    /              .              /    /!
.          / |   /        Obstruction 1        /    / !
.         /  |  .-----------------------------.    /  !
.        /   !  2                .            3   /   !
.       /    !                   .               /    !
.     3.     !                   .             3.     !
.      !     !                   .              !     !
.      !     !                   .              !     !
.      !Obs 2!                   .              !Obs 3!
.      !     !                   .              !     !
.      !     .1                  .              |     .1
.      !    /                    .              !    /
.      !   /                     .              !   /
. . . .!. /. . . . . . . . . . . .              !  /
       ! /                                      ! /
       !/                                       !/
      2.                                       2.
```

Figure C.2a: External obstructions (facade parts) – side view

```
  ----------------------------------------
 |                               .            |
 |       IV = 1                  .   IV = 2   |
 |                               .            |
 |       Surface IVLK            .            |
  ------==.==.==.==.==---------. . . . . . |
      \                          |            |
       \                         |            |
        \                        |   IV = 3   |
         \                       |            |
          \                      |            |
Obstruction  \                    -----------
```

Figure C.2b: External obstructions (facade parts) – top view

<u>The method</u>
The projections of all obstructions and all surfaces of the building on a plane perpendicular to the solar rays are determined. The overlap between the projection of an obstruction and the projection of a surface gives information about the shading:
- 'no overlap' means 'no shading'
- 'overlap' means 'shading'; the size of the overlap is a measure for the shading (0.0-1.0)

<u>Remark:</u> another new method uses Ray-tracing to determine the shading factor; at the moment it is only in use for windows and is integrated with the calculation method for the internal solar distribution. For this method the window is divided into 10x10 points.

Diffuse solar shading
Diffuse solar shading by external facade parts, by own building parts and by setback of the window is simulated in subroutine 'schadw2d'.

To the diffuse solar radiation belong the isotropic component, the component from the horizon and the ground reflection component. The circumsolar component is treated as direct solar radiation.

In figure 2a and b the situation with obstructions is shown

The method
The shading by an obstruction on a surface is determined by the view factor between that surface and that obstruction.

The shading by setback of the window follows from the sum of the view factors between that surface and the edges around that surface: Fschzyv(IV,IVLK)

The shading by own building parts follows from the sum of the view factors between that surface and the own building parts: Fschegd(IV,IVLK)

The shading by other facade parts (obstructions) follows from the sum of the view factors between that surface and the several obstructions: Fschbel(IV,IVLK)

Total shading::
```
      Fschdif = Fschzyv(IV,IVLK) + Fschegd(IV,IVLK) + Fschbel(IV,IVLK)
```

Appendix D: Solar processor of VA114

Introduction

In IEA34/43 subtask B1 (MZ = Multi Zone-non air) and subtask E (DSF = Double Skin Façade) tests on Building Performance Simulations programs are conducted, where the solar radiation impinging on the façade is the most important driving force. From first comparisons it seemed VA114 predicts a somewhat higher incident solar radiation on the façade starting from the same solar source on the horizontal surface. In this appendix the solar processor of VA114 is described in short to give the other task participants inside in that model. An earlier version of this appendix was distributed and reactions were gathered. A summary of these reactions is given. It did not lead directly to the cause, but the comments and suggestions given will be checked. That will be done in due time, but not as part of this IEA34/43 Task.

The description of VA114's solar processor

Solar position

Solar position is given by solar height (h) and solar azimuth (az). Both are calculated half way the hour.

Used formulas:

- hour angle OHM
  OHM = 2 * π / 24 * (12,5 – ST)

  with solar time ST
  ST = KL – DTIME
  In this formula
  KL = hour of the day
  DTIME = time shift in hours
  The time shift DTIME is given by
  DTIME = EQT/60 – (DLONGD/15 – ITIMEZ)
  with
  EQT = equation of time (in minutes); EQT depends on day of the year
  DLONGD = longitude of site (in degrees; East = positive)
  ITIMEZ = time zone (East = positive)

- Solar height H and solar azimuth AZ
  Sinus of solar height (sinh) and cosinus of solar azimuth (cosaz) are both calculated based on solar declination, latitude of site and hour angle OHM.

Splitting in Direct and Diffuse radiation

For IEA-34/43 MZ (subtask Multi-Zone Non air) the GH (Global radiation on the horizontal) and GBN (Normal Beam radiation) is given on tape. With sinus of solar height (sinh) follows for the GBH (Horizontal Beam radiation):

GBH = GBN * sinh

and for the GDH (Horizontal Diffuse radiation)

GDH = GH – GBH

For IEA-34/43 DSF (subtask Double Skin Façade) the GH (Global radiation on the horizontal) and GDH (Horizontal Diffuse radiation) is given on tape. For the GBH (Horizontal Beam radiation) follows:

GBH = GH – GDH

and with sinus of solar height (sinh) the GBN (Normal Beam radiation):

GBN = GBH / sinh

Remark:
GBN should be lower than a maximum value GBN,max that is based on the outer atmospheric normal radiation G0N and the air mass AIRM. Correction:

IF (GBN > (GBN,max +55,6)) THEN GBN = GBN,max

The corrected GBN results in a corrected GBH and with GDH = GH – GBH in a corrected GDH.

Splitting Diffuse on the horizontal in 3 components

The diffuse on the horizontal surface is split into 3 components based on Perez [1]:

- Isotropic component D1
  D1 = GDH * (1,0 – F1ACC)
- Circumsolar component D2
  D2 = GDH * (F1ACC / CZET)
- Component from the horizon D3
  D3 = GDH * F2ACC

With

F1ACC = new circumsolar brightness coefficient
F2ACC = horizon brightness coefficient
CZET = cosinus of zenith angle

Remark:
F1ACC and F2ACC should be both between 0,0 and 1,0; circumsolar (D1) has as maximum value of 500 W/m^2.
If not values F1ACC, F2ACC or D1 are given the limit value and components are recalculated.

Calculation of total solar radiation on a tilted surface

By geometric formulas the contribution of the direct component, the 3 diffuse components and the ground reflected component to the total radiation on the tilted surface are calculated.

The used formulas:

- Direct solar radiation:
  GBT = GBN*COS(Teta)
  With
  GBN = Normal Beam radiation
  Teta = angle of incidence of solar radiation on the tilted surface

- Diffuse isotropic radiation:
  GD1 = D1 * 0,5 * (1,0 + COS(Beta))
  With
  D1 = diffuse isotropic component on horizontal
  Beta = tilt of surface

- Diffuse circumsolar radiation:
  GD2 = D2*COS(Teta)
  With
  D2 = diffuse circumsolar component
  Teta = angle of incidence of solar radiation on the tilted surface

- Diffuse radiation component from horizon:
  GD3 = D3 * SIN(Beta)
  With
  D3 = diffuse component from the horizon
  Beta = tilt of surface

- Ground reflection:
  GRT = GH * RHO * 0,5 * (1,0 - COS(Beta))
  With
  GH = total radiation on the horizontal
  RHO = ground reflectivity
  Beta = tilt of surface

Total radiation on tilted surface:

GT = GBT + GD1 + GD2 + GD3 + GRT

<u>Remark</u>
VA114's solar processor is described. The big lines are given. If necessary more details can be provided, such as details about calculation of:

- equation of time EQT
- solar height and solar azimuth
- outer atmospheric normal radiation G0N
- Perez factors F1ACC and F2ACC; zenith angle ZET
- Angle of incidence of solar radiation impinging on the tilted surface
- ……..

Reactions and suggestions from participants

Valuable reactions were received from Joel Neymark (USA) and Paul Strachan (GB).

Joel Neymark

He read about the Perez 1987, 1988 anisotropic sky model in Duffie and Beckman (*Solar Engineering of Thermal Processes*, 1991) that there are a number of disagreements that could occur with respect to how the model details are implemented ...
e.g.

- for calculating circumsolar diffuse a maximum for cos(zenith angle) of cos(85) is shown (*remark VABI: VA114 takes that into account*).
- the implementation of the brightness coefficients could easily be different among modelers (for those using a Perez model).

Duffie and Beckman note that this Perez model generally predicts slightly higher total radiation on a tilted surface, so in the MZ work the VA114 results are consistent with that. Duffie and Beckman recommend Perez for surfaces with azimuth angle far away from 0 [which is common for many building vertical surfaces]

Paul Strachan

Most of the calculations looked OK to him.

One difference is that VA114 is using Perez 1987. Paul's program ESPr was updated to the Perez 1990 model (probably also used by TRNSYS-TUD and Energy+). His experience: it does make some difference, but not a huge amount.

Paul (ESPr) supplied detailed results on direct and diffuse radiation for the comparative tests concerning solar radiation on the façade. For the period April 17 - April 30 a comparison between ESPr and VA114 was made [2]:
- concerning the solar sum over the period:
  - Direct - VA114 is 1,4% higher than ESPr
  - Diffuse - VA114 is 4,2% higher than EPSr
  - Total - VA114 is 2,8% higher than EPSr
- daily plots show VA114 is somewhat higher in the peaks!!!

Paul suggested another possibility for comparisons: compare with the detailed solar processing analysis that used the EMPA data set.
It was published as:

Loutzenhiser P G, Manz H, Felsmann C and Strachan P A, Frank T and Maxwell G M Empirical Validation of Models to Compute Solar Irradiance on Inclined Surfaces for Building Energy Simulation, Solar Energy, 81(2), Feb 2007, pp 254-267.

All the measured data and the predictions are included on the IEA34/43 FTP site. Measured were direct normal as well as global horizontal and diffuse horizontal.

Other comparisons by Vabi Software BV

The solar results of the comparative and empirical DSF-tests were studied intensively. There were a lot of observations, concerning all programs [3]. But our conclusion about the VA114 solar processor is:

> On total radiation and direct radiation VA114 is close to the other programs.
> On diffuse radiation two groups of programs can be distinguished, a higher group and a lower group; VA114 belongs to the higher group and is the highest in that group.

So the differences are much smaller than was found from the earlier comparisons

Remark: information about what model assumptions other solar processors are using is not available at the moment. The individual Modeler's reports should provide that information. Not all Modeler's reports are available at the moment

Resume

In this appendix VA114's solar processor is described in big lines. Valuable reactions / suggestions were received from task participants. It did not lead directly to the cause of the differences, but the suggestions given will checked. That will be done in due time, but not as part of this IEA34/43 Task. Until now it was concluded the differences between VA114 and the other programs are much smaller than was found from the first, earlier comparisons

Literature

[1] Perez et all
"A new simplified version of the Perez diffuse irradiation model for tilted surfaces", Solar Energy Voume 30, No. 3, pp. 221-231, 1987.

[2] Wijsman, A
"Solar radiation VA114 versus ESPr", Excel sheet, June 12th, 2007

[3] Wijsman, A
"Solar radiation predicted by the several programs", May 31st, 2007

Appendix E: Questionnaire completed for the program VA114

GENERAL

1	**Program name and version number**	**VA114 – version 2.25**
2	**Name of organization performed the simulations**	**VABI Software bv**
3	**Name of person performed simulations and contact information**	**A. Wijsman** **Email: a.wijsman@vabi.nl**

4 Program status

☐ Freeware
X Commercial
☐ Other, please specify

5 Time convention for weather data: first interval in the weather input lasts 00:00-01:00, climate is assumed constant over the sampling interval

X Yes
☐ No, please specify

CALCULATION OF BOUNDARY CONDITIONS

6 Please specify the solar model for calculation of incident solar radiation
See appendix D to this Modeller report

7 Transmission of the direct solar radiation into zone 1

☐ Calculated with the constant solar heat gain coefficient (g-value)
☐ Calculated with the g-value as a function of incidence (function of incidence is fixed within code)
☐ Calculated with the g-value as a function of incidence (function of incidence is user defined)
X Other, please specify: Calculated with Transmission (as a function of incidence – user defined) and Absorption in the pane;

8 Transmission of the direct solar radiation into zone 2

☐ Treated as diffuse solar radiation and calculated with the constant g-value
☐ Calculated with the g-value as a function of incidence (function of incidence is fixed within code)
☐ Calculated with the g-value as a function of incidence (function of incidence is user defined)
X Other, please specify: Calculated with Transmission and Absorption in the panes; properties at angle of incidence of 45 degree

9 Transmission of the diffuse solar radiation into zone 1

☐ Calculated with the solar heat gain coefficient at the solar incidence 60^o
X Other, please specify: Calculated with Transmission (at solar incidence of 58 ^{o}) and Absorption in the pane.

10 Distribution of solar radiation to the surfaces in the zone 1

☐ Distributed equally to all surfaces
☐ Calculated according surface area weighting
☐ Calculated according to solar path and view factors
X Other, please specify: Different treatment for Direct and Diffuse solar radiation. Distribution of Direct solar is calculated by solar path; partly absorbed and partly diffuse reflected at surfaces that are hit. Distribution of Diffuse solar and Diffuse reflected Direct solar is calculated by absorption factors (based on view factors and absorption coefficients of the surfaces that are hit)

11 Distribution of solar radiation to the surfaces in the zone 2

☐ Distributed equally to all surfaces
☐ Calculated according surface area weighting
☐ Calculated according to solar path and view factors
X Other, please specify: same as distribution in zone 1

MODEL DEFINITIONS

12 Air temperature in the zone 1 is calculated as:

X One node temperature
☐ Few zones are stacked on the top of each other and the air temperature in each of zones is calculated, please specify number of stacked zones
☐ Other, please specify

13 Air temperature in the zone 2 is calculated as:

X One node temperature
☐ Few zones are stacked on the top of each other and the air temperature in each of zones is calculated, please specify number of stacked zones
☐ Other, please specify

HEAT EXCHANGE WITH EXTERIOR

14 External heat transfer coefficients

X Split radiative/convective
☐ Combined radiative/ convective
☐ Other, please specify

15 External heat transfer coefficients are calculated with identical assumptions for all surfaces (window frame, window glazing, walls etc.)

☐ Yes
X No, please specify : External heat transfer coefficients are not calculated (see external convection and external radiative heat exchange)

16 External convection

☐ Constant coefficients fixed within code
X User-specified constant coefficients
☐ Calculated within code as a function of orientation
☐ Calculated within code as a function of wind speed
☐ Calculated within code as a function of wind speed and direction
☐ Other, please specify

17 External radiative heat exchange

☐ Assumed to be ambient temperature
X Assumed to be sky temperature
☐ Other, please specify

HEAT TRANSFER WITHIN ZONES

18 Internal heat transfer coefficients

X Split radiative/convection
☐ Combined radiative/ convective
☐ Other, please specify

19 Internal heat transfer coefficients are calculated with identical assumptions in all zones and for all surfaces (window frame, window glazing, walls etc.)

☐ Yes
☐ No, please specify : Ixternal heat transfer coefficients are not calculated (see internal convection and internal radiative heat exchange)

20 Internal convection

☐ Constant coefficients fixed within code
X User-specified constant coefficients
☐ Calculated within code as a function of orientation (vertical/horizontal)
☐ Calculated within code as a function of temperature difference
☐ Calculated within code as a function of air velocity in the zone
☐ Calculated within code as a function of surface finishes
☐ Other, please specify

21 Longwave radiation exchange within zone

☐ Constant linearized coefficients
☐ Linearized coefficients based on view factors
X Linearized coefficients based on view factors and surface emissivities
☐ Nonlinear treatment of radiation heat exchange
☐ Other, please specify

WINDOW

22 Window

X Window frame and glazing are modelled as separate elements of construction; properties are user defined
☐ Window frame and glazing are modelled as separate elements of construction, but the total U-value is calculated within the code
☐ Window frame and glazing are modelled as separate elements of construction, but the total U-value and g-value are calculated within the code
☐ Other, please specify

23 Glazing temperature

☐ Calculated for 1 nodal point on the basis of fixed resistance
X Calculated dynamically, using the same scheme as for opaque elements
☐ Other, please specify

AIRFLOW MODEL

24 Discharge coefficient

X Fixed within the code
☐ User-specified fixed value
☐ Calculated by code, please specify what are the parameters involved in code calculations

☐ Other, please specify

25 Pressure difference coefficients

☐ Fixed within the code, identical for all openings sharing the same surface
X User-specified, identical for all openings sharing the same surface
☐ User-specified for every opening
☐ Other, please specify

26 Calculated mass flow rate in the model is a function of

X Buoyancy force
X Wind pressure
X Wind fluctuations
☐ Other, please specify

ESRU

Report

IEA SHC Task 34 / ECBCS Annex 43

Subtask E: Double Skin Facade

ESP-r Modeller Report

Comparative Test Cases

Paul Strachan

23rd July 2007

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1. Introduction

ESP-r, Version 11.3 of April 2007, was used for the modelling.

ESP-r is Open Source software. Authors are Energy Systems Research Unit, University of Strathclyde, Scotland, UK; Natural Resources Canada; and other groups and individuals.

The program is based on a finite volume approach, with user-selectable timesteps.

The tests reported here are based on the revised Comparative Test Specifications of June 2007.

2. Modelling Assumptions

Internal convection: it was assumed that buoyancy-driven convection correlations would be most appropriate for the internal surfaces of both the double façade and the test room in the case of the DSF100_2, DSF200_3, DSF200_4 cases. For the DSF400_3 case, the convection along the walls of the double façade was based on an equation given by Incropera and DeWitt for channel flow ($Nu = 0.023\ Re^{0.8}\ Pr^{0.7}$). For the prescribed mass flow rate, this gave a convection coefficient of 3.1 W/m^2K.

DSF100_2 case:
The double façade was modelled as a single zone: it was therefore assumed that the air was fully mixed. Given the likely complex flows that may exist in the façade, the alternative was to use CFD to model the temperature and air velocity distribution. This can be done in ESP-r, and a preliminary model was established, but results have not yet been submitted.

It was assumed that the double façade was perfectly sealed.

DSF200_3, DSF200_4 and DSF400_3 cases:
The double façade was modelled as 3 stacked zones to represent the temperature stratification. Tests in previous projects had indicated that 3 stacked zones were usually sufficient to represent the temperature gradient. Boundaries between the stacked zones were assumed to be essentially massless and fully transparent.

3. Modelling algorithms

Solar radiation
ESP-r uses the Perez 1990 anisotropic diffuse sky model for calculating diffuse radiation. Direct and diffuse transmission, glazing absorption and internal zone distribution are calculated separately. Ray tracing is used to allocate the direct solar transmittance to the appropriate internal surface for both the double façade and test room. Diffuse radiation passing through the window is allocated to surfaces not in the same plane as the window based on surface area and absorptivity. After the first bounce, direct radiation is treated as diffuse and added to the reflected diffuse radiation. This is iteratively spread to all internal zone surfaces based on the area and absorptivity (in the case of opaque surfaces) or the absorptances and transmittances (in the case of transparent constructions) until all radiation is accounted for.

Airflow
For the DSF200_3, DSF200_4, and DSF400_3 cases, the airflow is modelled using an airflow network approach, which is integrated with the thermal model so that the calculated airflows are based on nodal temperatures from the thermal model (as well as wind-driven pressures), and the resulting predicted airflows are used in the energy balances of the thermal simulation.

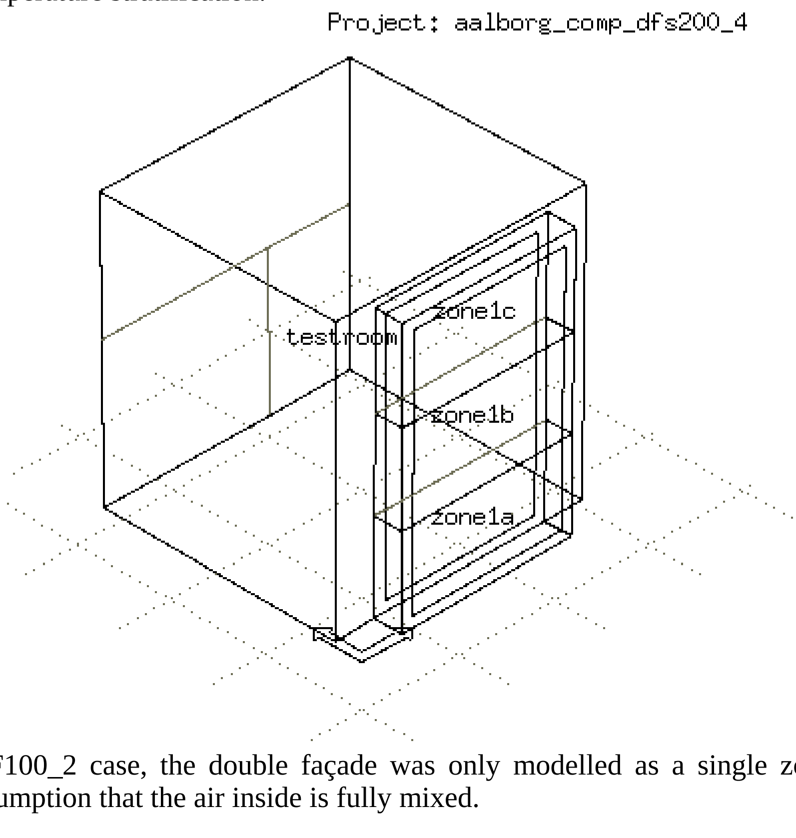
The network model is simple in this case – an internal node for each of the 3 stacked zones in the double façade and two external nodes at the top and bottom openings. The top and bottom openings were modelled using the orifice equation with user specified discharge coefficients (0.65 for both openings). Opening areas were given as $0.6m^2$ for the bottom and $0.6m^2$ for the top. Pressure coefficients were included as boundary conditions for the openings as given in the specifications. A wind speed reduction factor of 0.922 was included from the 10m wind speed to bring it down to the wind speed at the height of the double façade, which is the reference height for the specified pressure coefficients.

Convection and longwave radiation

These were calculated explicitly both internally and externally for all surfaces. In the case of convection, buoyancy correlations were used for the internal surfaces (except for the mechanically ventilated case when a channel flow correlation was used as explained above) and an algorithm based on correlations with wind speed and direction was used for external surfaces. For longwave radiation, external radiation was calculated based on estimates of sky and ground temperature, with all vertical surfaces assumed to have viewfactors of 50% to sky and 50% to ground. Internal viewfactors were explicitly calculated for the time-varying internal longwave radiation exchanges for both the double façade and test room.

4. Modelling Options

The building model for the DSF200_4 case is shown below, which is the same as for the DSF200_3 and DSF400_3 cases. The double façade was modelled as 3 stacked zones to represent temperature stratification.



For the DSF100_2 case, the double façade was only modelled as a single zone, with the resulting assumption that the air inside is fully mixed.

Glazing properties: as input, ESP-r requires the optical properties (transmittance and layer absorptances) at angles of incidence of 0, 40, 55, 70 and 80 degrees. For the single and double glazed units in the double façade, these were obtained using Window5 – the glazings specified were taken from the IGDB glazing database. For the single glazing the following values were used:

Angle	0	40	55	70	80
Solar transmission	0.726	0.702	0.656	0.532	0.318
Solar absorption	0.207	0.224	0.235	0.237	0.211

For the double glazed unit, values were as follows:

Angle	0	40	55	70	80
Solar transmission	0.560	0.539	0.488	0.344	0.167
Solar absorption outer	0.121	0.133	0.144	0.158	0.157
Solar absorption inner	0.163	0.163	0.152	0.123	0.070

Framing: this was lumped and modelled as a separate surface.

Simulation timestep: 15 minutes. Results data were post-processed to provide hourly averages.

5. Modelling Difficulties

ESP-r does not output the incident direct and diffuse or the solar altitude in the results file. Instead, the simulation trace facility was turned on, and the required data extracted by processing the output.

6. Software Errors Discovered and/or Comparison Between Different Versions of the Same Software

None.

7. Results

N/A

8. Conclusions and Recommendations

9. References

Incropera F P and Dewitt D P, 2002, Fundamentals of Heat and Mass Transfer, 5th Edition, John Wiley.

Window5, available from http://windows.lbl.gov/software/window/window.html

Modeler Report
IEA Task34/Annex43 Double façade test cases

Clemens Felsmann
Technical University of Dresden
Institute of Thermodynamics and Building Systems Engineering
July 24, 2007

Building Energy Simulation Software and Version(s):

The software tool of TRNSYS-TUD is a research code that was developed at the Institute of Thermodynamics and Building Systems Engineering of Technical University of Dresden (TUD) based on the frame of the former TRNSYS version 14.2. Modifications and developments at the original source code were necessary to stabilize calculation processes, to improve both user-friendliness as well as handling of the software and to extend fields of software application. In this context some new features have been added especially to the building model, as detailed long-wave radiation exchange, under-floor heating and thermally activated building systems, detailed solar distribution, internal windows, simple day lighting, etc. Also the ability to run with very little simulation time steps (seconds) was implemented. The realization of some of these features has been initialized by the IEA Task34/Annex43 software validation tests. The air flow model of TRNSYS-TUD originally based on COMIS but was also upgraded with some new features as for instance air flow model through large openings.

Building Model

The building model was built by dividing both Zone 1 (double skin façade) and Zone 2 (Cube) into 4 sub-zones each. Each of the sub-zones is represented by a single air temperature node. Sub-zones are stacked upon each other and are separated by fictitious walls. Due to this configuration temperature stratification could be modeled. The air temperature inside DSF reported in the output file is calculated based on the air temperatures of each of the stacked zones which have been weighted according to the specific air volumes of four sub-zones using the following equation:

$$\vartheta_{\mathrm{air,DSF}} = \frac{0.94\mathrm{m}^3 \times \vartheta_{\mathrm{air,DSF,1}} + 4.66\mathrm{m}^3 \times \vartheta_{\mathrm{air,DSF,2}} + 4.66\mathrm{m}^3 \times \vartheta_{\mathrm{air,DSF,3}} + 0.94\mathrm{m}^3 \times \vartheta_{\mathrm{air,DSF,4}}}{0.94\mathrm{m}^3 + 4.66\mathrm{m}^3 + 4.66\mathrm{m}^3 + 0.94\mathrm{m}^3}$$

The fictitious walls between stacked sub-zones are dimensionless, without any mass, and fully transparent. They also allow vertical air flow. The vertical airflow is calculated by the program depending on temperature and pressure conditions at the nodes of the airflow network assuming a large opening. A c_D-value of 0.5 was used for the simulations.

Figure 1 shows a grid of the building model.

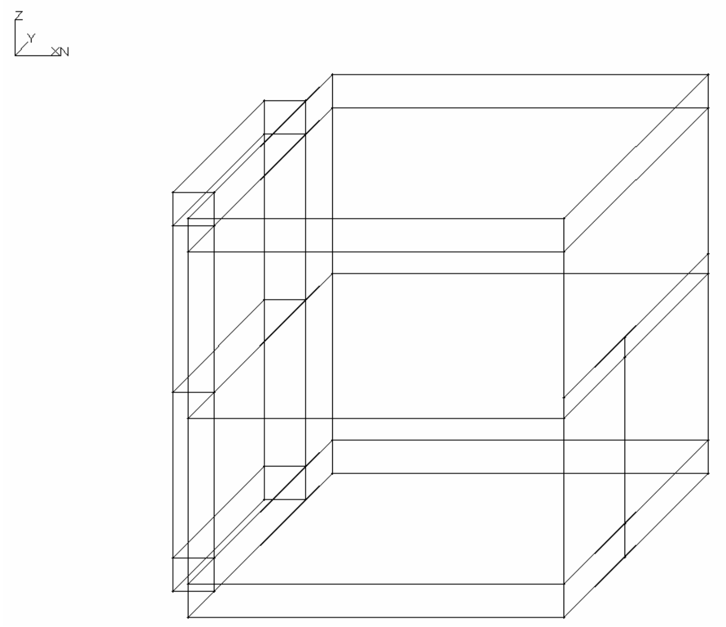


Figure 1: Building grid model

Optical and thermal properties of the glass (external and internal windows) have been calculated using WINDOWS 5.2a [1] and OPTICS 5.1[2]. IGDB identifiers were given in the specification. Figure 2 shows optical glazing properties as used for simulation in dependency on solar incident angle. This angle again depends on the sun's position at the sky and varies with time.

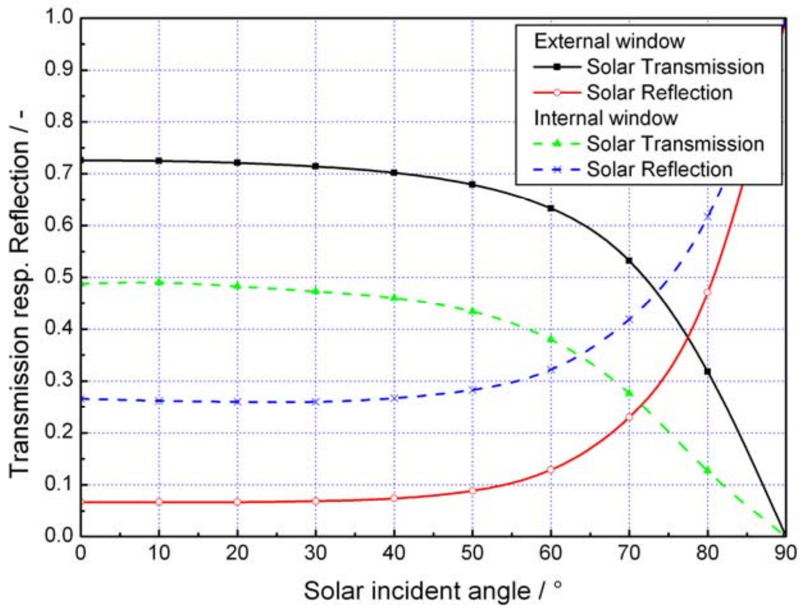


Figure 2: Optical glazing properties

Distribution of solar radiation within the zones is calculated in two steps:

1. At first direct solar radiation is distributed according to an algorithm that accounts for geometric relations between the sun's position and different locations of surfaces. Reflected parts of direct solar radiation were treated as diffuse.
2. Afterwards all diffuse radiation is distributed by an area weighted method.

Solar reflectance properties of surfaces have been calculated based on given spectral data. The normalized relative spectral distribution of solar radiation defined in prEN410 [3] and ISO9050 [4] was used to calculate a uniform reflectance value for all surfaces. Figure 3 shows spectral distribution defined in the relevant standards.

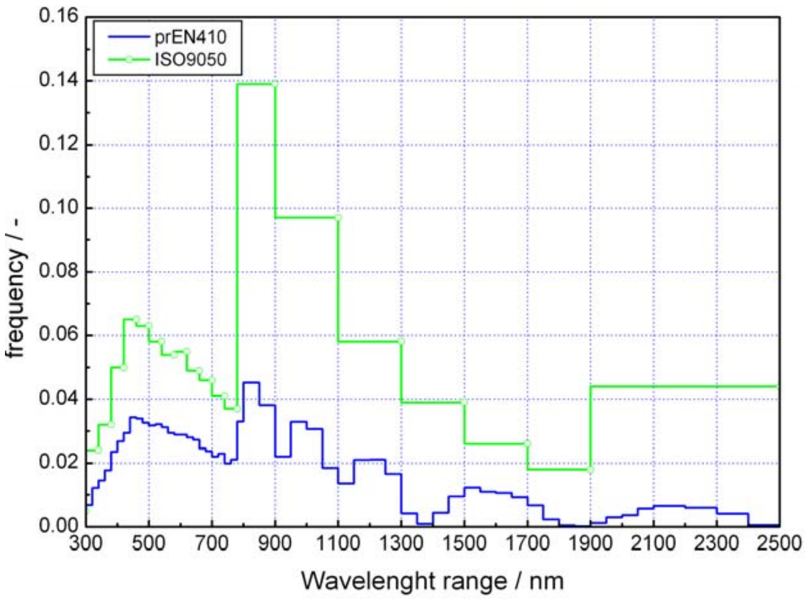


Figure 3: Frequency of solar radiation spectrum

The solar properties used in empirical simulations are as follows:

	Zone 1 (DSF)	Zone 2 (Cubus)
Solar Reflectance	78%	76 %
Solar Absorptance	22 %	24 %

Convective film coefficients have been fixed. Different values were chosen to model the impact of air flow on heat transfer.

External walls: 4.4 W/m²K (inside) 25 W/m²K (outside)

Roof / external window: 3 W/m²K (inside) 25 W/m²K (outside)

Floor: 3 W/m²K

Internal walls / internal window: 4.4 W/m²K (both sides)

Radiative heat transfer depends on view factors, emission properties and surface temperatures.

Test Case 100_2

All openings were closed. This test case was easily to simulate. The simulation time step was 0.1 hr = 6 min.

Test Cases 200_3 and 200_4

Free area of the openings had to be 0.6m² for both external and internal windows. The air flow model of TRNSYS TUD calculates area A of the openings in dependency on the angle α windows are opened as follows:

$$A=B \times H \times f(\alpha)$$

Here the function $f(\alpha)$ again depends on window construction. For these software validation exercises a function as depicted in Figure 4 was used. This function was found from a literature review.

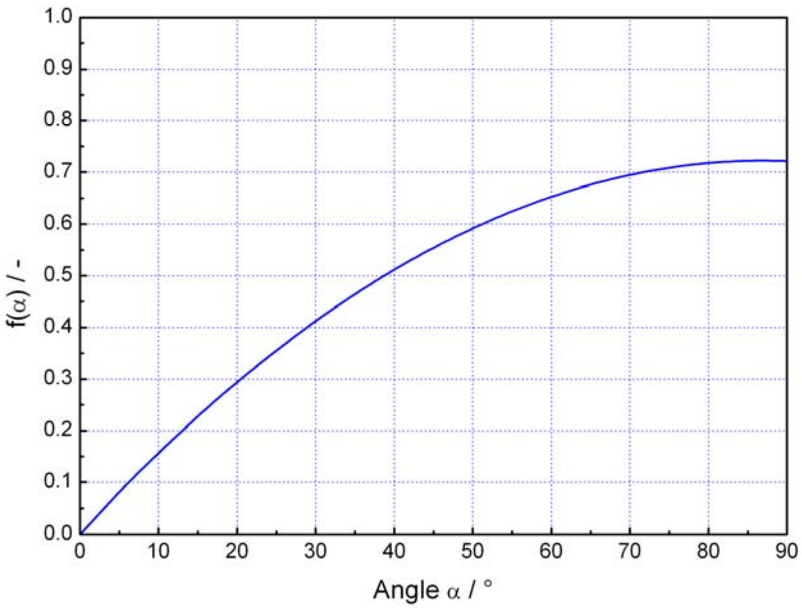


Figure 4: Correction of free area of openings

Using the curve above both external and internal openings have been assumed to be opened with an angle of about 26° to realize a free area as requested.

The simulation time step was 0.1 hr = 6 min.

Test Case 200_e

The simulation time step was 0.1667 hr = 10 min. A 24 hr period for preconditioning was defined. Detailed boundary conditions as provided for the ground and the adjacent zones have been used for simulation but no surface spectral data could be taken into account. Different from the wind profile described in the empirical test case specification a wind profile power law was used. Figure 5 shows a comparison between measure wind profile values and the power law approximation. The wind profile exponent was set to 0.34.

Due to the specified free area of openings windows were assumed to be opened at an angle of 16° (bottom opening) and 13.3° (top openings), respectively.

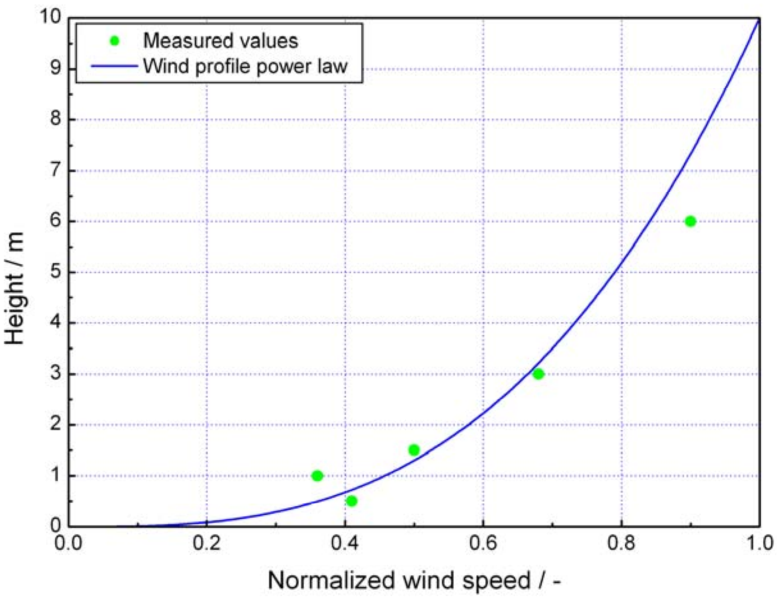


Figure 5: Comparison between measured values and wind profile power law

Test Case 400_3

Openings were assumed to be opened with an angle of 45°. Independent from this the air flow through the building was nearly fixed by defining a constant fan air flow.

The simulation time step was 0.1 hr = 6 min.

References

[1] WINDOWS 5.2a, 2005, Lawrence Berkeley National Laboratory (LBNL)

[2] OPTICS 5.1, 2003, Lawrence Berkeley National Laboratory (LBNL)

[3] prEN410: Glass in building - Determination of luminous and solar characteristics of glazing; German version EN 410:1998

[4] ISO9050: Glass in building - Determination of light transmittance, solar direct transmittance, total solar energy transmittance, ultraviolet transmittance and related glazing factors

Comparative Test Cases
Modeller Report

IEA ECBCS Annex 43/SHC Task 34
Validation of Building Energy Simulation Tools

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Index

1 Introduction

IDA Indoor Climate & Energy (ICE) is a dynamic, modular building simulation program. The current program version is 3.0. The program simulates a multi-zone building with an energy supply system and a ventilation system in a given climate. Temperatures, energy and mass flows and are outputs from the program. Also humidity and CO_2 fractions are calculated.

IDA is an object-oriented simulation environment designated to handle a wide range of different types of simulation problems. The systems to be simulated are decomposed into subsystems that are modelled using the Neutral Model Format (NMF). These models are then connected together to form a simulation model of the original system. The equation solver can solve most systems of differential-algebraic equations that can be formulated in NMF. Both steady-state and dynamic problems can be dealt with, as well as discontinuities in the solutions.

IDA systems exist on 3 different levels:

- Wizard level: The user fills in a form (or a few forms in turn) and starts a simulation. The user has no direct control over the physical or mathematical model of the simulated system.
- Physical level: The user builds a physical model of the simulated system, but has no direct control over the mathematical model.
- Mathematical level: The user directly builds the mathematical model of the simulated system. No physical model required.

The output from the simulations is on a building or a zone level and can be presented either as diagrams or reports.

The output from the simulations is on a building or a zone level and can be presented either as diagrams or reports.

Building level

- AHU temperatures in central AHU
- AHU airflows: Air flows through central AHU

- Plant temperatures: Boiler & chiller, in & out
- Power supplied by plant; Heat and cooling supplied by plant
- Purchased Energy Totals of purchased energy, by source: Electricity, primary energy
- Used energy Details of energy used: Central coils, local units, others
- Lost work Account of work hours; lost due to over or under heating
- Free energy, transmitted through zone envelope or generated within zones

Zone level

- Main temperatures; Air and operative temperatures
- Heat balance; Detailed heat balance for zone
- Air temperatures at floor and ceiling, in case of displacement ventilation.
- Fanger's comfort indices PPD, PMV
- Indoor Air Quality measures: ac/h, CO_2 level, humidity
- Daylight level at desktop (1st person)
- Directed operative temperatures
- Air flow in zone, in/out through internal/external walls or mechanical ventilation
- Airborne heat flow into zone; Airborne net heat flows into zone, through internal walls, envelope and mechanical ventilation
- Temps and heat balance in zone; Zone temperatures and summary of heat balance for the last day of simulation.
- Free energy transmitted through zone envelope or generated within zone

More information regarding the software can be obtained by:

EQUA

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E-mail: info@equa.se

Web: www.equa.se

2 Model description of IDA ICE 3.0

A comprehensive description of the models of IDA ICE for thermal simulation is given below. An extensive description of the program models (for version 1.02) is given by Bring et al. (1999).

2.1 External environment

Climate files gives hourly data of air temperature, relative humidity, wind direction, wind velocity, direct normal solar irradiation and diffuse horizontal solar irradiation.

2.2 Free stream wind velocity

The free stream air velocity, V, at the building height, H, is calculated from the air velocity of the climate file, V_{ref}, at the hight H_{ref} as (ASHRAE, 1997):

$V = a * V_{\mathrm{ref}} * (H / H_{\mathrm{ref}})^b$, where the wind profile coefficient, a, and the wind profile exponent, b, can be set.

2.3 Air pressure at ground level

The total air pressure at the ground level is calculated from: $P = P_{\mathrm{air}} + C * 0.5 * \rho * V^2$, where C is the wind pressure coefficient, P_{air} is the static air pressure, ρ is the air density and V is the free stream air velocity at building height level. C is interpolated from wind pressure coefficients supplied for the 8 main wind directions.

2.4 Longwave radiation exchange between façade and ambient

The difference between the ambient air temperature and the effective sky temperature is assumed to be constantly $T_a - T_{sky} = 5$°C. The ground is assumed to have the same temperature as the air. The net IR radiation from the façade surface to the ambient is calculated as $\varepsilon*\sigma*(T^4 - T_a^4) + F*\varepsilon*\sigma*(T_a^4 - T_{sky}^4)$, where F is the view factor to the sky, ε is the emittance and T is the temperature of the façade surface.

2.5 Outdoor surface convection coefficient

The external convection heat transfer coefficient is calculated from (Clarke, 1985):

$h_c = 5.678 * (a + b * (V_{loc} / 0.3048)^n)$, where V_{loc} is the local wind velocity. On the windward side of the building, $V_{loc} = \max(0.25*V, 0.5)$, and on the leeward side, $V_{loc} = 0.3 + 0.05*V$, where V is the free stream velocity at building height level. For $V < 4.88$ m/s, a, b and n are 1.09, 0.23 and 1, respectively, otherwise they are 0, 0.53 and 0.78.

2.6 Solar irradiation

Three models are available for calculating the diffuse solar irradiation on the façade surface: ASHRAE (1997), Kondatjev (1977) and Perez (1990). The ASHRAE (default) method calculates diffuse irradiation and ground reflected irradiation from view factors and ground reflectivity.

2.7 Zones

A building consists of an arbitrary number of zones. The air of a zone has one node with a heat capacity. The zone air can be chosen to have one temperature (well-mixed), a fixed temperature gradient or a calculated temperature gradient (for displacement ventilation). For a gradient, the air temperature next to a surface is interpolated between the air temperatures at the floor and ceiling levels. A zone surface is modelled with a uniform temperature.

2.8 Ground coupling

The temperature of the ground can be set by the user to a fixed value (default 10°C). Thickness and thermal properties of the layers outside and under the basement's walls and slab are specified. Default values are 0.1 m insulation (k = 0.036 W/mK) + 1 m soil (k = 1.0 W/mK).

2.9 Internal longwave radiation exchange

Longwave radiation heat exchange between internal surfaces is calculated with the net radiation method from emittance values and view factors.

2.10 Internal convective heat transfer coefficients

The internal convective heat transfer coefficient is calculated from inclination and temperature difference between surface and air (Brown, 1963). The model is based on measurements by Min et al. (1956).

2.11 Walls

Walls (including floor and ceiling) can be chosen to be divided into a number of nodes, each with a heat capacity and a heat resistance between adjacent nodes. An adiabatic wall model (for inner walls with neglectable heat transfer) is also available, as well as a wall model with a constant temperature on the back side.

2.12 Windows

Windows are specified with *g* (*SHGC*) and solar *T* at normal incidence and *U* for the glazing and for the frame. *g* and *T* can also be given as relative values to a one pane (*SC* and *SSC*) or a two pane (*F*1 and *F*2) reference window. The transmittance of the diffuse irradiation is calculated as 0.77 / 0.87 * *T*. The incidence angle dependence is calculated from an algorithm for the *g* factor of a two pane standard window, derived by fitting trigonometric functions in different angle intervals:

$85° < \theta \leq 90°$: $g_{ref}(\theta) = 1.48 * \mathrm{Cos}(\theta)$

$75° < \theta \leq 85°$: $g_{ref}(\theta) = (1.8 * \mathrm{Cos}(\theta) - 0.028)$

$0° < \theta \leq 75°$: $g_{ref}(\theta) = (-0.105 + \mathrm{Cos}(\theta) * (2.821 + \mathrm{Cos}(\theta)*(-2.998 + \mathrm{Cos}(\theta)*1.071)))$

else: $g_{ref}(\theta) = 0$

where θ is the incidence angle. $g(\theta)$ and $T(\theta)$ for the window are then obtained by multiplying $g_{ref}(\theta)$ with *F*1 (= 1.15**SC*) and *F*2 (= 1.15**SSC*), respectively.

A detailed pane-by-pane window model will be available in the next IDA-ICE version.

2.13 Transmission and distribution of solar radiation to the zone

The transmitted part of the solar irradiation (*T* for normal incidence) is assumed to enter the zone diffusively from the inner pane of the window, while (*g* - *T*) is assumed to be transferred to the zone by convection and IR radiation from the inner pane. The absorption distribution of the transmitted part of the solar irradiation is calculated from view factors and reflectance values of the inner surfaces of the zone. Also the reflected solar irradiation from the zone through the window is calculated.

2.14 Shading

Constant shading factors, which are to be multiplied with *g*, *T* and *U* of the window, are specified for each window. Geometrical shading screens and constructions can be edited in the program.

2.15 Double façade

A double façade is modelled in a special function as an external window outside an internal window and a wall. The air inside the cavity of the double façade has one temperature node. The air in the double façade is connected to the environment by leak functions at the top and the bottom, in which the mass flow rate is calculated as Aleak*cd*sqrt(2*rho*dP), where Aleak*cd is given as one parameter and DP is the pressure difference across the leak. If the size of dP is lower than a set value, a linear relation between the flow and dP is used instead. Leaks can also be connected to the inner zone at arbitrary height.

3 Modelling assumptions in IDA ICE 3.0

3.1 Input (weather data)

The input inserted in IDA ICE 3.0 is:

- External air temperature, °C: The external air dry bulb temperature
- Diffuse solar irradiation, W/m^2: Diffuse solar irradiation on the horizontal surface
- Direct solar irradiation, W/m^2: Direct normal solar irradiation (calculated from the global, diffuse solar irradiation and solar height)
- Wind direction, deg: Direction in the data sheet is given in degrees from the north, so east corresponds to 90 degrees
- Wind speed, m/s
- Relative humidity, %

3.2 Output

The available output from IDA ICE 3.0 is:

- Direct solar irradiation on the window surface (W/m^2, Mean hourly value)
- Diffuse solar irradiation on the window surface (W/m^2, Mean hourly value)
- Total solar irradiation on the window surface (W/m^2, Mean hourly value)
- Total solar radiation received on the external window glass surface (kW, Mean hourly value)
- Solar radiation transmitted from the outside into zone 1 (kW, Mean hourly value)
- Solar radiation transmitted from zone 1 into zone 2 (first order of solar transmission) (kW, Mean hourly value)
- Energy used for cooling/heating in the zone 2 (kW, Mean hourly value, with the '+'sign for heating and '-'sign for cooling)
- Hour averaged surface temperature of external window surface facing zone 1 (°C Mean hourly value; to include into the report as a figure of vertical temperature distribution)

- Hour averaged surface temperature of internal window surface facing zone 2 (°C Mean hourly value)
- Hour averaged floor surface temperature in the zone 2 (°C Mean hourly value)
- Hour averaged ceiling surface temperature in the zone 2 (°C Mean hourly value)
- Hour averaged air temperature in the zone 1 (°C Mean hourly value)
- Airflow rate in zone 1; only for the cases 200_3 and 200_4 (m^3/h Mean hourly value)

3.3 Simulation

IDA ICE 3.0 allows iterative simulation of an initial time period. The start-up period assumed was the 1st of October.

3.4 Environment

3.4.1 Ground properties

The ground temperature was assumed of 10°C for the whole simulation period. The ground reflection was considered 0.2

3.5 Geometry-constructions

3.5.1 Zone dimensions

The zone 2 is shown in Figure 3.1, as inserted in IDA ICE 3.0. The zone height was assumed 5.584 m (from inner side of the floor to the inner side of the ceiling).

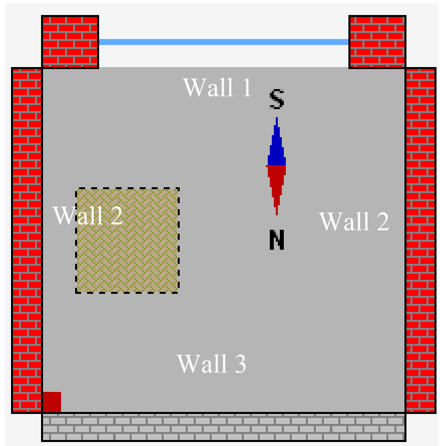

Figure 3.1 Zone 2

3.5.2 Description of Wall 3

The walls 2 and 1 are connected to the outdoors, while the wall 3 is divided in three parts as shown in Figure 3.3.

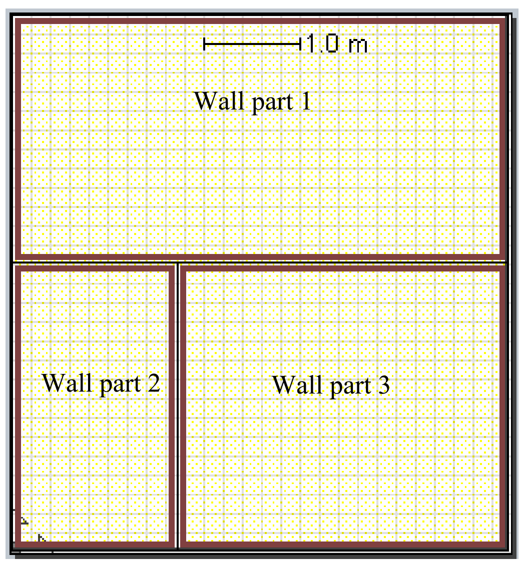

Figure 3.2. Wall 3

The wall part 1 is connected to the outdoors, the wall part 2 to a zone with constant 10°C and for the wall part 3 the heat transmission is ignored (as described in the specifications). The zones behind the wall parts 2 and 3 were not included in the simulations.

3.5.3 Opaque parts

The walls 2, 3 and the roof are defined as external wall construction with thermal transmittance 0.08332 W/m^2K. The wall 1 (south facing) has thermal transmittance 0.0508 W/m^2K. The floor is a separate construction with thermal transmittance 0.1977 W/m^2K. Both building elements are inserted according to the specifications. Thermal bridges are not included in the calculations. For the surface finishes the longwave emissivity was considered 0.88 and the shortwave reflectance 0.6.

3.5.4 Window

The window size is 19.374 m^2. The frame fraction of the total window area was 0.166% (or 3.216 m^2).

The thermal transmittance for the external pane is $U_{ext.pane}$=5.7 W/m^2K and for the frame is U_{frame}=3.63 W/m^2K. The thermal transmittance for the inner glazing unit (double pane) is $U_{int.window}$=1.2 W/m^2K and for the frame is U_{frame}=3.63 W/m^2K. The internal and external emissivities were set to 0.84. The solar and light transmittance has been inserted as specified. Thermal bridges are not included in the calculations.

3.5.5 Double skin façade cavity

The distance between the two skins (cavity depth) is 0.56 m. The openings were now assumed vertical as described in the specifications, but horizontal at the height of 0 and 5.584 m since this option is not given in IDA.

Since the default value of the discharge coefficient (Cd) in IDA ICE 3.0 is equal to 1 equivalent inlet and outlet openings were assumed: inlet opening = outlet opening = Cd x free opening area = 0.39 m^2

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