Hensen, J. L. M. and Radosevic, M. 2004.
Some quality assurance issues and experiences in teaching building performance simulation.
IBPSA News, International Building Performance Simulation Association, vol. 14, no. 2, pp. 22-33

Some quality assurance issues and experiences in teaching building performance simulation

J.L.M. Hensen and M. Radošević

Technische Universiteit Eindhoven, Center for Buildings & Systems TNO - TU/e, Netherlands
www.bwk.tue.nl/fago/hensen

ABSTRACT: Computer modeling and simulation is a powerful technology for addressing interacting technical architecture, mechanical, and civil engineering issues in passive and low energy building and systems. Assuming responsibility for the correctness of the results is of paramount importance for (future) engineers. Therefore it rightfully receives considerable attention in teaching building simulation. The validation test results discussed in this paper warn users of several issues, in particular that although a particular simulation software is commercially available and widely in use that does not necessarily guarantee its quality. The paper concludes that the main ingredients for professional and efficient quality assurance are domain knowledge and simulation skills of the user in combination with verified and validated building performance simulation software.

INTRODUCTION

As elaborated elsewhere [1], building performance simulation is possibly the most powerful technology for an integral approach of building and systems in view of global issues such as CO2 emission and fossil fuel depletion and local environmental concerns related to health, comfort and productivity.

Correct and efficient use is something which needs to be learned during education and training of professionals such as building physicists, building design engineers, environmental engineers, and heating ventilation and air-conditioning engineers.

This paper addresses some quality assurance issues in that teaching and training context.

BUILDING SIMULATION COURSES

In the Department of Architecture, Building and Planning of the Technische Universiteit Eindhoven, teaching of building performance simulation is done through dedicated courses and by application of the technology in individual and group design project work. All class descriptions, courseware and assignments are available at www.bwk.tue.nl/fago/hensen

The core courseware consists of a collection of modules as described in [2] and contains introductory materials (what is, and why should building energy and environmental simulation be used), practical exercises (how to properly use a real building energy modeling and simulation environment) and materials describing theoretical background (finding out how building energy modeling and simulation actually works). This courseware can be used in a variety of ways, such as in self-learning mode, for distance learning, as online course material, for dissemination purposes, as supporting lecture material, as reference material in project work, to encourage student self-study and for research purposes.

This general courseware is also extensively used in three dedicated courses: Introduction, State-of-the-art and Capita Selecta of building performance simulation. These classes are intended for building engineering and building services 2nd year undergraduate, 1st year masters and final masters or starting PhD students. (The Introduction and Capita Selecta courses are also taught at the Czech Technical University in Prague at the civil engineering and mechanical engineering faculties.)

All courses combine a theoretical part with a practical part. In the Introduction course, the practical part consists of learning to work with commercial building simulation software which runs under the MS Windows operating system. In the State-of-the-art course the practical part involves learning to work with a research strength building simulation environment in a UNIX environment. In the Capita Selecta course a variety of software tools are used for the practical work.

QUALITY ASSURANCE

As argued before (e.g. [3], [4], [5]) a first and paramount requirement to appreciate and assure quality of modeling and simulation studies is sufficient domain knowledge by the user of the software. Apart from domain knowledge, it is also very important to make future engineers aware of quality assurance issues and to teach them knowledge and skills to be able to deliver quality in later design practice. This is one of the main topics in both the theoretical and practical parts of the before mentioned simulation courses.

Apart from the required domain knowledge, there are two other important elements in terms of quality assurance, which are very often underestimated when using computer simulation in the context of building design.

- Using a correct simulation methodology including selection of the appropriate level of modeling resolution. For example, simulation is much more effective when used for comparing the predicted performance of design alternatives, rather then when used to predict the performance of a single design solution in absolute sense. In practice it is also often seen that high resolution modeling approaches (in particular computational fluid dynamics (CFD) and ray tracing rendering methods) are used for applications where a lower resolution method would be quite sufficient and much more efficient.
- Solving the right equations sufficiently accurate, as opposed to solving the wrong equations right. Of course a user should know which parameter values should be input in the model. In addition, there are now many modeling approaches where a user should also decide which model to use. This is specifically the case in many open simulation environments (e.g. Matlab toolboxes) and in higher resolution approaches (for example wall functions and turbulence models in CFD, and the various reflection models involved in ray tracing).

Quality assurance obviously also assumes the use of verified and validated software. There exist several techniques for verification and validation of building performance simulation software; see Appendix I. One of the most economic and effective techniques is inter-model comparison in which the simulation results from a software to be tested are compared with the results from previously tested other programs using the same model description and boundary values. An important international effort in this area is the ongoing BESTEST initiative (e.g. [6], [7]), which is now finding its first footholds in professional standards (e.g. the proposed Standard Method of Test - SMOT 140 - by the American Society of Heating, Refrigeration and Air-conditioning Engineers - ASHRAE) and national standards (e.g. the Energie Diagonse Referentie - EDR effort in The Netherlands). Appendix II provides a short overview of the BESTEST procedure.

The above mentioned theoretical issues and practical approaches are addressed at increasing levels of complexity in the Introduction, State-of-the-art and Capita Selecta simulation courses mentioned above.

SOME VALIDATION EXCERCISES

During the Introduction course - which is part of the 2nd year undergraduate building engineering and building services curriculum – the students have to carry out part of the BESTEST procedure. As mentioned before, for this course we use commercial MS Windows based building simulation software. This particular software has the advantage that it is easy to learn and that it has a user interface which appeals to students. The disadvantage is that the calculation methods are not the most advanced in the field. For this reason it was decided to do some additional testing. This paper only addresses the thermal calculations, which are based on the CIBSE admittance method [8] which originally intended to provide a manual prediction method for peak cooling loads. Appendix III provides a brief overview.

The BESTEST procedure starts with very simple cases. Step by step more complexity is added in order to test different features and aspects of the software. The results which will be presented are for the simple cases and assume a single zone building sized 8 x 6 x 2.7 m^3. Some tests are for a building without windows, some involve opaque windows, and some involve transparent windows of 3 x 2 m^2 in the south facing wall as indicated in Figure 1. All material properties and building operation details are defined in [6]. In the BESTEST cases tested here, the floor is thermally decoupled from the ground. This is modeled in the software by a very thick layer of insulation (1m) with density and specific heat at the lowest value accepted by the software (density – 1kg/m^3 and specific heat – 1J/(kgK)).

The tested software does not provide the option for input of internal short wave absorption, and as end-users we are not able to answer the question if and what value is used in the calculations. Therefore, although the BESTEST procedure requires different inputs for this parameter; it was only possible to enter the value of external absorption. Additionally, the value for infrared emissivity is predetermined in the software and could not be changed. However, the results for cases with higher values of infrared emissivity were in the acceptable range. This is also in agreement with the fact that most common building materials have high emissivities [8].

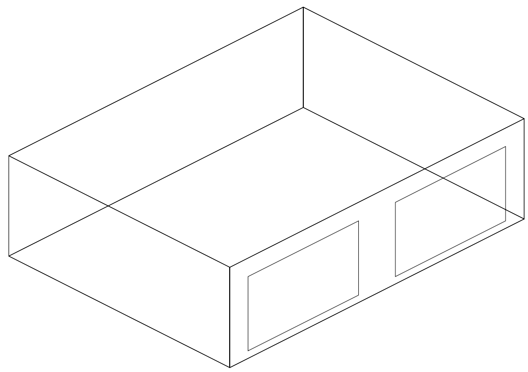

Figure 1.: Geometry of the model

RESULTS

The first deviation from the BESTEST results has been observed already at the beginning of the procedure. Case number 230 (the 6th case, which tests infiltration) resulted in too high energy demand for heating as can be seen in Figure 2.

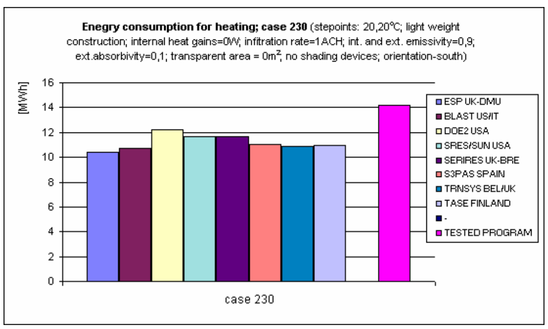

Figure 2: Annual energy consumption for heating for BESTEST case 230 predicted by the tested program in comparison to results of other programs

The deviation from the acceptable range decreases with lower infiltration rates. This was observed by comparison of the results with case 410 (Figure 3) where the infiltration rate is 0.5 air change per hour (ACH). For case 230, the deviation relative to the closest other is 13.5% whereas for case 410 it is only: 4.2%.

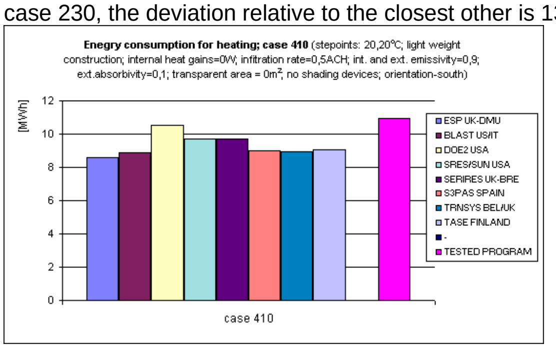

Figure 3: Annual energy consumption for heating for BESTEST case 410 predicted by the tested program in comparison to results of other programs

The next problem relates to solar transmittance. The results for annual heating and cooling load for this specific case 270 are represented in Figures 4 and 5. The annual energy consumption for heating is underestimated and for cooling it appears to be overestimated.

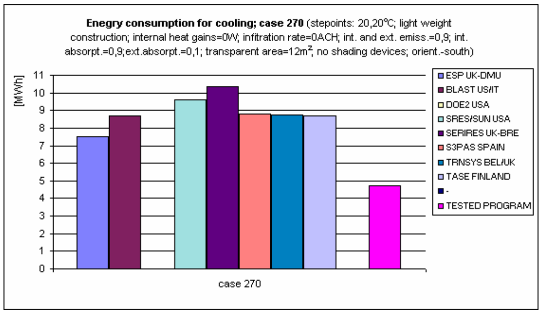

Figure 4: Annual energy consumption for cooling for BESTEST case 270 predicted by the tested program in comparison to results of other programs

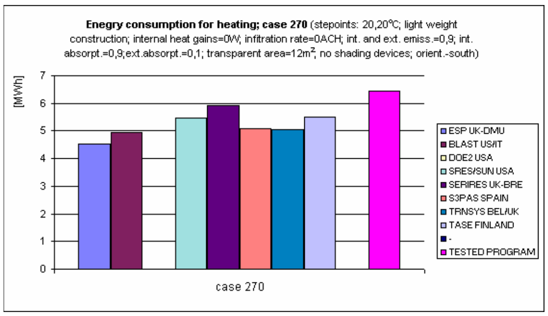

Figure 5: Annual energy consumption for heating for BESTEST case 270 predicted by the tested program in comparison to results of other programs

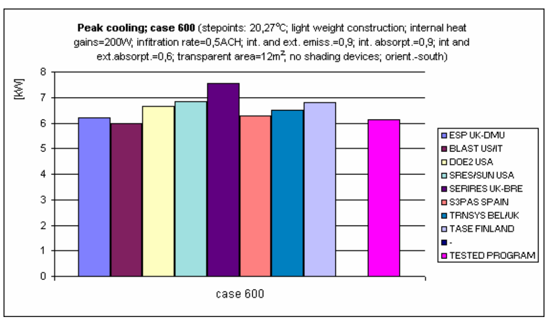

Figure 6: Peak cooling load for BESTEST case 600 predicted by the tested program in comparison to results of other programs

It is interesting to note the results for peak cooling demand in Figure 6. The prediction from the tested program is acceptable.

Further analysis of the results shows that a deviation in maximum heating load appears only when there is infiltration assigned to a model. Then, the program show slightly higher values then the results in BESTEST report. For more information see [9].

DISCUSSION

Even though only a small part of the BESTEST procedure was carried out, the results indicated several errors. Although implementation and coding errors cannot be ruled out, we now think that most of these erroneous predictions are related to the underlying calculation method. The admittance method gives rise to several critical issues when used for dynamic building energy simulations.

Firstly, the method was originally developed as a manual calculation method for prediction of peak cooling loads and was not intended for estimating heating loads of for heating and cooling energy consumption.

Secondly, the method uses some parameters, which sound familiar but have an unusual definition, such as the solar heat gain factor at the environmental node, as briefly described in Appendix IV. Even if the user realizes this uncommon definition, he/she still faces the problem that the corresponding value is not available in literature or otherwise.

Thirdly, the method requires the user to input certain parameters that are extremely difficult or even impossible to obtain, such as the alternating solar heat gain factor of a glazing system.

In order to be consistent with the admittance model the mean and alternating solar heat gain factors are defined. The alternating factor represents the ratio of the swing in solar load in an environmental node due to both indirect and direct solar heat load, and the swing in the external incident solar irradiation on the glazed surfaces. Each swing is defined relative to the mean of the specific variable. Due to the time delay associated with a surface responds to short-wave radiation, the peak load in the environmental node does not appear simultaneously with the peak in the incident solar radiation as shown on Figure 7. This causes variation of the alternating solar heat gain factor during a day, and there is no single value that is representative of all hours of the day (see Figure 8). It can be higher then one, as the **swing** in the load may be greater then the swing in the incident solar radiation in the particular moment of time.

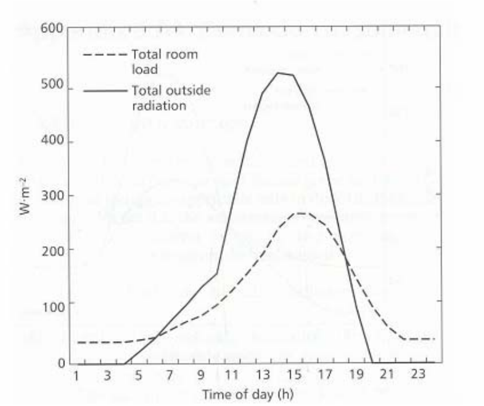

Figure 7: Solar load profile and profile of incident solar radiation during a day for a certain building [8]

In the literature only one value is given. For example in [10], the values are given for southwest facing windows in UK and for time of peak cooling for different windows and light/heavy construction. The value of alternating solar heat gain factor is typically lower during peak hours, due to the large swing in incident solar radiation, but this still depends on construction.

Although, use of the single value from the CIBSE guide can give reasonable accurate results for maximum loads it certainly leads to miscalculations for overall energy consumption. The deviations would depend on the building mass, because this drives thetime delay between the peaks appearances.

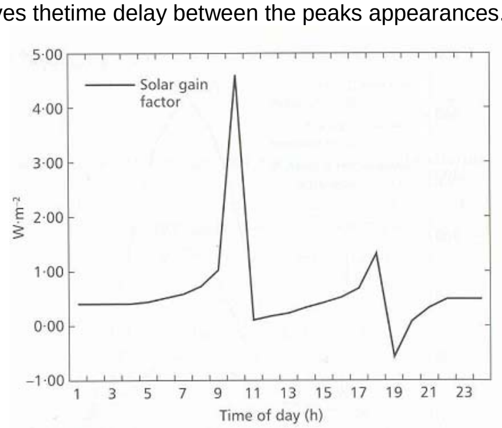

Figure 8: Alternating solar heat gain factor during a day for a certain building [8]

As it could be seen from the BESTEST results in general, the overall energy consumption for cooling was underestimated and for heating overestimated. The reason for this may be in not adequate use of the alternating solar heat gain factor. Only one value is used, while this parameter varies during the day and is construction dependent.

IN CONCLUSION

This paper has highlighted several issues related to quality assurance in building performance simulation. Taking care of these issues is in principle the responsibility of the person who uses the simulation model to predict what will happen in future reality. Appreciating this is of paramount importance for (future) engineers and therefore it rightfully receives considerable attention in teaching building simulation.

The validation test results discussed in this paper warn users of several issues, in particular that although a particular simulation software is commercially available and widely in use that does not necessarily guarantee its quality.

In our view the main ingredients for professional and efficient quality assurance are domain knowledge and simulation skills of the user in combination with verified and validated building performance simulation software.

REFERENCES

[1] J.L.M. Hensen, E. Djunaedy, M. Radosevic and A. Yahiaoui. Building Performance Simulation for Better Design: Some Issues and Possible Solutions. Proc. 21st International Conference PLEA, 2004 Eindhoven (NL). Passive and low energy architecture

[2] J.L.M. Hensen, M. Janak, N.G. Kaloyanov and P.G.S. Rutten. Introducing building energy simulation classes on the web. 1998. ASHRAE Transactions, vol. 104 Pt 1

[3] J.L.M. Hensen, "On the thermal interaction of building structure and heating and ventilating system." PhD thesis Technical University Eindhoven, 1991.

[4] J.L.M. Hensen. Design support via simulation of building and plant thermal interaction. H.Timmermans. Design and Decision Support Systems in Architecture, 227-238. 1993. Dordrecht (NL), Kluwer Academic Publishers.

[5] J.L.M. Hensen and J.A. Clarke. Building systems and indoor environment: simulation for design decision support. International Conference on Design and Decision Support Systems in Architecture & Urban Planning, 177-189. 2000. Eindhoven University of Technology.

[6] R. Judkoff and J. Neymark. International Energy Agency Building Energy Simulation Test (BESTEST) and Diagnostic Method. 1995. National Renewable Energy Laboratory.

[7] J. Neymark, R. Judkoff, G. Knabe, H.-T. Le, M. Durig, A. Glass and G. Zweifel. HVAC BESTEST: A procedure for testing the ability of whole-building energy simulation programs to model space conditioning equipment. 7th International IBPSA Conference, 369-376. 2001. Brazil, International Building Performance Simulation Association.

[8] Environmental design, CIBSE Guide A, Chartered Institution of Building Services Engineers, London 1999.

[9] M. Radosevic and J.L.M. Hensen. FAGO Report 03.73; Critical review and testing of a building performance simulation software, for educational purposes. Technische Universiteit Eindhoven

[10] CIBSE guide Volume A; Design data Chartered Institution of Building Services Engineers, London, 1988.

[11] Handbook of Fundamentals, American Society of Heating, Refrigerating and Air-conditioning Engineers – ASHRAE, Atlanta 1997.

APPENDIX I – VALIDATION TECHNIQUES

Validation and testing is a necessary part of any software development process. It is intended to ensure credibility by eliminating physical errors, bugs, algorithm errors, and documentation errors.

In [6], the authors identify seven main sources of error, which given the context of heat and mass transfer in building and plant configurations, translate into:

1. Differences between the actual weather conditions and the outdoor conditions assumed in the simulation;
2. Differences between the actual effect of occupant behaviour and those effects assumed by the user;
3. User error in deriving building and plant input files;
4. Differences between the actual thermal and physical properties of the building and plant and those input by the user;
5. Differences between the actual heat and mass transfer mechanisms operative in individual components and the algorithmic representation of those mechanisms in the program;
6. Differences between the actual interactions of heat and mass transfer mechanisms and the representation of those in the program; and
7. Coding errors.

The error sources 1 through 4 are called external since they are independent of the internal workings of the method of calculation. External errors are not under the control of the developer of the computer program. Error sources 5 through 7 are called internal and are directly linked to the internal workings of a prediction technique. Internal errors are contained within the coding of the program. Internal errors, are related to the ability of the program to predict real building and system performance when perfect input data is introduced.

There are a few techniques that can be used to assess the quality of a whole building energy simulation program:

- Empirical validation

The results from a program are compared with the results obtained from monitoring a test cell, real building or laboratory experiment.

- Analytical validation

The results from the program are compared with the known analytical solution or a generally accepted numerical method for a specific isolated heat transfer mechanism under very simplified, pre-defined boundary condition.

- Comparative testing

The results are compared with results obtained from other programs. The comparing programs are usually pre-validated empirically and/or more detailed and likely more physically correct.

Each of these approaches has its strength and weaknesses. See [6].

APPENDIX II – BESTEST

BESTEST tests the program ability to model heat transfer associated with building fabric, basic thermostat controls, internal gains and mechanical ventilation [6]. It was developed for systematically testing whole building energy simulation models and diagnosing the sources of predictive disagreement. The technique consists of a series of carefully specified test case buildings that progress systematically from the extreme simple to the relatively realistic. In this method, output values for the cases, such as annual loads, annual maximum and minimum temperatures, peak loads, and some hourly data are compared and used in conjunction with diagnostic logic to determine the algorithms responsible for predictive differences. The results for each case building, defined in the BESTEST method are obtained from several state-of-the-art simulation tools, which have been empirically validated themselves (such as ESP-r and TRNSYS) and are available in [6].

The BESTEST procedure starts with light weight building tests and finishes with heavy weight. Step-by-step it incorporates different values for internal heat gains, infiltration rates, internal and external infrared emissivity, internal and external short-wave absorbivity, different area of transparent surfaces, orientations, shading devices as well as HVAC operation strategies.

The more realistic cases, although geometrically simple, test the ability of the programs to model combined effects of thermal mass, direct solar gain windows, window-shading devices, internally generated heat, infiltration, sunspaces, earth coupling, and dead band and setback thermostat control. The more simplified cases facilitate diagnosis by allowing excitation of particular heat transfer mechanisms. Simply, by modelling and simulating those specific case buildings in a program, and then comparing the results obtained for the same case using other different software (available in BESTEST report), it is possible to diagnose errors if any.

Starting from the simplest model, the room without windows, tests continues over more complex models introducing or changing one of the input parameters per each new model. Hence, each upgrade of the previous models introduces and tests specific isolated algorithm. Of course, before extending the tests to a next model the results of earlier, already tested models have to satisfy certain criteria. Only then, the result of the validation will be complete. The validation process is schematically represented in Figure 9.

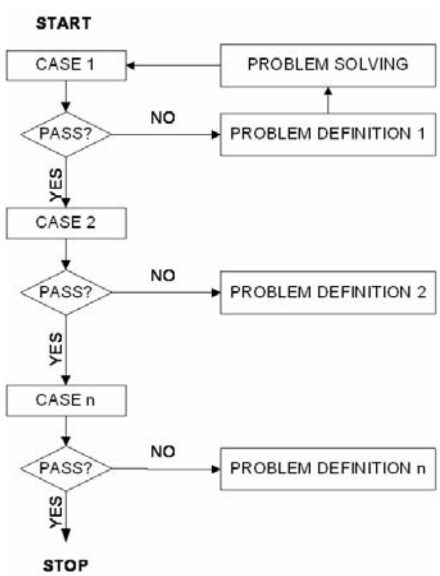

Figure 9: Validation methodology with BESTEST

APPENDIX III – ADMITTANCE METHOD

The CIBSE admittance method dates back from the 1960's when it was developed in order to enable engineers in practice to estimate peak cooling loads using manual calculations. It basically constitutes a simple representation of a highly dynamic process; ie. the building, as a physical body with thermal mass and heat capacity, under the influence of variable outside conditions and variable internal gains.

The admittance method (also known as the "means and swings" method) uses a steady state approach for the "mean" values in combination with a dynamic part that describes all deviations from steady state, i.e. the "swings".

The admittance method is based on the assumption that all thermal dynamics can be represented by the response to a sine wave with a period of 24 hours. Using this method there is no need for solving partial differential equations and it is possible to use the method for manual calculations. By introducing several parameters the admittance method expresses the building dynamics in a simple way. The parameters are defined depending on:

the type of the thermal input, thermal properties and thickness of the construction, surface finishes and furnishings within the space.

In other words, for load or temperature calculations it is necessary to determine the mean values either for temperature or for load and then the swing (mean to peak) for either one or the other value. Both values are obtained from the heat balance equation. The method involves heat balance equations for both steady state and for the deviations from the mean. The later equation involves parameters, such as: decrement and time delay of the thermal input from the outside towards inside due to the heat accumulation within the construction. The overall calculation procedure is presented in [8].

APPENDIX IV – SOLAR HEAT GAIN

This appendix tries to explain the discrepancy between solar heat gain factor (SHGF) in the admittance method and the common understanding of the same [11].

The SHGF at the environmental node in the admittance method does not consider only the heat transfer phenomena due to solar radiation through the window, but involves also other heat transfer phenomena in the room that occur when short wave radiation enters the room. Short wave radiation is absorbed at the surface, which causes the temperature of the surface to rise. Part of the absorbed heat is conducted through the construction of the wall and accumulated and part is released into the space by convection or long-wave radiation mechanisms (Figure 10). The effect is a rise in environmental temperature. Accumulation inside the wall construction will influence the surface to respond on incident solar radiation after a certain time delay and with a certain decrement. That is why the SHGF value depends on the types of constructions (i.e. heavy or light).

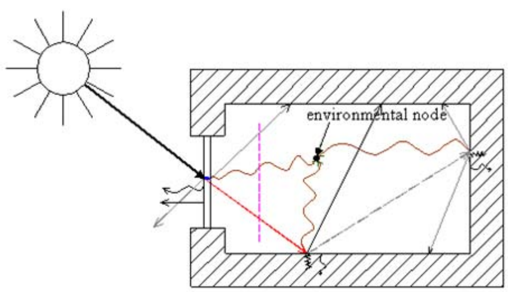

Figure 10: Heat transfer processes due to solar short wave irradiation on the window

The alternating solar heat gain coefficient for light as well as for heavy constructions input to the model in the tested program is not described by BESTEST, but taken from additional source [10]. The difference in the results could be due to the input parameters problem, but as the additional input values taken from reliable source correspond to the specific model description it can be argued that either the algorithm for solar gain calculation does not work properly or that it was not implemented in the correct way.

The algorithm that deals with solar transmittance has to be checked, improved or considered changing.