RADTEST - THE EXTENSION OF PROGRAM VALIDATION TOWARDS RADIANT HEATING AND COOLING

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ABSTRACT

Radiant heating and cooling, including building component embedded systems, have become a common heating and/or cooling technology in the recent few years. Some currently available building simulation programs have the ability to model these systems. Some others do not, but users have developed their way of modeling by using the program's limited possibilities. A systematic and complete validation with enough diagnostic power for this type of problem was missing to date. This was developed in the frame of IEA Task 22 'Building Energy Analysis Tools'. A set of validation cases was added to the BESTEST suite existing from earlier IEA projects. Five participants, using the programs CLIM2000, DOE-2, ESPr, IDA-ICE and TRNSYS, submitted their results in a multi step procedure. This helped develop the test procedure and at the same time delivered a base set of results to compare to. So a basis for the future validation of further programs in this area was formed.

INTRODUCTION

The Systems

Radiant heating and cooling systems are known all over the globe. There are several types of systems. The best known heating system is the floor heating system with a water loop under a concrete slab. Through the thermal resistance of the concrete slab, the heat transmission from the water loop in the floor to the room is delayed, and the floor surface temperature is on a lower temperature level. This behavior creates a comfortable room climate and is probably the main reason for the widespread use of this type of system.

Frequently used cooling systems are cooled beams which are small water cooled panels placed on the bottom side of the ceiling. Another system type well known in Europe are thermally active building elements. This system is similar to the floor heating, with the hydronic circuit in the center of a massive concrete ceiling or floor. This concrete element is often cooled down during night time to a lower temperature level than the adjacent space. During daytime the direct solar radiation and internal radiative gains are stored in the concrete slab. Due to the massive concrete, the heat flux arrives with delay in the middle of the concrete. In this way, the stored heat can be removed by the water loop during night time. The big advantage of this operation is that the heat can be removed, when low temperature heat sink possibilities are available.

Possibilities with Simulation Programs – Needs for Tests

To take into account the behavior of radiant heating and cooling in dynamic simulation programs, specific models or modeling methods are available. Depending on the specific program's level of detail and method of calculation, water based loops are easily added to construction elements, or there is a need for an abstraction e.g. in the form of a layer with a temperature that can be set to a prescribed operation pattern. In some cases, real "workaround" ways have to be used, e.g. by using the program's zone model to describe a conditioned layer within a construction as a "dummy zone". Several problems are linked to this procedure such as surface heat transfer coefficients, air instead of water properties etc.

Some of these methods are frequently used and well known. But there is a need to validate these models and methods to improve confidence in them.

Context

Several projects within research programs of the International Energy Agency (IEA) have addressed the issue of validation of building simulation programs in the past. Experience has shown, that validation can be addressed by three methodological approaches, as described by Neymark et al., 2001:

- Empirical validation
- Analytical validation
- Comparative testing

All three methods have their strengths and weaknesses, and only the combination covers all the issues of a complete program validation.

One of the most frequently used and widespread applications of the comparative approach is referred to as ENVELOPE BESTEST, described in Judkoff and Neymark, 1995. This has been transformed to a standard (BSR/ASHRAE, 2001) and forms the base also for the work described here.

This work was developed in the frame of the project IEA Task 22 'Building Energy Analysis Tools', which was terminated in Autumn 2002 and generated a series of different reports and tests. The work described here is fully reported in Achermann and Zweifel, 2003.

Goal

The goal of this work is to give a tool which can show if the tested programs are able to accurately model radiant heating and cooling systems, and which gives some diagnostic indications to localize the problem for the case where they do not. Additionally, the relation between the simplified approaches and the detailed floor heating and cooling models shall be quantified.

DESCRIPTION OF THE TEST SUITE

The purpose of the test suite specification is to create a uniform set of unambiguous test cases for a software to software comparison. Not all the programs require exactly the same input data. Therefore, the test description is given in a way that allows the use of many different simulation programs (representing different degrees of modeling complexity).

RADTEST contains 14 runs and is subdivided in two parts. In the first part, a simplified method with a constant temperature layer is used. In the second part, a detailed hydronic system model is used. Tables 1 and 2 give an overview of the different test cases.

Simplified Cases

The set of test cases for the simplified approach as given in table 1was found in an iterative process. The cases are set up in a way that one aspect is added at a time when going from one case to another, and the “noise” of influences not being directly related to the problem addressed is limited to a minimum.

Since radiative systems are strongly connected to the space or zone, which they are sitting in, modeling of the latter is essential for a successful modeling of the system. Therefore the test suite starts at this point. The basic case 800 is a rectangular single zone model with high thermal mass, two “opaque windows” (which are highly conductive and massless walls and do not have any solar radiation transmittance), without ground coupling.

Table 1
Simplified test cases

CASE	DESCRIPTION	TEST OBJECTIVE
800	Corresponds to case 800 from ENVELOPE BESTEST. High mass construction with opaque window. Adiabatic floor with active storage capacity	**Basic case**
1800	Totally insulated 2 zone model. - no infiltration - no internal loads	Heat transmission through interior construction element
1805	Totally insulated 2 zone model. - infiltration Ach=1.0 1/h - internal loads 200 W from 1st May to 30 September. (purely convective)	Presence of internal loads
1810	Constant temperature layer between the concrete layer and the insulation Surface coefficient on floor purely convective	Convective model
1815	Replace purely convective surface coefficient by combined coefficient Radiation from floor 100% to ceiling	Radiation model
1820	Normal distribution of radiation to all surfaces	Distribution of radiation
1830	Real constructions for walls and roof. Internal gains purely convective 365 days. Ach=0.5 1/h	More realistic zone load
1840	“Opaque window” is added. Internal Loads set to case 800 values	Influence of highly conductive wall
1850	Real window is introduced	Influence of incoming radiation
1860	Equal to case 1850 but the internal gains are purely radiative	Influence of radiative heat source
1870	Equal to case 1850 but the internal gains are purely convective	Influence of convective heat source
1880	Lower level of the constant layer temperature Set points for summer 18°C and winter 30°C	Influence of temperature change on heating and cooling energy demand
1890	Equal to case 1850, but during summer time, the temperature layer set point is only active from 8 pm to 6 am	Influence of interrupted operation on cooling energy demand

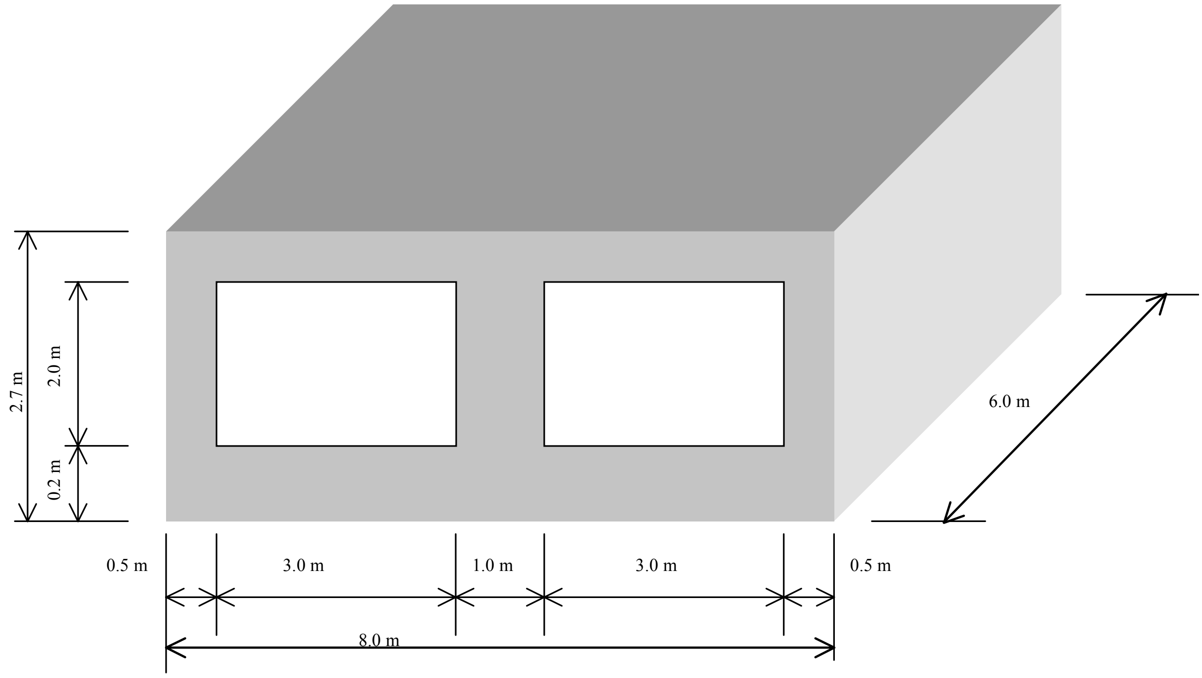


Figure 1: Graphic representation of the zone model

At this stage the zone model corresponds exactly to case 800 from the ENVELOPE BESTEST (Judkoff and Neymark, 1995) and therefore seamlessly connects to that test suite. It is shown in figure 1. The meaning of this case is that the user has a benchmark for his zone model. If any results fail at this stage, the modeler is advised to first run the diagnostics cases from ENVELOPE BESTEST.

Since radiative systems are often embedded in building elements, they usually have heat emission parts to two zones situated on both sides of the element, even if not intended. Therefore a second zone had to be added to all the further tests. A strongly insulated, nearly adiabatic zone surrounded by ground is inserted below the primary zone, as shown in figure 2. In cases 1800 and 1805 the heat flow between the zones without the influence of a radiative system is observed.

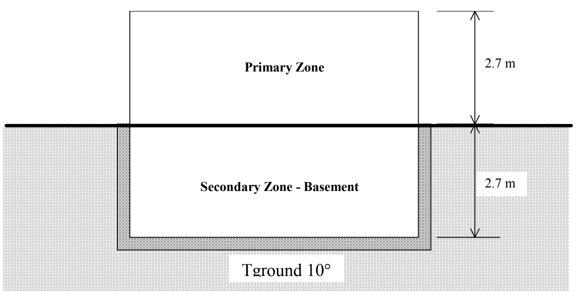


Figure 2: Addition of a second zone

In cases 1800 to 1830, also the active zone is modeled as a highly insulated zone. This eliminates even more the influence of the outdoor climate compared to the base case 800. It is added step by step again from case 1830 upwards. In case 1830 the insulated envelope is removed. An opaque window and afterwards a real window are inserted in the model.

From case 1810 upwards, a layer with a defined temperature is placed in the center of the floor construction. This represents the radiative system, and its temperature is kept at a constant value which changes only seasonally (40° C 24 hours/day from October 1 to April 30, 20° C 24 hours/day from May 1 to September 30). It is up to the user to choose an appropriate method to model this, depending on his program's capabilities. The behavior of the heat transfer from this layer to the active zone is observed in detail. For all tests, the temperature of the primary zone is controlled to a constant set point by a separate, ideal and purely convective heating and cooling system. The power and energy demand of this system are observed parameters.

This means it is not the radiative system itself which is used to control the active zone, but it influences its energy balance. It has to be emphasized that this is not in contradiction to practice. The real systems of this type are often designed to run on a preset pattern rather than on a control scheme connected to the room conditions, which is impossible in many cases due to the high inertia. However, the second system inserted here may be missing in practice, when the oscillations of the room temperatures are in an acceptable range (to prove this is a task for the programs the test is addressed to).

The radiative system is kept unchanged for all cases from 1810 up to 1870. It is on the zone and load side where changes are made in order to test the reaction in combination with the radiative system. The different test objectives of the cases can be seen in table 1.

With the last cases, 1880 and 1890, different control strategies with different set points and different schedules for the temperature layer are tested.

Detailed Cases

The detailed test cases contain a description of a real floor heating system. At this stage, the modeler is advised to model this system in the most detailed way the program allows. The goal of this test is on one hand to compare the detailed case results with the simplified ones, and on the other hand to compare the different modeling approaches.

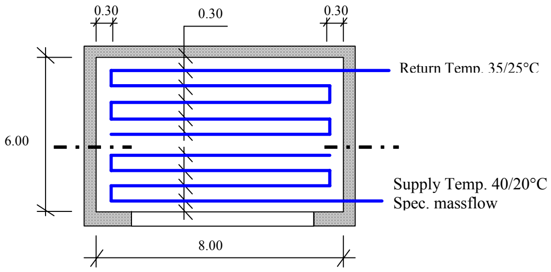


Figure 3: Detailed description of radiative system

The two cases differ only in terms of operation, as shown in table 2.

Table 2
Detailed test cases

2800	Real case with detailed water loop model Whole year 24h/d mass flow
2810	Real case with detailed water loop model During summer time mass flow provided only from 8 pm to 6am.

RESULTS

Participating Organizations and Programs

A set of sample results has been produced by participants of the IEA SHC Task 22 project. Table 3 gives an overview of the participating programs and organizations.

The results were produced in a first round as a blind test. This is a good solution to improve the test specification. According to the results of the first round, some errors in the test specification were detected and the specification was modified and adjusted. Obvious disagreement between results from different programs were discussed and improved in a second round. In some cases a third round was necessary to eliminate program bugs or faults because of misinterpretation of the specification. Bugs and modeled errors were reported for each of the programs in a "modeler report".

Table 3
Participating programs and organisations

PROGRAM	AUTHORING ORGANIZATION	IMPLEMENTED BY
TRNSYS	Transsolar/TUD	TUD, Dresden University of Technology Germany
DOE 2.1E	LBNL	HANS DÜRIG AG - Simulation für Gebäudeenergie Riggisberg, Switzerland
IDA-ICE 3.0	EQUA Sweden	Lucerne School of Engineering and Architecture, University of Applied Science of central Switzerland
CLIM2000	EDF	Electricité de France, France
ESP-r/ HOT3000	CANMET	CANMET Energy Technology Centre, Ottawa, Canada

The final results from the participating programs are presented in Achermann and Zweifel, 2003 in tables and diagrams. They represent the best currently available state-of-the-art in whole building simulation predictions for radiant heating and cooling systems. But, as for all comparative validation tests, they cannot be considered to represent a "truth" standard. The results show a certain amount of disagreement among the programs for many of the cases. The range represents algorithmic differences in the current state-of-the-art as defined by the group of international experts from IEA Task 22. For any given case, a program that yields values in the middle of the range should not be perceived as better as or worse than a program that yields values at the border of the range – or even outside. Investigating the source(s) of the difference(s) is worthwhile, but the existence of a difference does not necessarily mean a program is faulty. Experience shows, that when programs show a major disagreement with a range, often a bug or questionable algorithms can be found. And the set of tests is designed to provide the necessary diagnostic power to easily find the area of an erroneous algorithm.

Example Results

The comparison to earlier ENVELOPE BESTEST results is not shown here. All results were within the range.

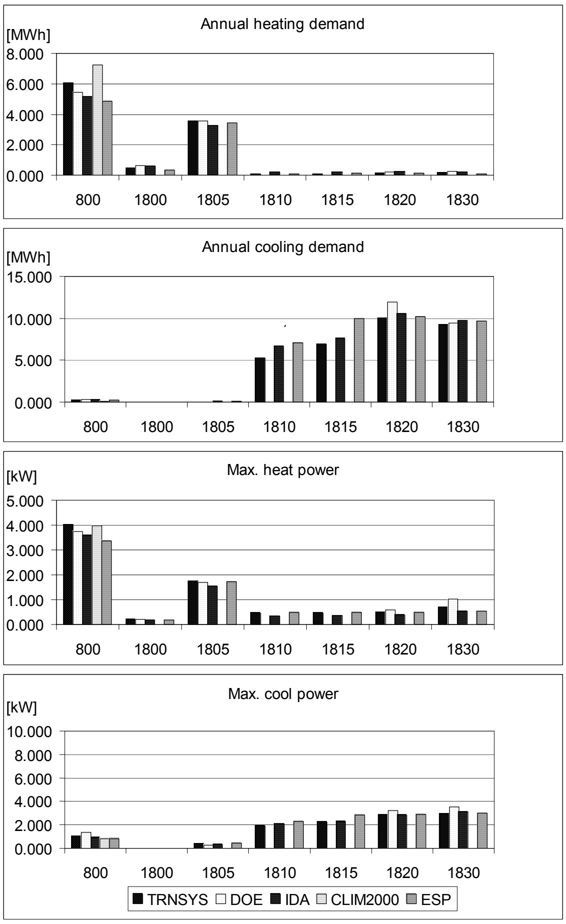


Figure 4: Overall results for cases 800 to 1830

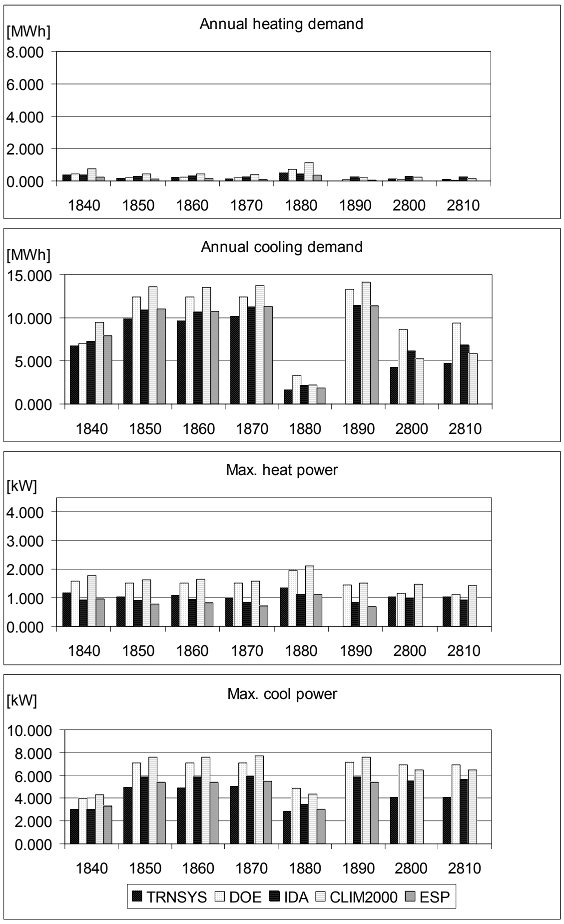


Figure 5: Overall results for cases 1840 to 2810

Figures 4 and 5 show an overview of annual energy needs and peak loads for both heating and cooling for the different cases.

As can be seen in figures 4 and 5, not all test cases were performed by all programs. Sometimes it is not possible to make the necessary simplifications in a certain program to meet the requirements. As an example, in DOE-2 the radiative/convective split of the inside surface film coefficient cannot be influenced.

It can be seen that the variation among the programs is considerable. This is well known from other validation tasks. It can also be seen however, that the changes from one case to another is quite uniform, which means that the programs correctly predict the physical changes between the cases. This can be made more clearly visible by plotting the differences between the cases ("delta results"). An example with temperature results is shown in figure 7. If there is a systematic error in a program, however, this may be suppressed in these delta plots.

Figure 6 shows that the DOE-2 program has a systematic difference with the maximum floor surface temperature for all cases from 1850 upwards. These are the cases which have a real window.

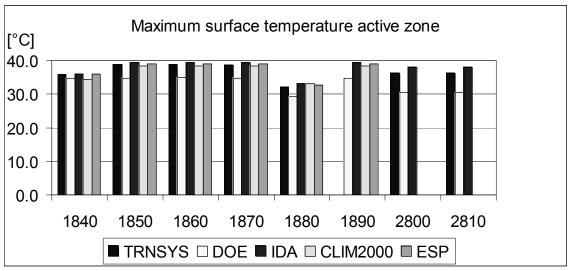
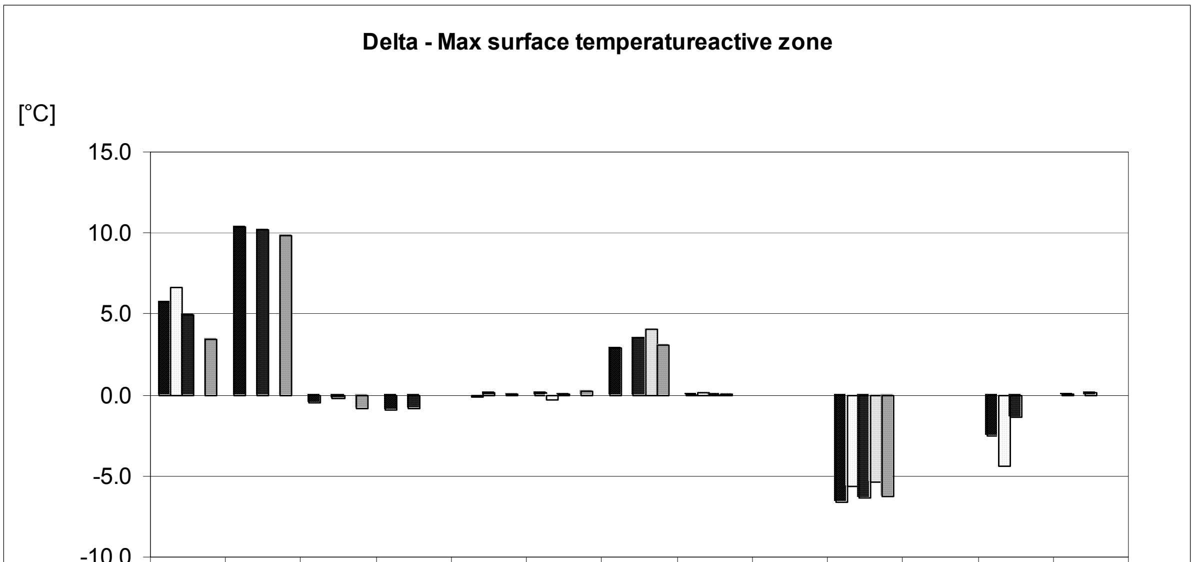


Figure 6: Maximum floor surface temperature for cases 1840 to 2810

In figure 7, which shows the delta results for the same temperature as figure 6, this can only be seen at one single place: for the difference between case 1850-1840, DOE-2 shows a 0, where all the other programs have a 3 to 4 K difference.

Figure 8 shows an example of a temperature plot from a detailed water loop case. It shows that despite of very different approaches in the different programs, the return water temperatures calculated are almost perfectly the same during the times of operation. The differences become bigger during the times where the system does not operate, but at these times this has no influence on the energy balance of the system.



	1805-1800	1810-1805	1815-1810	1820-1815	1830-1820	1840-1830	1850-1840	1860-1850	1870-1850	1880-1850	1890-1850	2800-1850	2810-2800
TRNSYS	5.8	10.4	-0.5	-0.9	-0.1	0.2	2.9	0.0	-0.1	-6.6	0.0	-2.5	0.0
DOE	6.6	0.0	0.0	0.0	-0.1	-0.3	0.0	0.1	0.0	-5.6	0.0	-4.4	0.0
IDA	5.0	10.2	-0.3	-0.9	0.1	0.0	3.5	0.0	-0.1	-6.3	0.0	-1.4	0.1
CLIM2000	0.0	0.0	0.0	0.0	0.0	0.0	4.1	0.0	0.0	-5.4	0.0	0.0	0.0
ESP	3.4	9.9	-0.8	-0.1	0.0	0.2	3.1	0.0	-0.1	-6.3	0.0	0.0	0.0

Figure 7: Delta maximum floor surface temperature results for cases 1805 to 2810

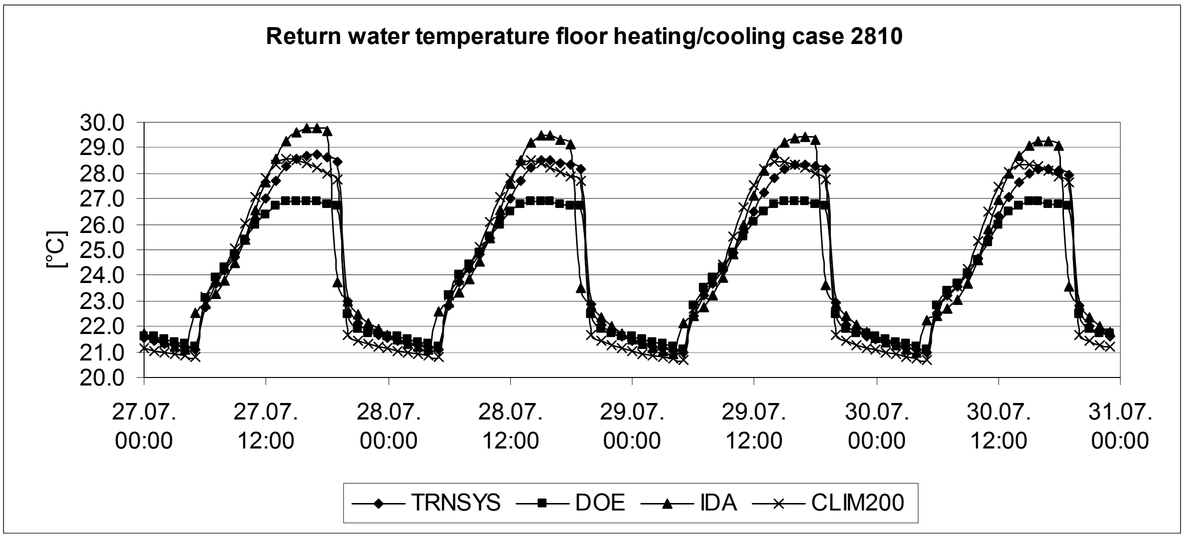


Figure 8: Return water temperature plot for a detailed water loop model

CONCLUSIONS

The different approaches of modeling radiant heating and cooling systems lead to satisfying results. It is interesting to see that programs like DOE-2.1E, which has not a special radiant heating system included, can be used and modified in a way that leads to reasonable results (except for surface temperature calculations).

Overall, it may be said that all the participating programs calculate the radiant floor systems in the same way. To use this approach to estimate floor temperatures and energy consumptions is a reasonable approach.

The main goal of the RADTEST development, to provide a tool which can be used as a test for the capability of programs to accurately model radiant heating and cooling systems, can be considered as reached as far as the simplified approach are concerned.

For the cases with a detailed water loop system model there has been made a good start However, in this field RADTEST should provide more test cases in a future work. The aim of further tests should focus on:

- Different pipe configurations
- Different control strategies on different temperature levels.

ACKNOWLEDGMENTS

We gratefully acknowledge the contributions from the modellers and the authors of sections on each of the computer programs used in this effort:

- ˜TRNSYS: Clemens Felsmann and Gottfried Knabe, Dresden University of Technology, Germany
- ˜DOE 2.1E: Markus Dürig, HANS DÜRIG AG – Simulation für Gebäudeenergie, Riggisberg, Switzerland
- CLIM2000: Joseph Ojalvo, Electricité de France (EDF), Fontainebleau, France
- ESP-R/HOT3000: Kamel Haddad, CANMET Energy Technology Centre, Ottawa, Canada

Also we highly appreciate the support and guidance from Michael Holtz, operating agent of Task 22, Ron Judkoff, Leader Subtask C, and from Joel Neymark, Neymark & Ass.

The work would not have been possible without the funding from the Swiss Federal Office of Energy, represented by Mark Zimmermann, Swiss Federal Laboratories for Materials Testing and Research (EMPA), Dübendorf, Switzerland, and from the Lucerne School of Engineering and Architecture (HTAL), which also supported the conference contribution.

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