RADTEST – Radiant Heating and Cooling Test Cases

A Report of Task 22, Subtask C
Building Energy Analysis Tools
Comparative Evaluation Tests
July 2003

Supporting Documents

INTERNATIONAL ENERGY AGENCY
Solar Heating & Cooling Programme

FHZ —> UNIVERSITY OF APPLIED SCIENCES OF CENTRAL SWITZERLAND

HTA

INTERNATIONAL ENERGY AGENCY
Solar Heating & Cooling Programme

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ZIG —> CENTER FOR INTERDISCIPILANY BUILDING TECHNOLOGY

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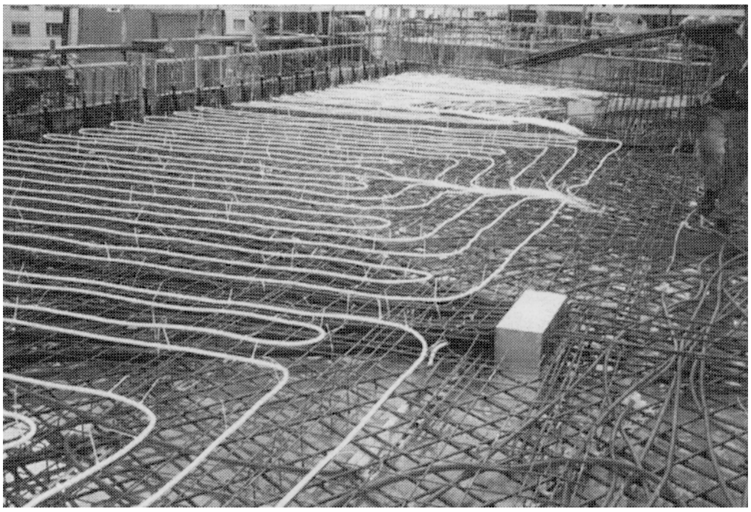

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PREFACE

INTRODUCTION TO THE INTERNATIONAL ENERGY AGENCY

BACKGROUND

The International Energy Agency (IEA) was established in 1974 as an autonomous agency within the framework of the Economic Cooperation and Development (OECD) to carry out a comprehensive program of energy cooperation among its 24 member countries and the Commission of the European Communities.

An important part of the Agency's program involves collaboration in the research, development, and demonstration of new energy technologies to reduce excessive reliance on imported oil, increase long-term energy security, and reduce greenhouse gas emissions. The IEA's R&D activities are headed by the Committee on Energy Research and Technology (CERT) and supported by a small Secretariat staff, headquartered in Paris. In addition, three Working Parties are charged with monitoring the various collaborative energy agreements, identifying new areas for cooperation, and advising the CERT on policy matters.

Collaborative programs in the various energy technology areas are conducted under Implementing Agreements, which are signed by contracting parties (government agencies or entities designated by them). There are currently 40 Implementing Agreements covering fossil fuel technologies, renewable energy technologies, efficient energy end-use technologies, nuclear fusion science and technology, and energy technology information centers.

SOLAR HEATING AND COOLING PROGRAM

The Solar Heating and Cooling Program was one of the first IEA Implementing Agreements to be established. Since 1977, its 21 members have been collaborating to advance active solar, passive solar, and photovoltaic technologies and their application in buildings.

The members are:

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

A total of 30 Tasks have been initiated, 21 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, a number of special ad hoc activities – working groups, conferences, and workshops – have been organized.

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

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	Advanced Solar Low Energy Buildings
Task 14	Advanced 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

Current Tasks and Working Groups:

Task 22	Building Energy Analysis Tools
Task 23	Optimization of Solar Energy Use in Large Buildings
Task 24	Solar Procurement
Task 25	Solar Assisted Cooling Systems for Air Conditioning of Buildings
Task 26	Solar Combisystems Working Group Materials in Solar Thermal Collectors
Task 27	Performance Assessment of Solar Building Envelope Components
Task 28	Solar Sustainable Housing
Task 29	Solar Crop Drying
Task 31	Daylight Buildings in the 21st Century
Task 32	Advanced Storage Concepts for Solar Thermal Systems in Low Energy Buildings
Task 33	Solar Heat for Industrial Process

TASK 22: BUILDING ENERGY ANALYSIS TOOLS

Goal and objectives of the task

The overall goal of Task 22 is to establish a sound technical basis or analyzing solar, low-energy buildings with available and emerging building energy analysis tools. This goal will be pursued by accomplishing the following objectives:

Assess the accuracy of available building energy analysis tools in predicting the performance of widely used solar and low-energy concepts;
Collect and document engineering models of widely used solar and low-energy concepts for use in the next generation building energy analysis tools; and
Assess and document the impact (value) of improved building analysis tools in analyzing solar, low-energy buildings, and widely disseminate research results tools, industry associations, and government agencies.

Scope of the task

This Task will investigate the availability and accuracy of building energy analysis tools and engineering models to evaluate the performance of solar and low-energy buildings. The scope of the Task is limited to whole building energy analysis tools, including emerging modular type tools, and to widely used solar and low-energy design concepts. Tool evaluation activities will include analytical, comparative, and empirical methods, with emphasis given to blind empirical validation using measured data from test rooms of full scale buildings. Documentation of engineering models will use existing standard reporting formats and procedures. The impact of improved building energy analysis will be assessed from a building owner perspective.

The audience for the results of the Task is building energy analysis tool developers and national building energy standards development organizations. 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

In order to accomplish the stated goal and objectives, the Participants will carry out research in the framework of four Subtasks:

Subtask A: Tool Evaluation
Subtask B: Model Documentation
Subtask C: Comparative Evaluation
Subtask D: Empirical Evaluation

Participants

The participants in the Task are: Australia, Canada, Finland, France, Germany, Spain, Sweden, Switzerland, United Kingdom, and United States. The United States serves as Operating Agent for this Task, with Michael J. Holtz of Architectural Energy Corporation providing Operating Agent services on behalf of the U.S. Department of Energy.

This report documents work carried out under Subtask C Comparative Evaluation.

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Executive Summary

This report describes the Radiant Heating and Cooling Test (RADTEST) project conducted by the Model Evaluation and Improvement International Energy Agency (IEA) Experts Group. The group was composed of experts from the Solar Heating and Cooling (SHC) Programme, Task 22, Subtask C.

This report documents a comparative diagnostic procedure for testing the ability of whole-building simulation programs to model the performance of radiant heating and cooling systems. Results from simulation programs that were used in field trials of the test procedure are also presented.

The test cases start from a case taken from the building envelope oriented suite BESTEST from IEA Task 12 / Annex 21 (1995). The configuration of this base case building (Case 800) is a single rectangular zone with heat transfer towards the outside through real construction building envelope. The window is represented as a highly conductive opaque surface. Mechanical equipment specification represents an idealised system without losses and a non proportional (on/off) control.

For the further cases, a second zone is added to this, and in order to isolate the relevant areas, the primary zone is first simplified as near adiabatic. A constant temperature layer is introduced in the floor between the two zones, representing the simplest way of modelling a radiative system. More zone features are progressively added to show the interaction between the zone load and the system.

In this way, eleven cases (including the Envelope BESTEST base case) have been proposed for testing the performance of radiant system models. Two more cases are defined to describe a radiant system in detail, including water loop design and operation.

The specific test cases are designed to test the influence of the following issues:

- Heat transmission through interior construction element
- Presence of internal loads
- Convective model
- Radiation model
- Distribution of radiation
- More realistic zone load
- Influence of highly conductive wall
- Influence of incoming radiation
- Influence of radiative heat source
- Influence of convective heat source

The tests have been performed by five organisations using five different programs as shown in the table below.

The results were produced in a first round as a “blind” test. 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. This helped adding diagnostic possibilities to the test suite.

At the final stage, the specification (part I: user’s manual) was restructured to improve clarity.

Program	Authoring organization	Implemented by
TRNSYS	Transsolar/TUD	TUD, Dresden University of Technology Germany
DOE 2.1E-116	LBNL / HTAL	HANS DÜRIG AG - Simulation für Gebäudeenergie Riggisberg, Switzerland
IDA-ICE 3.0	EQUA AB, Sweden	Lucerne School of Engineering and Architecture, University of Applied Science of Central Switzerland
CLIM2000	EDF	EDF, France
ESP-r/HOT3000	CANMET	CANMET Energy Technology Centre, Ottawa, Canada

Conclusions

The different approaches of modelling radiant heating and cooling systems lead to satisfying results. The simple approach of an active temperature layer, to provide cooling or heating load to the active zone shows a good agreement between the different programs. 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).

Over all, 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 aim of further tests should focus on:

– - Different pipe configurations

– - Different control strategies on different temperature levels.

1 Part I: Radiant Heating and Cooling Test Cases RADTEST User's Manual – Procedure and Specification

1.1 Introduction

Radiant heating and cooling systems are known all over the globe. Radiant heating systems are in use in residential buildings as floor heating systems. The majority of radiant cooling systems are in use in commercial buildings, primarily as ceiling-based systems. In many cases, radiant systems are used for heating and cooling purposes depending on the time of the year.

To take into account the behaviour of radiant heating and cooling in dynamic simulation programs, specific models or modelling methods should be available. Some of these methods are well known, but there is a need to validate these models and methods to improve confidence in them.

From this point of view, the following test cases were developed. To use synergies with former work, the test cases are based on the ENVELOPE BESTEST from IEA Task 12 [1-1].

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 hints to localise the problem for the case where they don't. Additionally, the relation between the simplified approaches and the detailed floor heating and cooling models should be quantified.

1.2 Background

There are several types of radiant heating and cooling 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 behaviour 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 cooling beams which are at least a small water cooled panel placed on the bottom of the ceiling. Also, well known systems 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 during night time, when low temperature heat sink possibilities are available.

1.3 General Description

1.3.1 Overview of the Test Cases

The purpose of this specification is to create a uniform set of unambiguous test cases for a software to software diagnostic 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 modelling complexity).

The procedure 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. Look at tables 1-11 thru 1-13 to get an overview of the different test cases.

The RADTEST contains 14 runs. It starts with case 800 and proceeds to case 2810. Case 800 is a rectangular single zone model with high thermal mass, an opaque window, without ground coupling. At this stage the zone model corresponds to case 800 from the ENVELOPE BESTEST. The meaning of this case is that the user has a benchmark for his model. If any results fail at this stage, the modeller should run first the diagnostics cases from ENVELOPE BESTEST [1-1].

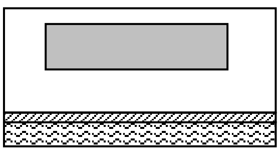
In cases 1800 to 1830 the active zone is modelled as a highly insulated zone and a second, unconditioned, semi-adiabatic zone is inserted below the primary zone. In cases 1800 and 1805 the heat flow between the zones is observed. From case 1810 upwards, a constant temperature layer is placed within the floor construction (e.g. floor heating system, dummy zone with constant temperature between floor constructions). The behaviour of the heat transfer to the active zone is observed in detail. In case 1840 the insulated envelope is removed. An opaque window and afterwards a real window are inserted in the model. At this model stage, several control strategies with different set points and different schedules for the temperature layer are tested.

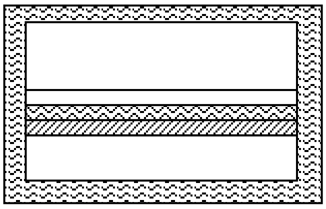
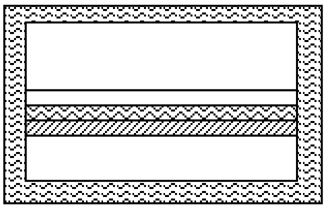
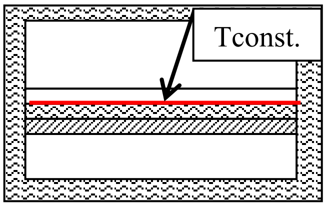
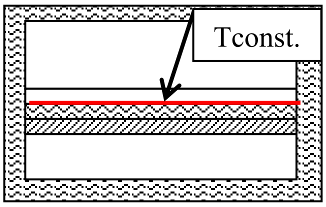
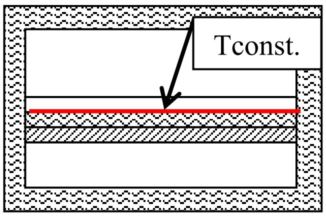
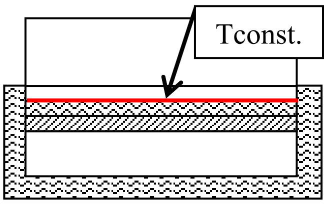
For all tests, the primary zone is held to constant set points with an ideal convective heating and cooling system. The power and energy demand of these systems are observed parameters.

For diagnostics of the building envelope component models, the diagnostic test set from ENVELOPE BESTEST [1-1] is adapted. For the system strategies, a new set of diagnostic cases is produced if necessary.

The complex test case contains a description of a real floor heating system. At this stage, it is up to the modeller to model this system in the most detailed way the program allows. The goal of this test is on one hand to compare the complex case result with the simple one, and on the other hand to compare the different modelling approaches.

Table 1-1 Simple Test Cases

CASE	Graphic	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**

CASE	Graphic	Description	Test objective
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

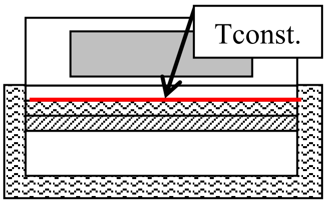
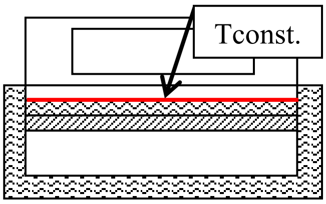
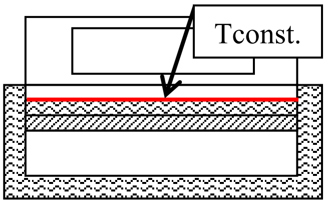
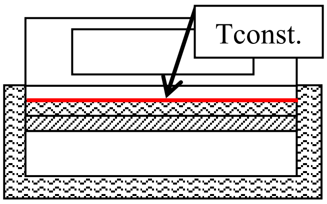
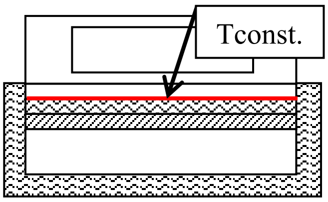
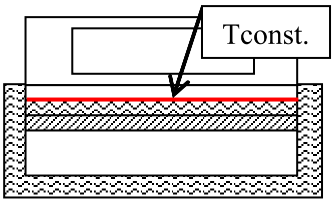
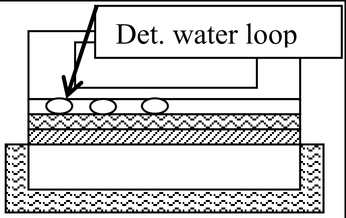
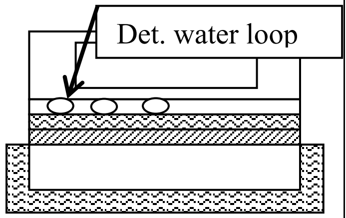
CASE	Graphic	Description	Test objective
1840		“Opaque window” is added. Internal Loads set to case 800 values	Influence of highly conductive wall
1850		Real window is introduced	Influence of incoming radiation
1860		Equal to case 1850 but the internal gains are only radiative	Influence of radiative heat source
1870		Equal to case 1850 but the internal gains are only convective	Influence of convective heat source
1880		Lower level of the constant layer temperature Setpoints for summer 18°C and winter 30°C	Influence of temperature change on heating and cooling energy demand
1890		Similar to case 1850, but during summer time, the temperature layer setpoint is only active from 8 pm to 6 am	Influence of interrupted operation on cooling energy demand

Table 1-2 Detailed Model Case Descriptions

CASE	Graphic	Description	Test objective
2800		Real case with detailed water loop model Whole year 24h/d massflow	
2810		Real case with detailed water loop model During summer time massflow provided only from 8 pm to 6am.	

1.3.2 How to use RADTEST

RADTEST is built as a stand alone test suite. The basic case 800 is adapted from the ENVELOPE BESTEST [1-1]. However, all specifications to run all cases are included in this paper.

Begin with case 800, which is a high mass building construction with an “opaque window” and without ground coupling. Case 800 corresponds to case 800 from ENVELOPE BESTEST. If the results appear reasonable, go to case 1800. If they do not correspond to reference results, go back to the ENVELOPE BESTEST diagnostic test cases.

From 1800 run all cases up to 1850. For these cases, use the description 1.4.2 to 1.4.9. The tests 1860 to 1890 have a similar description to 1850, but with different internal gains and different control strategies. If all the results appear reasonable – start with the design of the detailed cases 2800 and 2810. If these results show a good agreement, then the delta between the simplified cases 1850 and 1890 shall be compared with the cases 2800 and 2810 .

If anomalous results are observed, the reason for the disagreement should be located by evaluating the last added feature or in an element depending on this added element.

1.3.3 Model Approach: Rules for Performing the Test

- Use the most detailed level of modelling your program allows.
- Do not use constant combined convective and radiative film coefficients if your program can calculate surface radiation and convection in a more detailed or physically correct manner.
- If your program allows for initialisation or preconditioning (iterative simulation of an initial time period until temperatures and/or fluxes stabilize at initial values), then use that capability.
- If your program includes the thickness of walls in a three-dimensional definition of the building geometry, then wall, roof, and floor thickness should be defined such that the interior air volume of the building remains as specified (6m x 8 m x 2.7m = 129.6m3). Make the thicknesses extend exterior surfaces in addition to the currently defined internal volume.

- All references to time in this specification are to solar time, and assume that 1 hour equals the interval from midnight to 1 a.m. Do not use daylight saving time or holidays for scheduling.
- In some instances, the specification will include input values that do not apply to the input structure of your program. For example, your program may not allow adjustment for infrared emissivities. When this occurs, either use approximation methods suggested in your users manual, or simply disregard the non applicable inputs, and continue. Such inputs are in the specification for those programs that may need them.

1.4 Specific Input Information

1.4.1 Case 800: Base Case

1.4.1.1 Weather

Use the weather file (TMY) from disc supplied in the package. Site and weather characteristics are summarized in Table 1-3.

Table 1-3. Site and Weather Summary

Weather Type	Cold clear winters / Hot dry summers
Weather format	TMY
Latitude	39.8° north
Longitude	104.9° west
Altitude	1609 m
Time Zone	7
Ground reflectivity	0.2
Site	Flat, unobstructed, located exactly at weather station
Mean annual wind speed	4.02m/S
Ground temperature	10°C
Mean annual ambient dry-bulb temperature	9.71°C
Minimum annual ambient dry-bulb temperature	-24.39°C
Maximum annual ambient dry-bulb temperature	35.00°C
Maximum annual wind speed	14.89 m/S
Heating degree days (base 18.3°C)	3636.2°C-das
Cooling degree days (base 18.3°C)	487.1°C-days
Mean annual dew point temperature	-1.44°C
Mean annual humidity ratio	0.0047
Global horizontal solar radiation annual total	1831.82 kWh/m2 a
Direct normal solar radiation annual total	2353.58 kWh/m2 a
Direct horizontal solar radiation	1339.48 kWh/m2 a
Diffuse horizontal solar radiation	492.34 kWh/m2 a

1.4.1.2 Ground Coupling/ Adiabatic Zone

The floor insulation is made very thick to effectively decouple the floor thermally from the ground. The ground temperature is set to 10°C.

1.4.1.3 Drawings and Plans

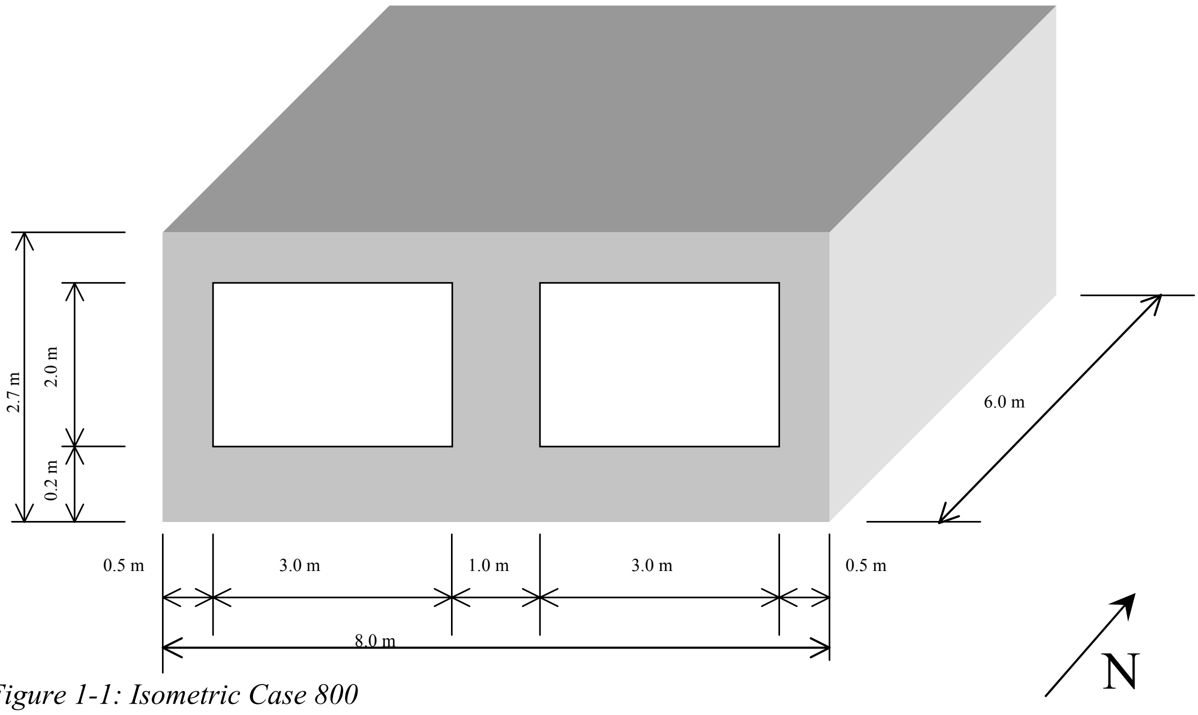


Figure 1-1: Isometric Case 800

1.4.1.4 Material specifications

Table 1-4: Material Specifications; Heavyweight Case (Metric)

Floor (inside to ground)

ELEMENT	k (W/mK)	Thickness (m)	U (W/m2K)	R (m2K/W)	Density (kg/m3)	CP (J/kgK)
Int. Surf Coeff.			8.290	0.121		
Concrete slab	1.130	0.080	14.125	0.071	1400.000	1000.000
Insulation	0.040	1.007	0.040	25.175	10.000	1400.000
Total air-air			0.039	25.366		
Total surf - surf			0.040	25.246		

Exterior Wall (inside to outside)

ELEMENT	k (W/mK)	Thickness (m)	U (W/m2K)	R (m2K/W)	Density (kg/m3)	CP (J/kgK)
Int. Surf Coeff. (see note 2)			8.290	0.121		
Concrete block	0.510	0.100	5.100	0.196	1400.000	1000.000
Foam Insulation	0.040	0.0615	0.651	1.537	10.000	1400.000
Wood Siding	0.140	0.009	15.556	0.064	530.000	900.000
Ext. Surf Coeff.			29.300	0.034		
Total air-air			0.512	1.952		
Total surf - surf			0.556	1.797		

Roof (inside to outside)

ELEMENT	k (W/mK)	Thickness (m)	U (W/m2K)	R (m2K/W)	Density (kg/m3)	CP (J/kgK)
Int. Surf Coeff.			8.290	0.121		
Plasterboard	0.160	0.010	16.000	0.063	950.000	840.000
Fiberglas quilt	0.040	0.1118	0.358	2.794	12.000	840.000
Roofdeck	0.140	0.019	7.368	0.136	530.000	900.000
Ext. Surf. Coeff..			29.300	0.034		
Total air-air			0.318	3.147		
Total surf - surf			0.334	2.992		

Surface Summary

Component	Area (m2)	UA (W/K)
Wall	63.6	32.580
Floor - near adiabatic	48.0	1.892
Roof	48.0	15.253
South “window” (highly conductive wall)	12.0	36.000
Infiltration		18.440 (see Note 1)

ACH	VOLUME (m3)	Altitude (m)
0.5	129.6	1609.000

Note 1: Infiltration derived from: ACH*Volume*(specific heat of air)*(air density at specific altitude)

Note 2: The interior film coefficient for floors and ceilings is a compromise between upward and downward heat flow for summer and winter.

1.4.1.5 High conductance Wall / Opaque Window

An element that may be thought of as a highly conductive wall or an opaque window is used. The properties of this element are as follows:

- Short wave transmittance = 0
- Interior and exterior infrared emissivities are the same as for the normally insulated wall
- Interior combined surface coefficient is 8.29 W/m^{2}K and exterior combined surface coefficient is 21 W/m^{2}K for cases were infrared emissivity is 0.9
- Exterior solar absorption is the same as for normally insulated walls
- Conductance, density, specific heat, and surface texture (very smooth) are the same as for the transparent window (See section 1.4.9.1)

1.4.1.6 Infiltration

The infiltration air exchange rate in the primary zone is set to 0.5.

If the program does not use barometric pressure from the weather data, or other automatic correction for the change in air density due to altitude, then adjust the specific infiltration rates to yield mass flow equivalent to what would occur at the specific altitude as shown in Table 1-5.

Table 1-5 Air changes for the primary zone

Altitude adjustment algorithm	Input air changes per hour (ACH)	Adjustment factor
Programs with automatic altitude adjustment	0.50	1
Programs with fixed assumption that site is at sea level (no automatic adjustment)	0.41	0.822 *

Specified rate * 0.822 = (altitude adjusted rate)

1.4.1.7 Internally Generated Heat (Casual Gains)

The internal heat is used to take into account heat gains from people, lights and equipment. For all cases the internal heat is 100% sensible and 0% latent.

Table 1-6 Internal Gain

Case	Gain (W)	Radiative portion	Convective portion
800	200	60 %	40%

1.4.1.8 Exterior Combined Radiative and Convective Surface Coefficients

If the program calculates exterior surface radiation and convection automatically, this section may be disregarded. If the program does not calculate this effect, use the information given in Table 1-7.

Table. 1–7 Exterior Surface Coefficient

Surface texture	Specified Emissivity E = 0.9
Brick or rough plaster (all walls and roof)	29.3 W/m2K
Glass or very smooth surface (Window and high conductive wall)	21.0 W/m2K

The exterior combined radiative and convective surface conductance for the glass and very smooth opaque surface are specified as equivalent for the convenience of input, even though the infrared emissivity for common window glass is usually 0.84.

Rain causes the surface temperature to rapidly approach the water temperature. Provide documentation if your program treats rain as a special case.

1.4.1.9 Interior Combined Radiative and Convective Surface Coefficients

If the program calculates interior surface radiation and convection, disregard this section. If the program does not calculate these effects, use the following American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) constant combined radiative and convective coefficients as shown in Table 1-8.

Table 1-8 Interior surface coefficient

Orientation of surface and heat flow	Specified Emissivity E = 0.9	
	Combined	Radative
Horizontal heat transfer on vertical surfaces	8.29 W/m2K	5.13 W/m2K
Upward heat transfer on horizontal surfaces	9.26 W/m2K	5.13 W/m2K
Downward heat transfer on horizontal surfaces	6.13 W/m2K	5.13 W/m2K

1.4.1.10 Mechanical System and Control

An ideal mechanical system is used to control the temperature of the primary zone. This means that the equipment has a 100% efficiency, with no duct losses and no capacity limitations. It has the following characteristics:

- Heat capacity = 1000 kW (effectively infinite)
  Purely convective
- Cooling capacity = 1000 kW (effectively infinite)
  Purely convective, sensible cooling only; no latent load calculation

The thermostat is non proportional in the sense that when the air temperature exceeds the thermostat cooling set point, the heat extraction rate is assumed to equal the maximum capacity of the cooling equipment. Likewise, when the air temperature drops below the thermostat heating set point, the heat addition rate equals the maximum capacity of the heating equipment. A proportional thermostat model can be made to approximate a non proportional thermostat model by setting a very small throttling range (the minimum allowed by your program). The set points are:

Heating = on if temp < 20°C

Cooling = on if temp > 27°C

1.4.2 Case 1800

Case 1800 is the same as the base case 800 except for the following specifications.

1.4.2.1 Ground Coupling/ Adiabatic Zone

A second “basement” zone is specified. This zone is a nearly adiabatically insulated box except for the top of this box which is connected to the floor of the primary zone. Walls and floor of the basement face to ground with a constant temperature of 10 °C.

The basement is a free floating zone with no system equipment and without any control.

1.4.2.2 Drawings and Plans

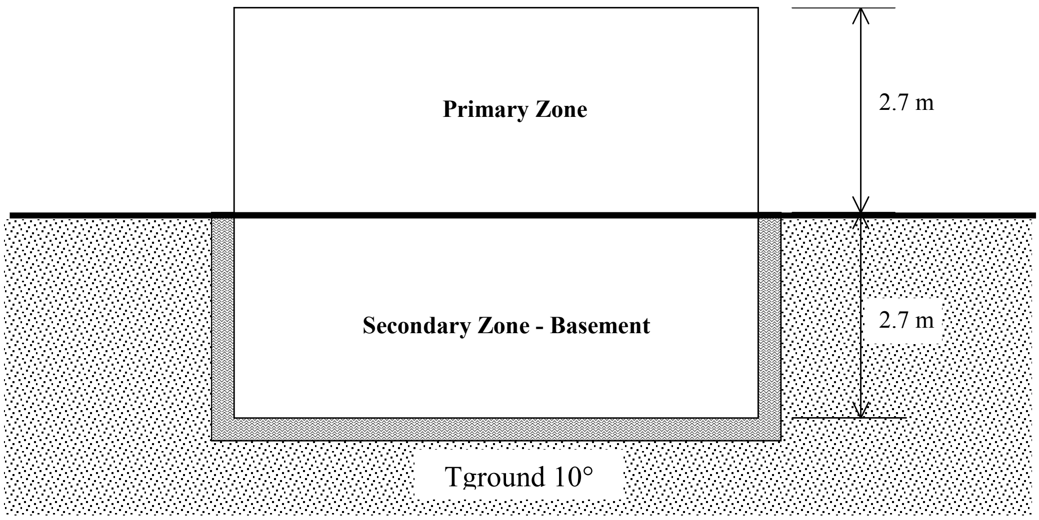


Figure 1-2 Cross Section

1.4.2.3 Material specifications

Table 1-9 Material Specifications (Metric)

Exterior Wall (inside to outside)

ELEMENT	k (W/mK)	Thickness (m)	U (W/m2K)	R (m2K/W)	Density (kg/m3)	CP (J/kgK)
Int. Surf Coeff. (see note 2)			8.290	0.121		
Concrete block	0.510	0.100	5.100	0.196	1400.000	1000.000
Foam Insulation	0.040	1.004	0.651	25.1	10.000	1400.000
Wood Siding	0.140	0.009	15.556	0.064	530.000	900.000
Ext. Surf Coeff.			29.300	0.034		
Total air-air			0.039	25.515		
Total surf - surf			0.039	25.360		

Roof (inside to outside)

ELEMENT	k (W/mK)	Thickness (m)	U (W/m2K)	R (m2K/W)	Density (kg/m3)	CP (J/kgK)
Int. Surf Coeff.			8.290	0.121		
Plasterboard	0.160	0.010	16.000	0.063	950.000	840.000
Foam Insulation	0.040	1.004	0.0398	25.1	10.000	1400.000
Roofdeck	0.140	0.019	7.368	0.136	530.000	900.000
Ext. Surf. Coeff..			29.300	0.034		
Total air-air			0.039	25.454		
Total surf - surf			0.040	25.299		

Floor (inside to basement)

ELEMENT	k (W/mK)	Thickness (m)	U (W/m2K)	R (m2K/W)	Density (kg/m3)	CP (J/kgK)
Int. Surf Coeff.			8.290	0.121		
Concrete slab	1.130	0.080	14.125	0.071	1400.000	1000.000
Insulation	0.040	0.050	0.800	1.250	10.000	1400.000
Reinforced concrete	1.800	0.200	9.000	0.111	2400.000	1100.000
Int. Surf Coeff.			8.290	0.121		
Total air-air			0.597	1.674		
Total surf - surf			0.698	1.432		

Wall basement (inside to ground)

ELEMENT	k (W/mK)	Thickness (m)	U (W/m2K)	R (m2K/W)	Density (kg/m3)	CP (J/kgK)
Int. Surf Coeff.			8.290	0.121		
Insulation	0.040	1.007	0.040	25.175	10.000	1400.000
Total air-air			0.040	25.296		
Total surf - surf			0.040	25.175		

Surface Summary

Component	Area (m2)	UA (W/K)
Wall	75.6	38.727
Floor - 3 Layer	48.0	28.656
Roof	48.0	15.253
Basement Floor	48.0	1.892
Basement Wall	75.6	2.988

1.4.2.4 Highly Conducting Wall / Opaque Window

The highly conducting wall is removed.

1.4.2.5 Infiltration

Infiltration is set to 0.

1.4.2.6 Internally Generated Heat (Casual Gains)

Internal gains are set to 0.

1.4.3 Case 1805

Case 1805 is the same as case 1800 except for the following specifications.

1.4.3.1 Infiltration

Infiltration is set to 1.0, with the same adjustment as for the base case (see section 1.4.1.6).

1.4.3.2 Internally Generated Heat (Casual Gains)

Table 1-10 Internal Gain

Case	Gain (W)	Radiative portion	Convective portion
1805	200	0 %	100%

1.4.4 Case 1810

Case 1810 is the same as case 1805 except for the following specifications.

1.4.4.1 Constant Temperature Layer

A constant temperature layer is inserted in the floor construction between the top concrete slab and the insulation layer.

Its temperature is maintained constantly at the following values:

Winter Period (from October 1 to April 30):	40°	24 hours/day
Summer Period (from May 1 to September 30):	20°	24 hours/day

1.4.4.2 Floor surface heat transfer

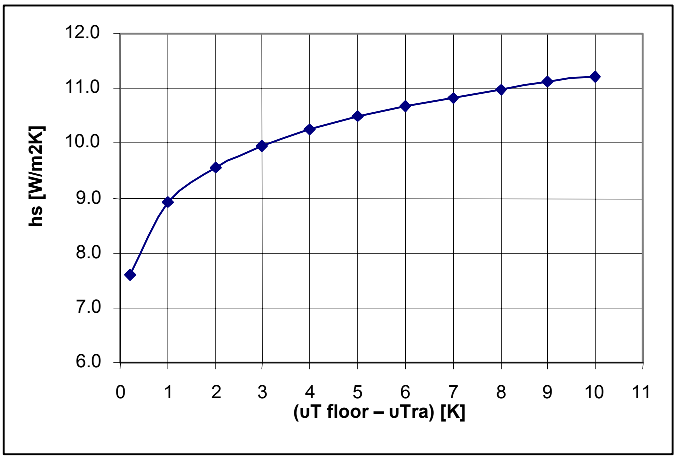
If your program allows it, the surface coefficients for the heated/cooled floor and ceiling shall be specified by the method developed by EMPA [1-2] as follows:

For floor heating systems the combined surface coefficient is a function of the difference between the mean floor temperature and the room-temperature.

$$h_s = 8.92*(\upsilon T_{floor} - \upsilon T_{ra})^{0.1}$$

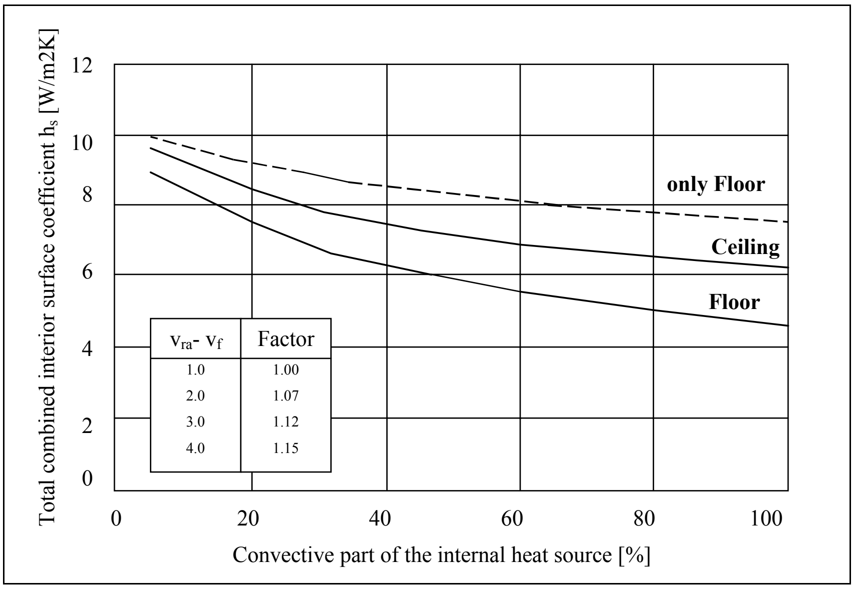
h_s Total combined interior surface coefficient [W/m^{2}K]
υT_{floor} Mean floor heat layer temperature [°C]
υT_{ra} Room temperature [°C]

Diagram 1-1 Combined interior surface coefficient for floor heating system



For the cooling case, the surface coefficient depends on the convective fraction of the heat sources. The dependency is shown in Diagram 1-2

Diagram 1-2 Combined interior surface coefficient for radiant cooling systems with $(\upsilon T_{ra} - \upsilon T_{floor}) = 1K$



Only floor: One conditioned surface (either floor or ceiling). Use this function for the Radtest

Ceiling: Combined surface coefficient for ceiling if the floor is conditioned at the same time.

Floor: Combined surface coefficient for floor if the ceiling is conditioned at the same time.

For other temperature differences h_s is multiplied with the factor in Diagram 1-2 or with the calculated value with:

$$h_{s,eff} = h_s(\upsilon T_{ra} - \upsilon T_{floor})^{0.1}$$

$h_{s,eff}$ Corrected Total combined interior surface coefficient [W/m^2K]
h_s Total combined interior surface coefficient [W/m^2K]
υT_{floor} Mean floor heat layer temperature [°C]
υT_{ra} Room temperature [°C]

As a deviation from the above description, for case 1810 the heat transfer on the top surface of the floor shall be assumed to be purely convective, but using the values for the combined coefficient.

1.4.5 Case 1815

Case 1815 is the same as case 1810 except for the following specifications.

1.4.5.1 Floor surface heat transfer

The heat transfer on the top surface of the floor is assumed to be combined radiative and convective according to the program's assumptions. If there is a need for a definition, assume 45 % to be convective. The radiative portion is connected only to the ceiling.

1.4.6 Case 1820

Case 1820 is the same as case 1815 except for the following specifications.

1.4.6.1 Floor surface heat transfer

The radiative portion of the floor surface heat transfer is connected to all surfaces according to the program's normal assumptions.

1.4.7 Case 1830

Case 1830 is the same as case 1820 except for the following specifications.

1.4.7.1 Exterior Walls

The wall and roof constructions of the primary zone are replaced by the ones from case 800 (see section 1.4.1.4).

1.4.7.2 Infiltration

The infiltration air exchange rate in the primary zone is set to 0.5 with the same assumptions as in case 800 (see section 1.4.1.6).

1.4.8 Case 1840

Case 1840 is the same as case 1830 except for the following specifications.

1.4.8.1 High conductance Wall / Opaque Window

The high conductance wall / opaque window from case 800 is introduced in the south (see section 1.4.1.5).

1.4.8.2 Internally Generated Heat (Casual Gains)

The internal heat gains are set to the values of case 800 (see section 1.4.1.7).

1.4.9 Case 1850

Case 1850 is the same as case 1840 except for the following specifications.

1.4.9.1 Transparent Window

The high conductance wall / opaque window is replaced by a real transparent window.

Many programs use different algorithms to calculate window transmittance, and therefore require different inputs. Therefore, a great deal of information about the window properties is provided so that equivalent input for the window will be possible for these programs. The basic properties of the window are provided in Table 1-11. The angular dependence of direct beam transmittance is given in Table 1-12. Additional information can be found in the glazing tables that were derived from Snell's Law, Bouger's Law , and the Fresnel Equation (Appendix E). For Programs that need transmittance or reflectance at other angles of incidence, calculate them using equations given with the glazing tables, or interpolate between the values in the glazing tables. Where other unspecified data is needed, then values that are consistent with those tabled will have to be calculated. For more information on glazing optical properties see Appendix E of ENVELOPE BESTTEST [1-1].

Tab. 1-11 Window properties

Property	Value
Extinction coefficient	0.0196/mm
Number of panes	2
Pane thickness (standard 1/8” glass under the inch-pound [IP] system)	3.175 mm
Air-gap thickness	13 mm
Index of refraction	1.526
Normal direct-beam transmittance through one pane in air	0.86156
Conductivity of glass	1.06 W/mK
Conductance of each glass pane	333 W/m2K (R- 0.003 m2K/W)
Combined radiative and convective coefficient of air gap (hs)	6.297 W/m2K (R- 0.1588 m2K/W)
Exterior combined surface coefficient (ho)	21.00 W/m2K (R- 0.0476 m2K/W)
Interior combined surface coefficient (hi)	8.29 W/m2K (R- 0.1206 m2K/W)
U-value from interior air to ambient air	3.00 W/m2K (R- 0.3333 m2K/W)
Hemispherical infrared emittance of ordinary uncoated glass	0.84 (use 0.9 for simplicity of input. If your program must use 0.84, this is acceptable because the effect on outputs will be less than 0.5%.)
Density of glass	2500 kg/m3
Specific heat of glass	750 J/kgK
Curtains, blinds, frames, spacers; mullions, obstructions inside the window	None
Double pane shading coefficient (at normal incidence)	0.916
Double pane solar heat gain coefficient (at normal incidence)	0.787

Table 1-12 Angle Dependence of direct-beam transmittance[a] for double pane window

Angle of incidence	0	10	20	30	40	50	60	70	80
Transmittance	0.74745	0.74682	0.74465	0.73989	0.72983	0.70733	0.65233	0.51675	0.26301

[a]Transmittance is defined as total direct-beam transmittance through the window assembly (no other solar absorbtance or reflectance, or transmission of radiation reflected from the room back out the window is included in these values)

1.4.9.2 Interior Solar Distribution

If your program does not calculate this effect internally, but requires distribution fractions from the user, assume that 100% of the incoming radiation strikes the floor first, and that all reflections are diffuse. Table 1-13 presents an approximate calculation of solar distribution fractions. Only use these approximations if your program does not provide a more detailed approach.

Table 1-13 Interior Solar distribution fraction versus window orientation and interior short-wave absorbance

Surface	Fraction [-]
Floor	0.642
Ceiling	0.168
North wall	0.053
East Wall	0.038
South Wall	0.026
West Wall	0.038
Solar lost through window	0.035

Appendix F of ENVELOPE BESTEST [1-1] has a detailed description of the algorithm used for calculating these solar fractions. Briefly, the calculations assume that:

- No solar radiation is directly absorbed by the zone air.
- All incident solar radiation initially hits the floor
- The fraction or radiation initially absorbed by the floor is the interior short-wave absorbance
- The remaining solar radiation is diffusely reflected such that it is distributed over the other surfaces in proportion on their shape factors (Kreith and Bohn 1993)
- The fraction of radiation absorbed by these surfaces is the interior short-wave absorbance.
- The remaining amount of the original as sunlight (after the second "bounce") is then assumed to be absorbed by all surfaces in proportion to their area-absorbance products.

Fractional values for the walls with windows include the portion of the solar radiation absorbed by the glass (as it passes back out the window) and conducted into the zone. Solar radiation absorbed by the glass (and conducted inwards) as it passes into the buildings is treated by most programs in their window transmissivity algorithms, and is therefore not included in the values in Table 1-8.

1.4.10 Case 1860

Case 1860 is the same as case 1850 except for the following specifications.

1.4.10.1 Internally Generated Heat (Casual Gains)

The internal heat gains are assumed to be 100 % radiative.

1.4.11 Case 1870

Case 1870 is the same as case 1850 except for the following specifications.

1.4.11.1 Internally Generated Heat (Casual Gains)

The internal heat gains are assumed to be 100 % convective.

1.4.12 Case 1880

Case 1880 is the same as case 1850 except for the following specifications.

1.4.12.1 Constant Temperature Layer

The temperatures of the constant temperature layer are set to the following values:

Winter Period (from October 1 to April 30):	30°	24 hours/day
Summer Period (from May 1 to September 30):	18°	24 hours/day

1.4.13 Case 1890

Case 1890 is the same as case 1850 except for the following specifications.

1.4.13.1 Constant Temperature Layer

The constant temperature layer is operated in the following manner:

Winter Period (from October 1 to April 30):	40°	24 hours/day
Summer Period (from May 1 to September 30):	20°	on from 20:00 to 6:00

1.4.14 Case 2800

Case 2800 is the same as case 1850 except for the following specifications.

1.4.14.1 Detailed water loop

The most detailed possible model shall be used with the following data:

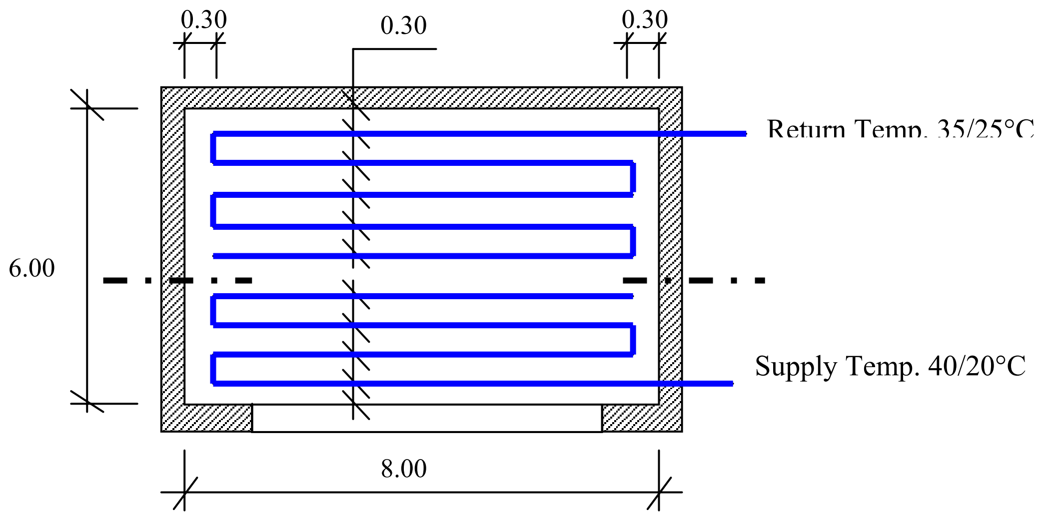


Figure 1-3: Floor plan for detailed cooling system: Case 2800/2810

Table 1-14: System parameters

Design Cooling Power	3500 W
Massflow	0.167 kg/s
Design supply temperature Winter/Summer	40/20 °C
Design return temperature Winter/Summer	35/25 °C

Table 1-15: Water pipe specifications

Material	PEX
Outside diameter	0.025 m
Inner diameter	0.020 m
Total pipe length	139.2 m
Roughness	0.007 mm
Density	938 kg/m3
Conductivity	0.35 W/mK

The flow temperatures of the detailed water loop (floor heating and cooling system) are set as follows:

Winter Period (from October 1 to April 30): 40° 24 hours/day
Summer Period (from May 1 to September 30): 20° 24 hours/day

1.4.15 Case 2810

Case 2810 is the same as case 2800 except for the following specifications.

1.4.15.1 Detailed Water Loop Operation

Winter Period (from October 1 to April 30): 40° 24 hours/day
Summer Period (from May 1 to September 30): 20° on from 20:00 to 6:00

1.4.16 Summarised Input Values Table

Table 1-16 Summarised input values table

Case	Setp.	INTGEN			ACH	INT IR	EXT IR	INT SW	EXT SW	GLASS	LAYER			SCHED	NEXT
	H , C	W	RAD	CONV	INFIL	EMISS	EMISS	ABSORP	ABSORP	m2 ORIENT	CONS	LOC	TEMP	h	TO
800	20, 27	200	0.6	0.4	0.5	0.9	0.9	NA	0.6	HC-W / S	AD	NA	NA	NA	AD
1800	20, 27	0	0	0	0	0.9	0.9	NA	0.6	0	3L	Mid	NA	NA	BA
1805	20, 27	200	0	1.0	1.0	0.9	0.9	NA	0.6	0	3L	Mid	NA	NA	BA
1810	20, 27	200	0	1.0	1.0	0.9	0.9	NA	0.6	0	3L	Mid	40/20	24	BA
1815	20, 27	200	0	1.0	1.0	0.9	0.9	NA	0.6	0	3L	Mid	40/20	24	BA
1820	20, 27	200	0	1.0	1.0	0.9	0.9	NA	0.6	0	3L	Mid	40/20	24	BA
1830	20, 27	200	0	1.0	0.5	0.9	0.9	NA	0.6	0	3L	Mid	40/20	24	BA
1840	20, 27	200	0.6	0.4	0.5	0.9	0.9	0.6	0.6	HC-W / S	3L	Mid	40/20	24	BA
1850	20, 27	200	0.6	0.4	0.5	0.9	0.9	0.6	0.6	12 / S	3L	Mid	40/20	24	BA
1860	20, 27	200	1.0	0.0	0.5	0.9	0.9	0.6	0.6	12 / S	3L	Mid	40/20	24	BA
1870	20, 27	200	0.0	1.0	0.5	0.9	0.9	0.6	0.6	12 / S	3L	Mid	40/20	24	BA
1880	20, 27	200	0.6	0.4	0.5	0.9	0.9	NA	0.6	12 / S	3L	Mid	30/18	24	BA
1890	20, 27	200	0.6	0.4	0.5	0.9	0.9	NA	0.6	12 / S	3L	Mid	40/20	24/10	BA
2800	20, 27	200	0.6	0.4	0.5	0.9	0.9	0.6	0.6	12 / S	3L	Mid	40/20	24	BA
2810	20, 27	200	0.6	0.4	0.5	0.9	0.9	0.6	0.6	12 / S	3L	Mid	40/20	24/10	BA

Abbreviations

H, C	Heating and Cooling	LAYER	Active temperature layer
INTGEN	Internal gains	- CONS	Floor construction AD= adiabatic,
ACH INFIL	Air changes per hour infiltration		1L = 1layer, 3L = 3 layers
INT / EXT IR EMISS	Internal /external infrared emissivity	- LOC	Location of active layer
INT / EXT SW ABSORP	Internal/external short-wave absorption	- TEMP	Temperature of active layer
ORIENT	Orientation S = south	SCHED	Schedule of active layer
HC-W / S	Highly conductive wall / south	NEXT TO	Boundary from the floor of active zone AD =
NA	Not active. No input value required		Adiabatic floor, BA = Basement

1.4.17 Required Outputs

All results should be inserted in the pre-formatted EXCEL sheet (RAD_RES.xls) on the enclosed CD. Instructions for using the spreadsheet are included at the top of the sheet and in Section 6.

1.4.17.1 Annual Outputs

The annual outputs are as follows:

Primary zone

- Annual Heating and Cooling loads for all cases (MWh).
- Annual hourly integrated peak heating and cooling loads (kW) with the data and hour when they occur.
- Annual hourly integrated maximum and minimum room temperature (°C) with date and hour when they occur.
- Annual hourly integrated maximum and minimum floor surface temperature (°C) with date and hour when they occur.

Secondary Zone (Basement)
Annual hourly integrated maximum and minimum room temperature (°C) with date and hour when they occur.

Detailed water loop
Annual hourly integrated maximum and minimum return water temperature (°C)

1.4.17.2 Daily Hour Outputs

If the program can produce hourly outputs, produce the hourly values for the specific day periods as shown in Table 1-17. To produce this output, run the program for normal annual run. Do not just run the required days because your result could contain temperature history errors.

Table 1-17 Hourly output files

Hourly outputs	Case number	Day
Hourly room temperatures (°C) (Primary zone and basement)	all	Jan 2-5./July 27-30
Hourly floor surface temperature of primary zone	1820 to 2810	Jan 2-5./July 27-30
Hourly heating(+) and cooling (-) (kWh) (designate cooling with a (-) sign)	all	Jan 2-5./July 27-30
Upward heat (+) and cool (-) flow from temperature layer	1810 to 2810	Jan 2-5./July 27-30
Downward heat (+) and cool (-) flow from temperature layer	1810 to 2810	Jan 2-5./July 27-30
Return water temperature (°C)	2800 to 2810	Jan 2-5./July 27-30

Table 1-18 Required Outputs

Case	**Zone 1**				**Zone 2**	**L to Z***		**Water loop**	**Description**
	T room	T floor	Q heat	Q cool	T room	Heat flux		Return water temperature	
						UP	DOWN		
800									Opaque window basic case 800 from ENVELOPE-BESTEST
1800									Fully insulated 2 zone model
1805									Internal and external loads
1810									Active layer only convective
1815									Radiation only to ceiling
1820									Normal distribution to all surfaces
1830									Normal insulated construction
1840									Opaque window
1850									Real Window
1860									Influence of internal gains 100% rad.
1870									Influence of internal gains 100% conv.
1880									Lower temp. level case
1890									Schedule for summer 8pm to 6am
2800									Detailed water loop
2810									Detailed water loop

* Active layer to zone

1.4.17.3 Excelsheet

Pre-formatted EXCEL sheet for required output data. Please fill the generated yearly hourly values in the predefined folder (case number) in the EXCEL sheet called RAD_RES.xls. The daily output will automatically be extracted from the yearly values.

1.5 References

[1-1] Judkoff R., Neymark J. (1995) ENVELOPE BESTEST: *Building Energy Simulation Test and Diagnostic Method*. International Energy Agency, Solar Heating and Cooling Programm -Task 12 and Buildings and Community Systems Annex 21, NREL/TP-472-6231

[1-2] Koschenz M., Lehmann B. (2000): Thermoaktive Bauteile; EMPA, Zentrum für Energie und Nachhaltigkeit (ZEN), 8600 Dübendorf, Switzerland, ISBN 3-905594-19-6

2 Part II: Production of Example Results

2.1 Participating Organisations

The final results of the participant of the IEA Task 22 RADTEST are presented in this report. The interpretation of the results refer to the programs listed in table 2-1.

Table 2-1: Participating programs and authors

	Authoring organization	**Implemented by**
TRNSYS	Transsolar/TUD	TUD, Dresden University of Technology Germany
DOE 2.1E	LBL	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	EDF, France
ESP-r/HOT3000	CANMET	CANMET Energy Technology Centre, Ottawa, Canada

The results were produced in a first round as a blind test. This is a good solution to improve the test specification. According 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 modelled errors are listed in section 2.5 “modeller reports”.

2.2 Interpretation of Results

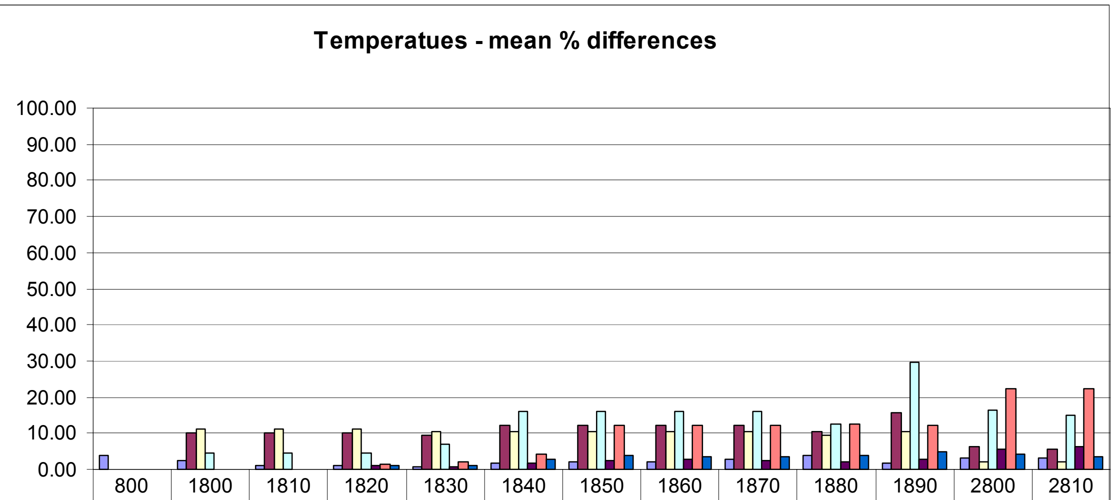
2.2.1 “Overall” and “Delta” Results (Section 2.4.1 and 2.4.2)

The final results from the participating programs are presented in tables and diagrams. There are no maximum and minimum ranges set for the diagnostic cases, because diagnostics will be performed by specialists for whom such simplifications will not be necessary. The ranges of the participating programs do not represent truth. They do represent the best current state-of-the-art in whole building simulation predictions for radiant heating and cooling systems. There is no truth standard in this type of exercise. For any given case, a program that yields values in the middle of the range should not be perceived as better or worse than a program that yields values at the border of the range. The range represents algorithmic differences in the current state-of-the-art as defined by the group of international experts from IEA TASK 22. Investigating the source(s) of the difference(s) is worthwhile, but the existence of a difference does not necessarily mean a program is faulty. The experience in that field shows, that when programs show a major disagreement with a range, often a bug or questionable algorithms can be found. The results show a certain amount of disagreement among the programs for many of the cases. The reference ranges reflect this disagreement.

There is a large amount of output data. Not all results can be described in detail. Some trends are apparent as evidence in the section overall results (Section 2.4.1 and 2.4.2). Observing the results from cases 1800 up to 2810, the results are not varying extremely. The criteria to judge the deviation of the results is the deviation from case 800, which correspond to the boundaries of case 800 from ENVELOPE BESTEST. It presents the spread of more than the five participating programs. All cases without the radiant floor system (case 800 to 1810) show a good agreement with the deviation boundaries from ENVELOPE BESTEST.

Observing the results from case 1815 up to 2810, the results are not varying extremely. The deviation of the room and surface temperatures shows an almost homogeneous behaviour. As listed in Table 2-2, the values are lying all in a range of 10% or less.

Table 2-2: Deviation of room and surface temperatures from mean value in %



	800	1800	1810	1820	1830	1840	1850	1860	1870	1880	1890	2800	2810
Tactive Mean	3.67	2.48	1.00	1.17	0.60	1.81	2.24	1.96	2.64	3.90	1.81	3.24	3.25
Tbase Mean		10.07	10.07	10.07	9.50	12.26	12.26	12.26	12.26	10.32	15.67	6.35	5.50
Tbase Max		11.30	11.30	11.30	10.53	10.53	10.53	10.53	10.53	9.42	10.53	2.13	1.98
Tbase Min		4.56	4.56	4.56	6.88	16.06	16.06	16.06	16.06	12.55	29.63	16.25	14.94
Tsurf Mean				1.07	0.58	1.73	2.60	2.69	2.41	1.95	2.69	5.72	6.38
Tsurf Max				1.49	2.09	4.33	12.32	12.14	12.15	12.39	12.25	22.14	22.40
Tsurf Min				0.90	1.07	2.80	3.73	3.32	3.56	3.81	4.77	4.01	3.49

The highest variation is seen for the basement temperature. This is due to the free floating temperature in that space, and that the basement is semi-adiabatic so that small variations in heat flows to the basement can easily result in large basement temperature variations. Also, on this graph case 1890 is the one with the highest spread of the deviation. It is the one with the lower set points. This means that the influence of the floor heating system is not as strong as on a higher temperature level. The heating and cooling equipment are out of control and the temperatures are free floating in between the dead band.

2.2.2 Detailed temperature values (Section 2.4.3 and 2.4.4)

To compare the behaviour of the room conditions, the temperatures are compared for several days under winter and summer conditions. Different trends are apparent.

- Case 1810, which has a purely convective heat transfer coefficient for the floor, shows a wide spread over the three participating programs. If the combined coefficient is used, the results are much closer. If the radiation part is distributed to all surfaces, the results are even closer. In contrast with the room temperature, the floor surface temperatures correspond for all cases almost perfectly.
- For all cases the floor surface temperatures show good agreement, except for DOE-2, which has a serious problem. In the real window case, the floor surface temperatures from DOE-2 are much lower (less sensitive on radiation) than the other programs.
- The detailed water loop results are in good agreement.
- The influence of the 100% convective or radiative fraction of the internal gains has no big influence on the room and surface temperatures. This statement is only valid for these special cases – if the fractions of internal and external loads are different, the result can vary much more.

2.3 Conclusions

The different approaches of modelling radiant heating and cooling systems lead to satisfying results. The simple approach of an active temperature layer, to provide cooling or heating load to the active zone shows a good agreement between the different programs. 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). Some questions should be cleared concerning cases 1810 to 1830. An analytical comparison between the convective heat surface coefficient should clarify if the deviation between the results comes from different algorithms or if they are affected by the modeller's modifications.

Over all, 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.

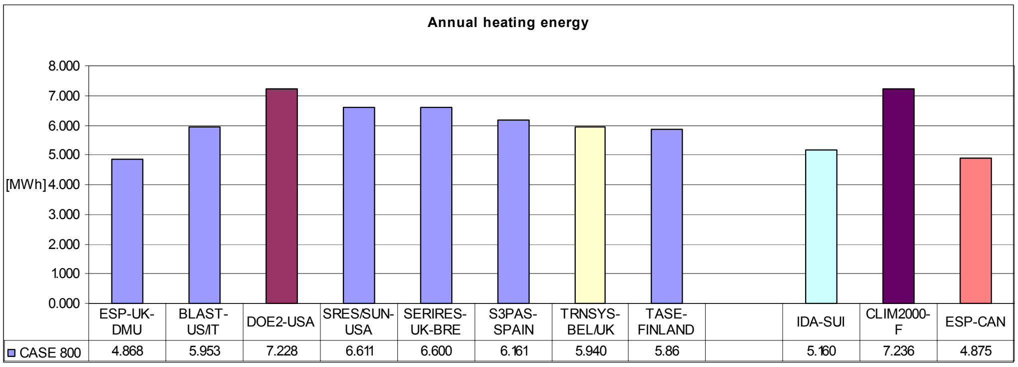
If the investigations go much deeper in detail, a detailed water loop system is necessary. In that field the RADTEST should provide more test cases in a future work. The aim of further tests should focus on:

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

2.4 Graphical Results

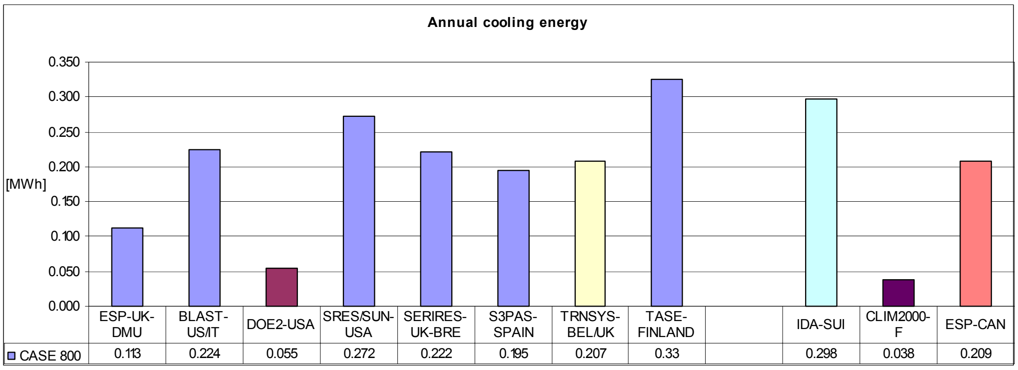
2.4.1 Overall Results

2.4.1.1 Case 800 benchmark (correspond to ENVELOPE BESTEST case 800)



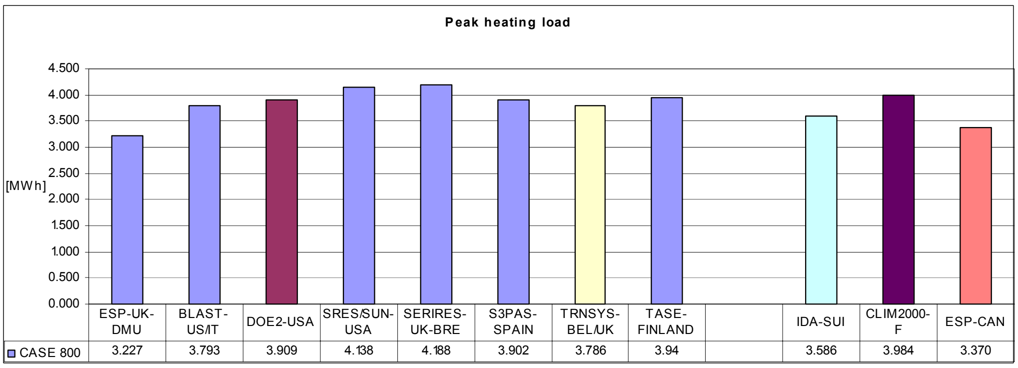
	ESP-UK-DMU	BLAST-US/IT	DOE2-USA	SRES/SUN-USA	SERIRES-UK-BRE	S3PAS-SPAIN	TRNSYS-BEL/UK	TASE-FINLAND		IDA-SUI	CLIM2000-F	ESP-CAN
CASE 800	4.868	5.953	7.228	6.611	6.600	6.161	5.940	5.86		5.160	7.236	4.875

All programs are in the range of case 800 from IEA Task 12 ENVELOPE BESTEST

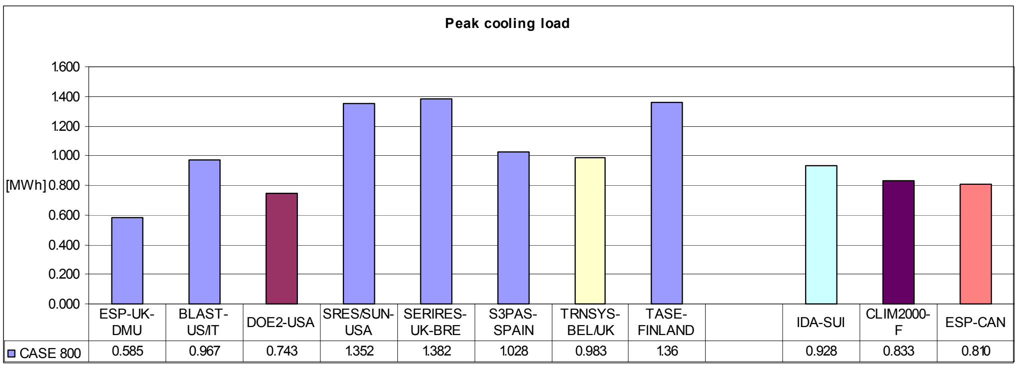


	ESP-UK-DMU	BLAST-US/IT	DOE2-USA	SRES/SUN-USA	SERIRES-UK-BRE	S3PAS-SPAIN	TRNSYS-BEL/UK	TASE-FINLAND		IDA-SUI	CLIM2000-F	ESP-CAN
CASE 800	0.113	0.224	0.055	0.272	0.222	0.195	0.207	0.33		0.298	0.038	0.209

CLIM2000 is on the edge of the boundaries. But still ok.

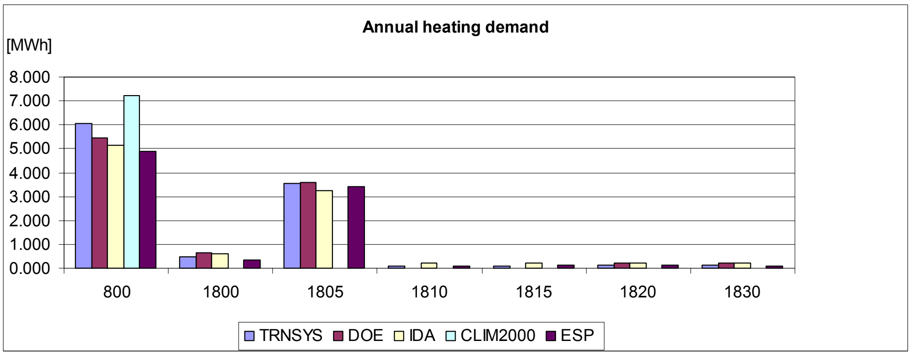


	ESP-UK-DMU	BLAST-US/IT	DOE2-USA	SRES/SUN-USA	SERIRES-UK-BRE	S3PAS-SPAIN	TRNSYS-BEL/UK	TASE-FINLAND		IDA-SUI	CLIM2000-F	ESP-CAN
CASE 800	3.227	3.793	3.909	4.138	4.188	3.902	3.786	3.94		3.586	3.984	3.370

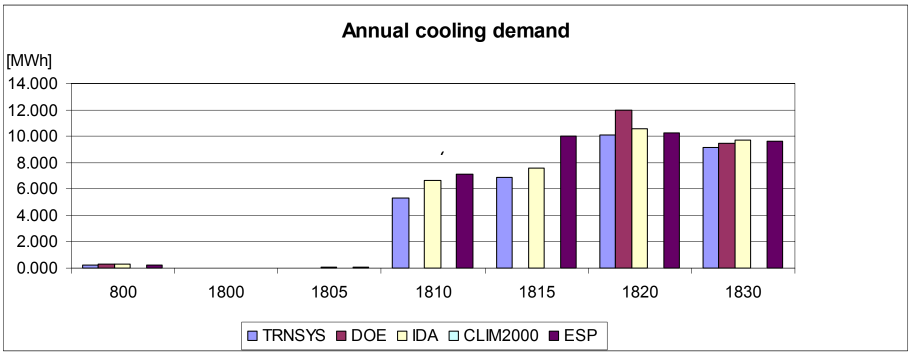


	ESP-UK-DMU	BLAST-US/IT	DOE2-USA	SRES/SUN-USA	SERIRES-UK-BRE	S3PAS-SPAIN	TRNSYS-BEL/UK	TASE-FINLAND		IDA-SUI	CLIM2000-F	ESP-CAN
CASE 800	0.585	0.967	0.743	1.352	1.382	1.028	0.983	1.36		0.928	0.833	0.810

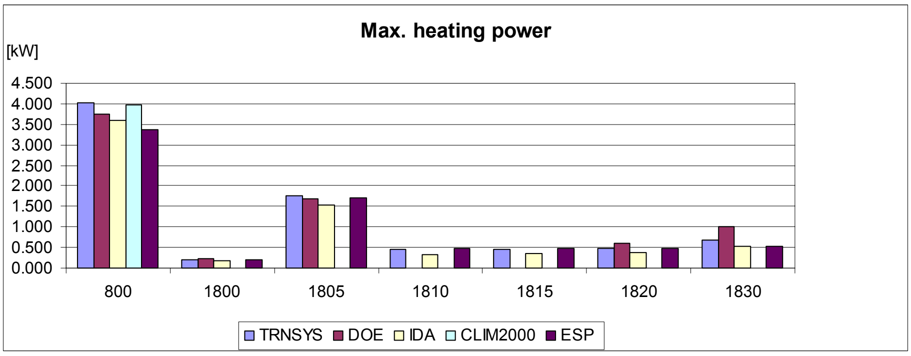
2.4.1.2 Overall results case 800 to 2810

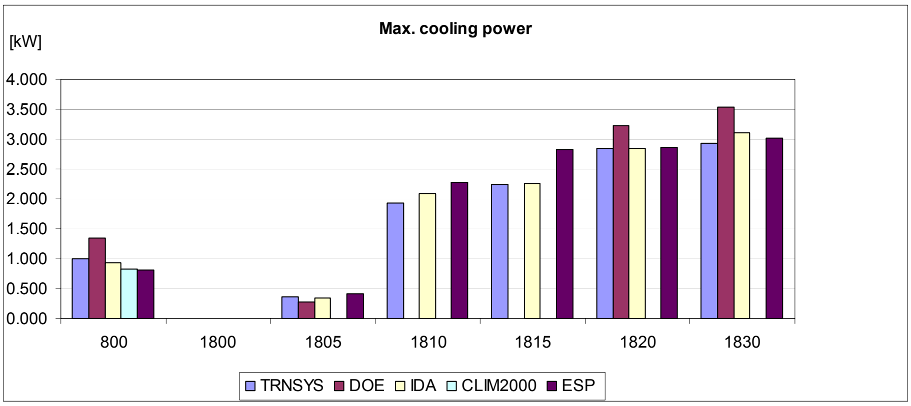


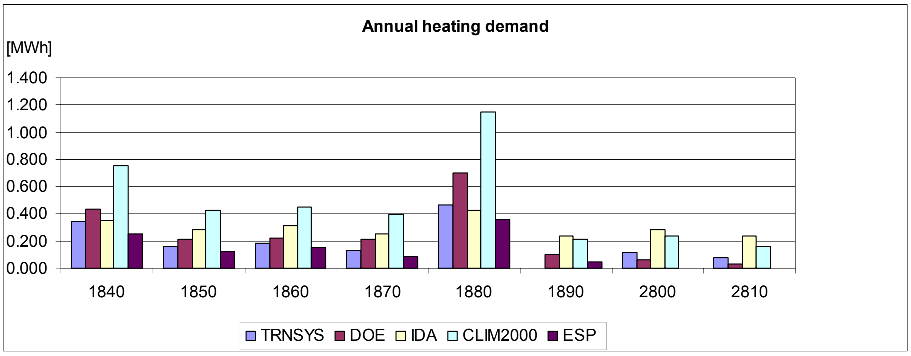
The annual additional heating consumption is reduced by the heat emitted by the active floor.

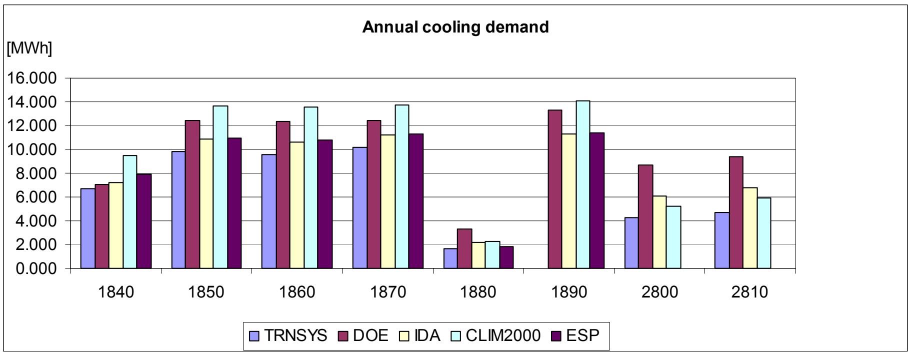


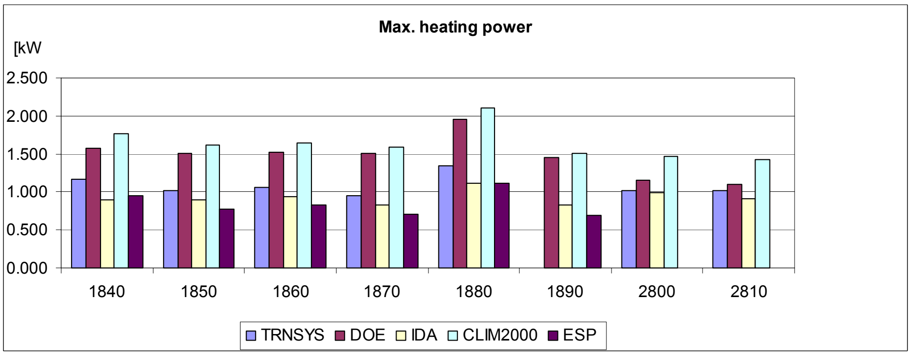
The cooling energy demand is increased by the influence of the heated floor in the intermediate season.

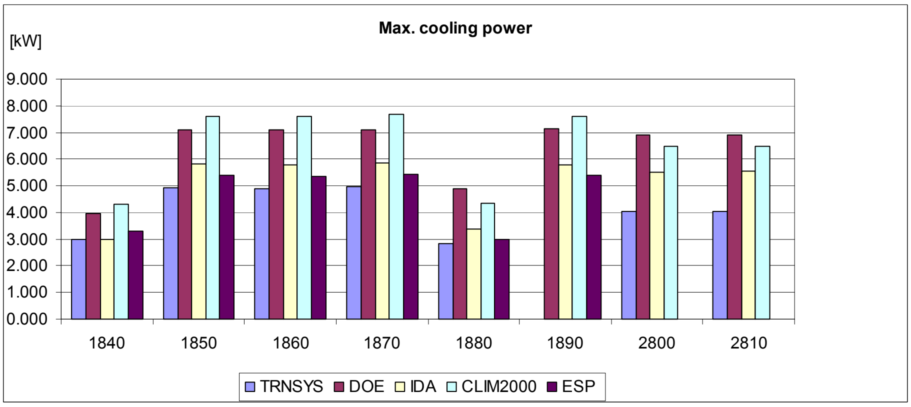




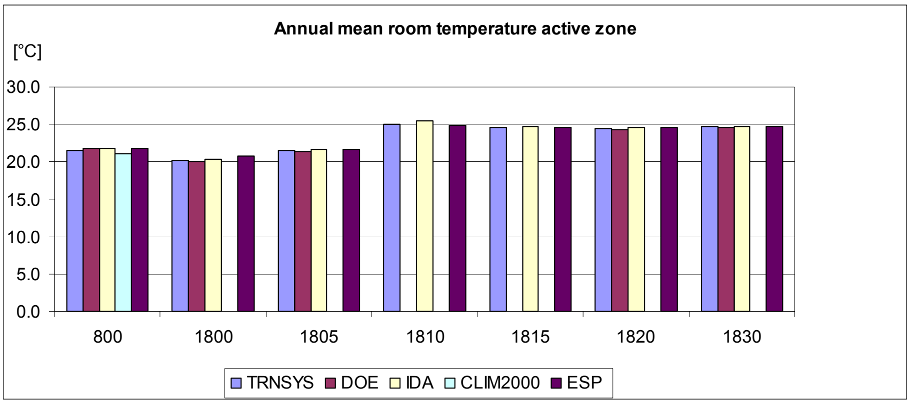

Annual heating demand
[MWh]
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
1840
1850
1860
1870
1880
1890
2800
2810
TRNSYS DOE IDA CLIM2000 ESP


Annual cooling demand
[MWh]
16.000
14.000
12.000
10.000
8.000
6.000
4.000
2.000
0.000
1840
1850
1860
1870
1880
1890
2800
2810
TRNSYS DOE IDA CLIM2000 ESP

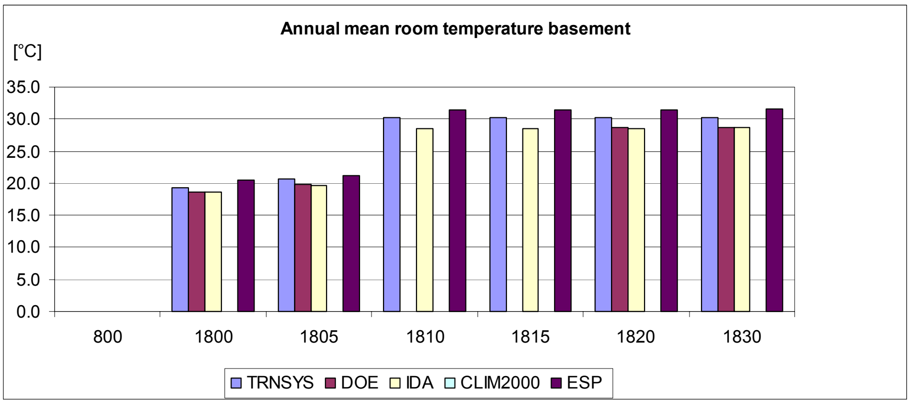

Max. heating power
[kW
2.500
2.000
1.500
1.000
0.500
0.000
1840
1850
1860
1870
1880
1890
2800
2810
TRNSYS DOE IDA CLIM2000 ESP


Max. cooling power
[kW]
9.000
8.000
7.000
6.000
5.000
4.000
3.000
2.000
1.000
0.000
1840
1850
1860
1870
1880
1890
2800
2810
TRNSYS DOE IDA CLIM2000 ESP

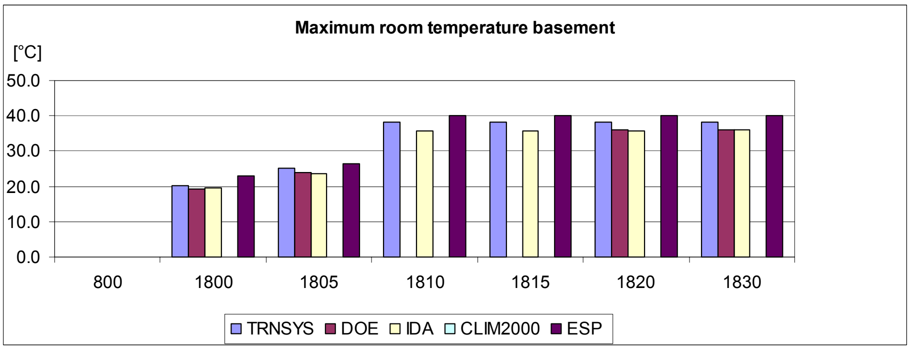
2.4.1.3 Room temperatures: Active zone (case 800 to 2810) and basement (case 1800 to 2810)

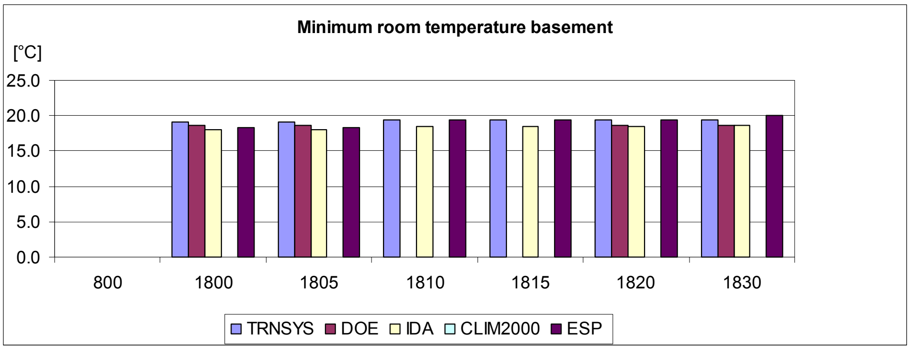


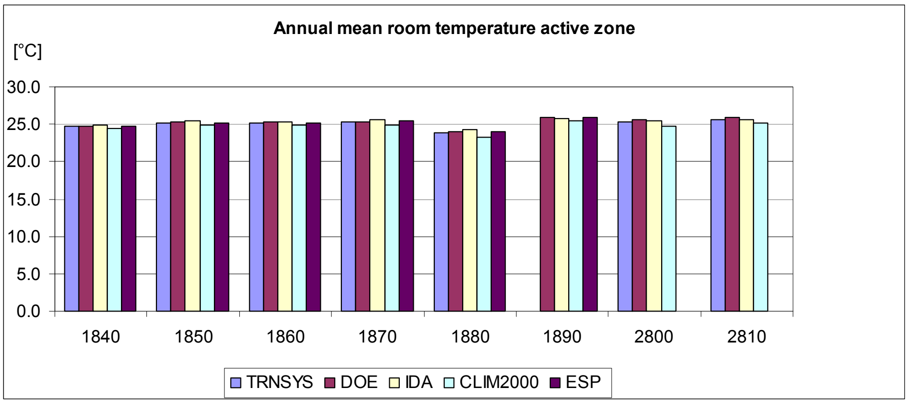
The room temperatures cannot vary extremely due to the small dead band.



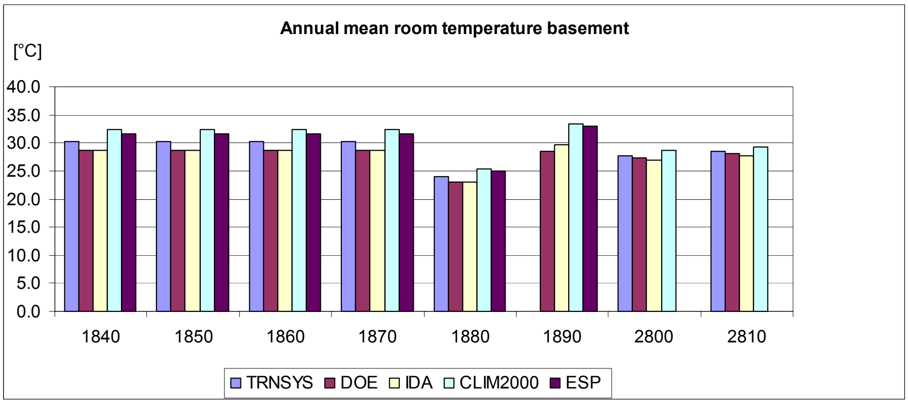
The free floating basement temperatures show a wider range.



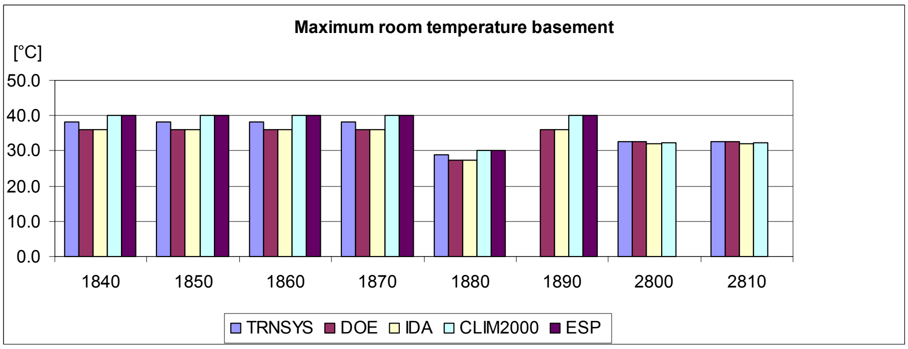


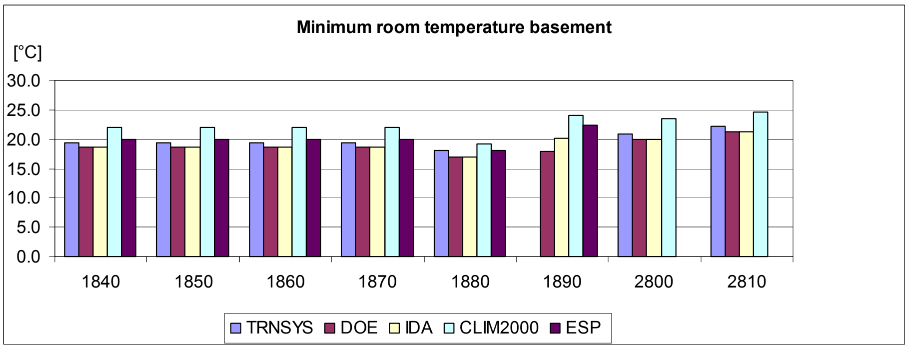


The room temperatures cannot vary extremely due to small dead band.

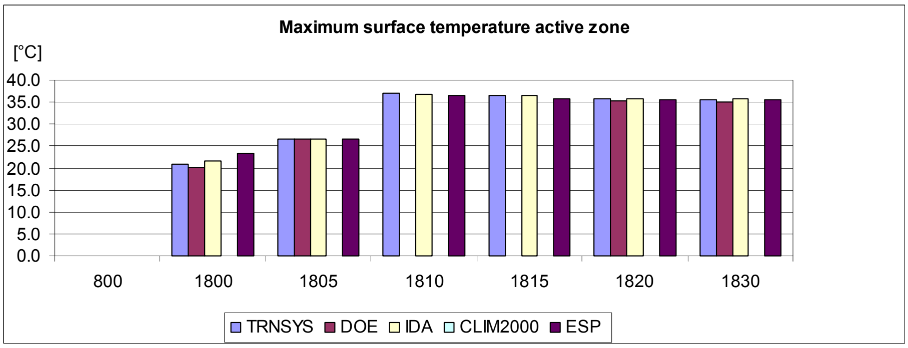


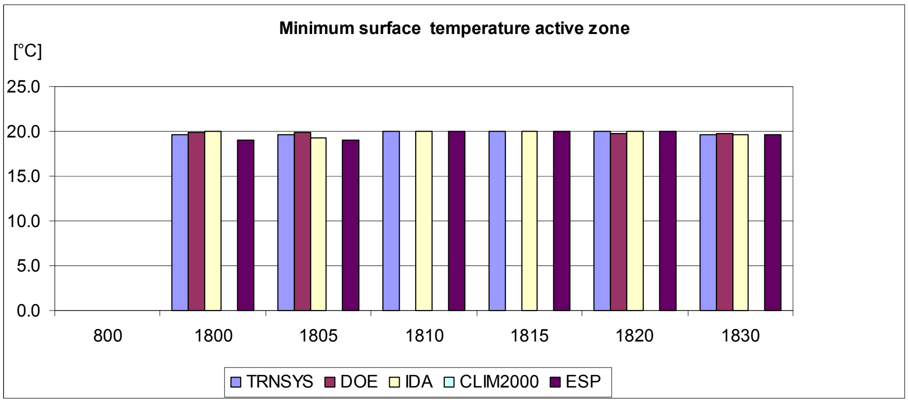
The free floating basement temperatures show a wider range.

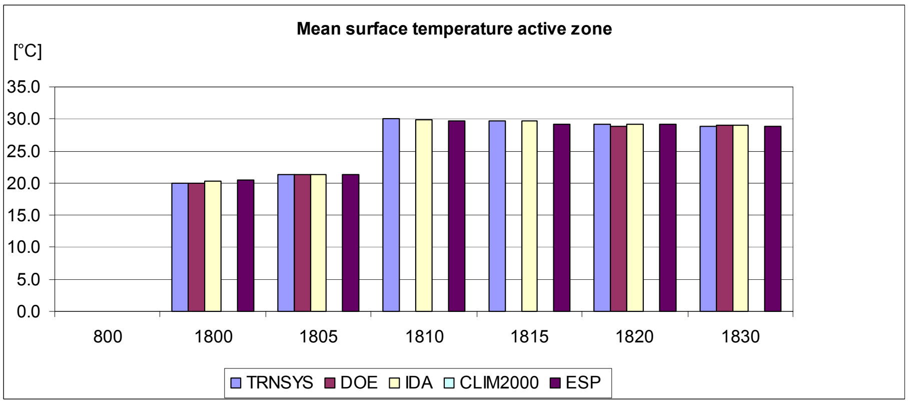


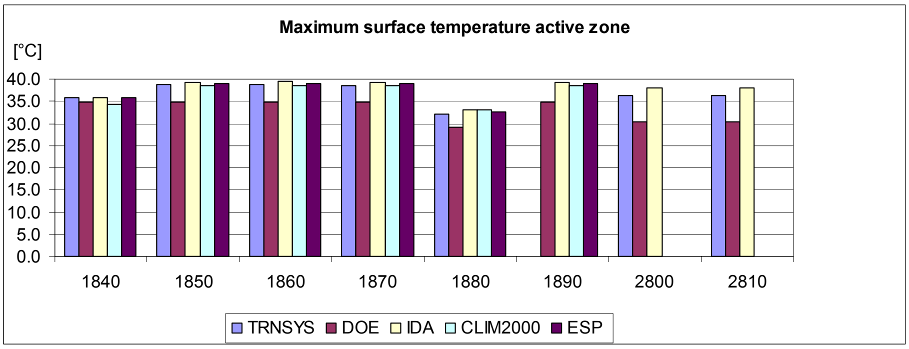


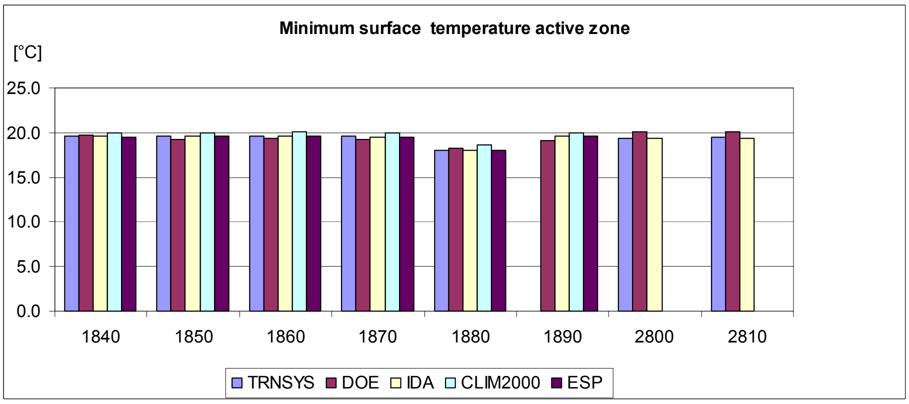
2.4.1.4 Floor surface temperatures active zone (case 1830 to 2810)

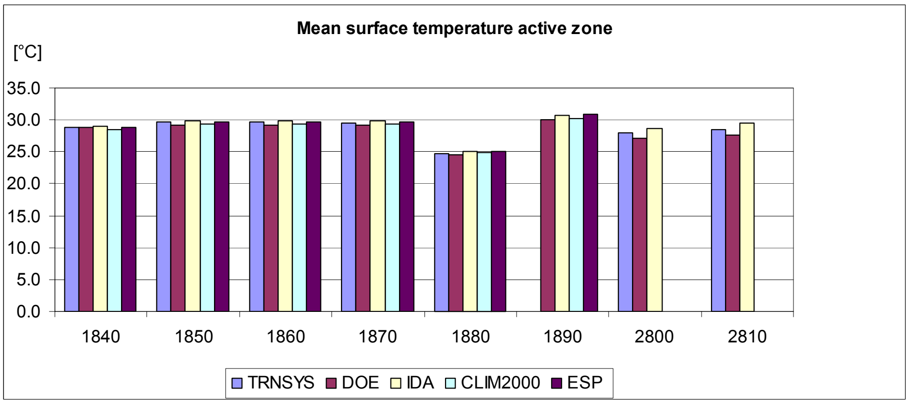




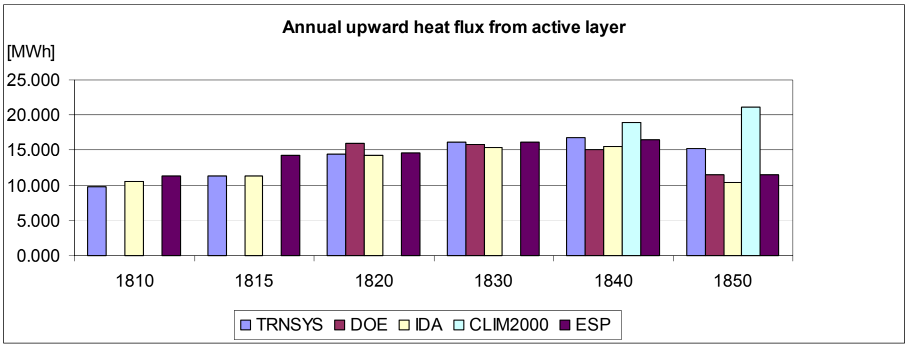


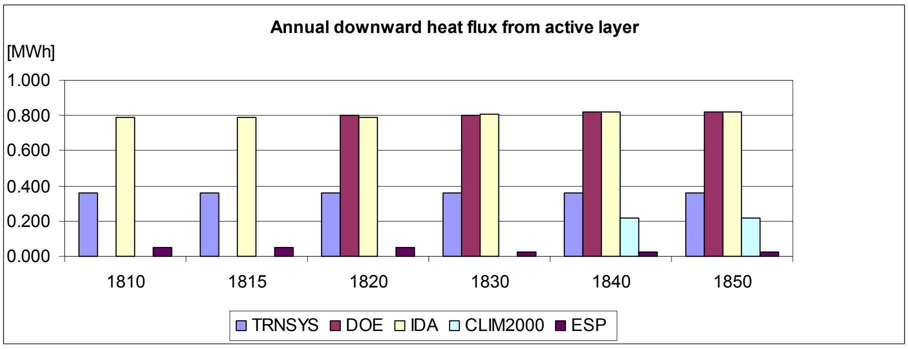

Maximum surface temperature active zone
[°C]
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1840
1850
1860
1870
1880
1890
2800
2810
TRNSYS
DOE
IDA
CLIM2000
ESP

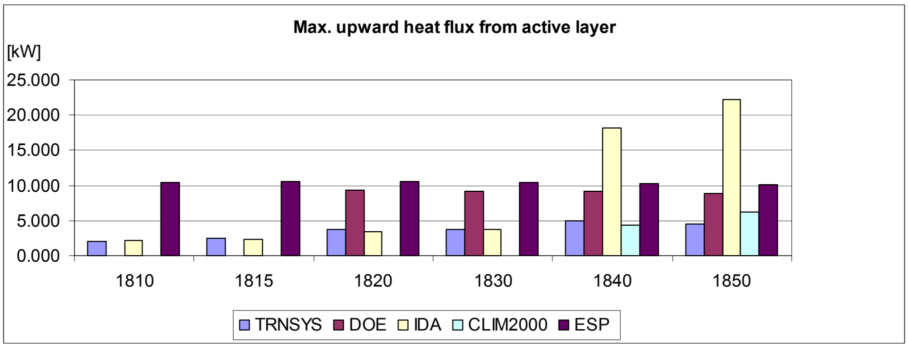

Minimum surface temperature active zone
[°C]
25.0
20.0
15.0
10.0
5.0
0.0
1840
1850
1860
1870
1880
1890
2800
2810
TRNSYS
DOE
IDA
CLIM2000
ESP

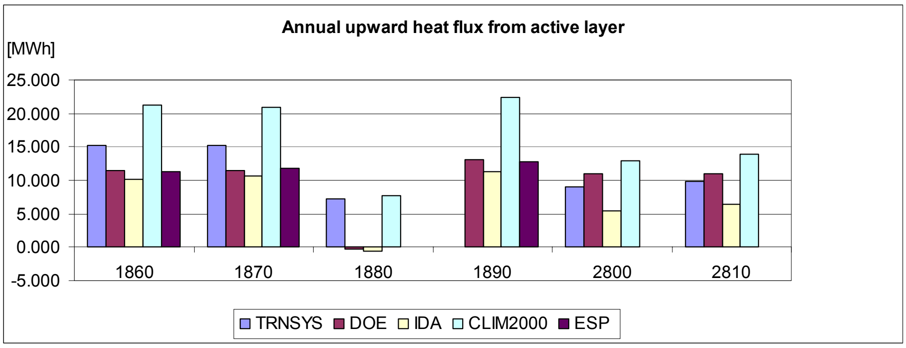

Mean surface temperature active zone
[°C]
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1840
1850
1860
1870
1880
1890
2800
2810
TRNSYS
DOE
IDA
CLIM2000
ESP

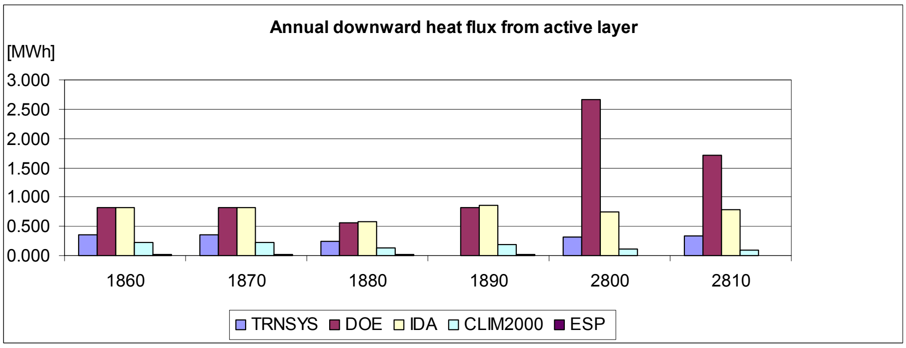
2.4.1.5 Annual heat fluxes case 1820 to 2810

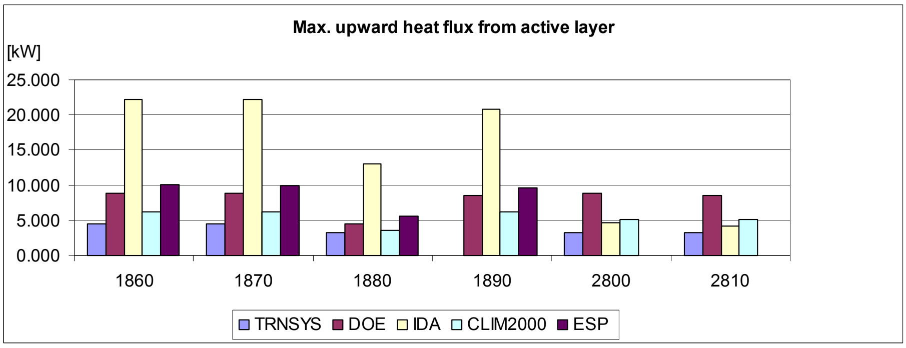






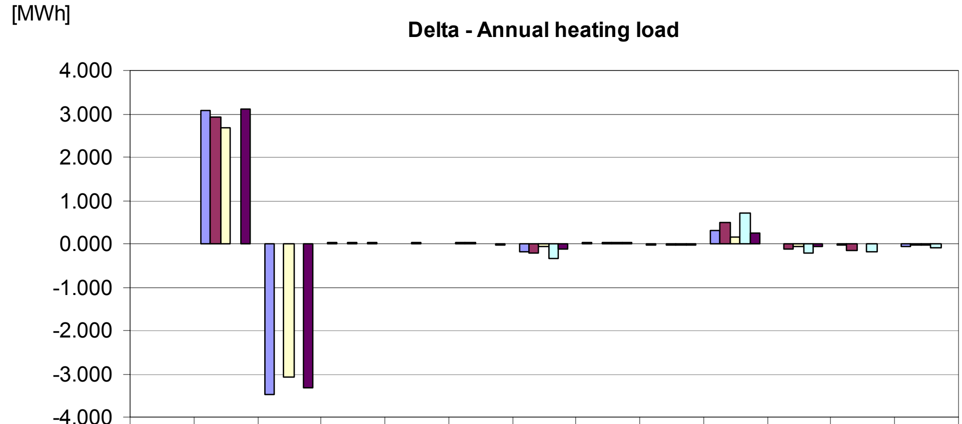

Annual upward heat flux from active layer
[MWh]
25.000
20.000
15.000
10.000
5.000
0.000
-5.000
1860
1870
1880
1890
2800
2810
TRNSYS DOE IDA CLIM2000 ESP


Annual downward heat flux from active layer
[MWh]
3.000
2.500
2.000
1.500
1.000
0.500
0.000
1860
1870
1880
1890
2800
2810
TRNSYS DOE IDA CLIM2000 ESP

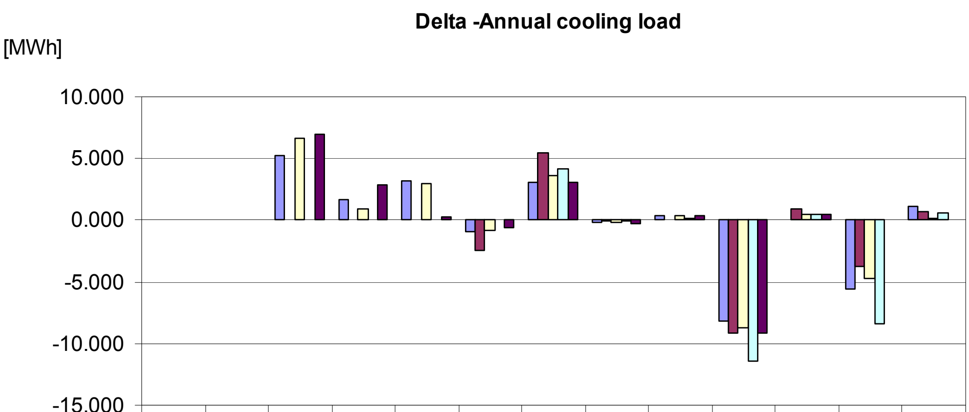

Max. upward heat flux from active layer
[kW]
25.000
20.000
15.000
10.000
5.000
0.000
1860
1870
1880
1890
2800
2810
TRNSYS DOE IDA CLIM2000 ESP

2.4.2 Delta results

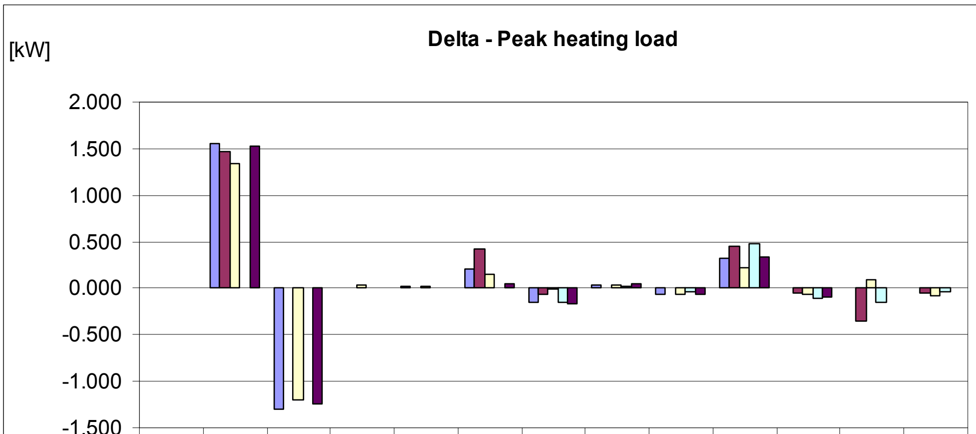
2.4.2.1 Delta Annual heating and cooling energy consumption - case 1800 to 2810



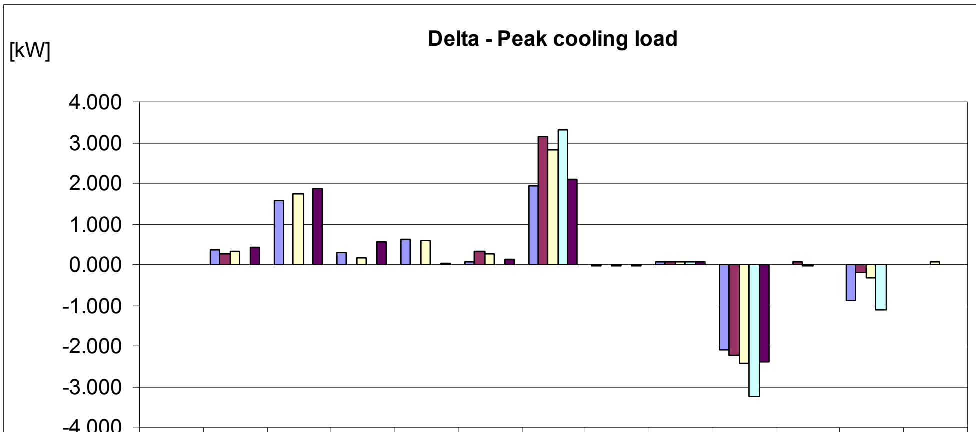
	1805-1800	1810-1805	1815-1810	1820-1815	1830-1820	1850-1840	1860-1850	1870-1850	1880-1850	1890-1850	2800-1850	2810-2800
TRNSYS	3.076	-3.467	0.016	0.012	0.035	-0.181	0.025	-0.032	0.303		-0.046	-0.071
DOE	2.921				0.027	-0.223	0.007	0.001	0.489	-0.115	-0.151	-0.031
IDA	2.679	-3.064	0.016	0.017	-0.010	-0.064	0.028	-0.033	0.139	-0.047	-0.002	-0.043
CLIM2000						-0.324	0.022	-0.032	0.720	-0.218	-0.194	-0.078
ESP-r	3.093	-3.332	0.026	0.002	-0.029	-0.133	0.031	-0.036	0.235	-0.075		



	1805-1800	1810-1805	1815-1810	1820-1815	1830-1820	1850-1840	1860-1850	1870-1850	1880-1850	1890-1850	2800-1850	2810-2800
TRNSYS	0.028	5.255	1.627	3.164	-0.896	3.090	-0.217	0.329	-8.193		-5.598	1.178
DOE	0.009				-2.498	5.402	-0.059	-0.010	-9.149	0.864	-3.780	0.743
IDA	0.044	6.605	0.926	2.988	-0.852	3.643	-0.224	0.346	-8.714	0.493	-4.742	0.203
CLIM2000						4.144	-0.085	0.127	-11.38	0.495	-8.357	0.615
ESP-r	0.075	7.008	2.903	0.227	-0.562	3.071	-0.232	0.358	-9.124	0.434		



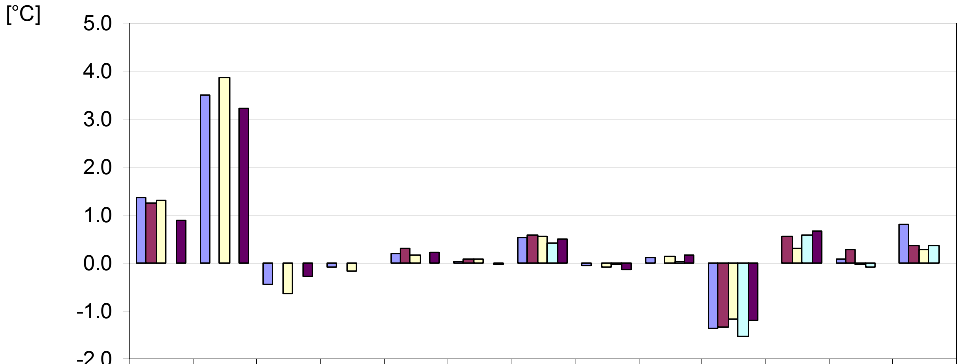
	1805-1800	1810-1805	1815-1810	1820-1815	1830-1820	1850-1840	1860-1850	1870-1850	1880-1850	1890-1850	2800-1850	2810-2800
TRNSYS	1.557	-1.295	0.009	0.016	0.202	-0.148	0.042	-0.064	0.323		0.001	0.000
DOE	1.471				0.416	-0.067	0.013	0.003	0.454	-0.056	-0.353	-0.050
IDA	1.345	-1.196	0.030	0.023	0.152	-0.003	0.041	-0.071	0.217	-0.071	0.087	-0.076
CLIM2000						-0.151	0.022	-0.034	0.485	-0.110	-0.155	-0.034
ESP-r	1.530	-1.240	0.010	0.000	0.050	-0.170	0.050	-0.070	0.340	-0.090		



	1805-1800	1810-1805	1815-1810	1820-1815	1830-1820	1850-1840	1860-1850	1870-1850	1880-1850	1890-1850	2800-1850	2810-2800
TRNSYS	0.358	1.567	0.310	0.618	0.071	1.929	-0.041	0.062	-2.097		-0.869	0.005
DOE	0.277				0.319	3.152	-0.011	0.062	-2.220	0.054	-0.183	0.003
IDA	0.341	1.747	0.171	0.587	0.250	2.835	-0.034	0.062	-2.437	-0.025	-0.319	0.066
CLIM2000						3.300	0.000	0.062	-3.240	0.000	-1.130	0.010
ESP-r	0.410	1.860	0.560	0.040	0.140	2.110	-0.030	0.062	-2.390	0.000		

2.4.2.2 Delta room temperatures: active zone and basement (case 1800 to 2810)

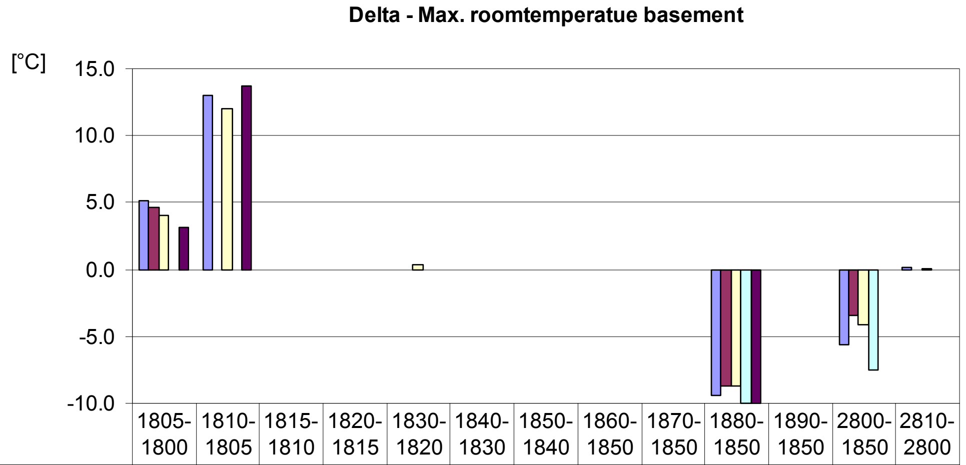
Delta - Annual mean room temperature active zone



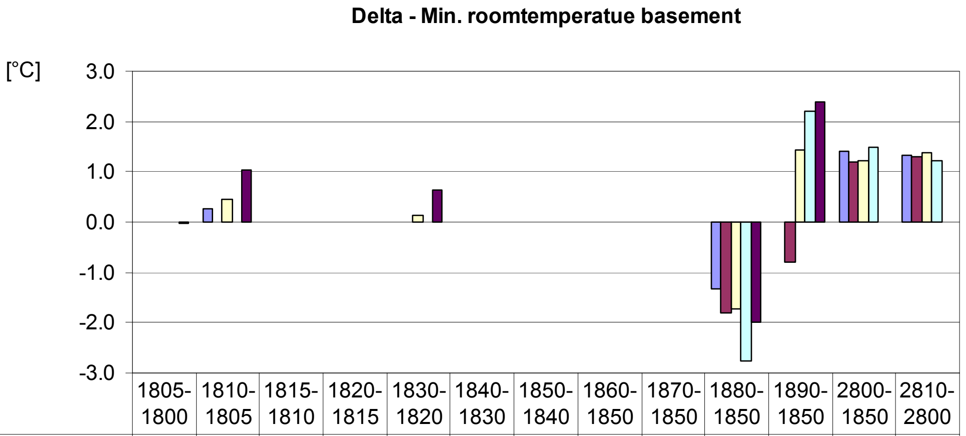
	1805-1800	1810-1805	1815-1810	1820-1815	1830-1820	1840-1830	1850-1840	1860-1850	1870-1850	1880-1850	1890-1850	2800-1850	2810-2800
TRNSYS	1.4	3.5	-0.4	-0.1	0.2	0.0	0.5	-0.1	0.1	-1.4		0.1	0.8
DOE	1.3				0.3	0.1	0.6	0.0	0.0	-1.3	0.6	0.3	0.4
IDA	1.3	3.9	-0.7	-0.2	0.2	0.1	0.5	-0.1	0.1	-1.2	0.3	0.0	0.3
CLIM2000							0.4	0.0	0.0	-1.5	0.6	-0.1	0.4
ESP	0.9	3.2	-0.3	0.0	0.2	0.0	0.5	-0.1	0.2	-1.2	0.7		

Delta - Annual mean roomtemperature basement

	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	1.2	9.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-6.2		-2.6	1.8
DOE	1.2				0.0	0.1	0.0	0.0	0.0	-5.7	-0.1	-1.3	0.8
IDA	1.1	8.8	0.0	0.0	0.2	0.1	0.0	0.0	0.0	-5.8	0.9	-1.8	0.5
CLIM2000							0.0	0.0	0.0	-7.0	1.0	-3.7	0.6
ESP	0.7	10.3	0.0	0.0	0.1	0.0	0.0	0.0	0.0	-6.6	1.4		



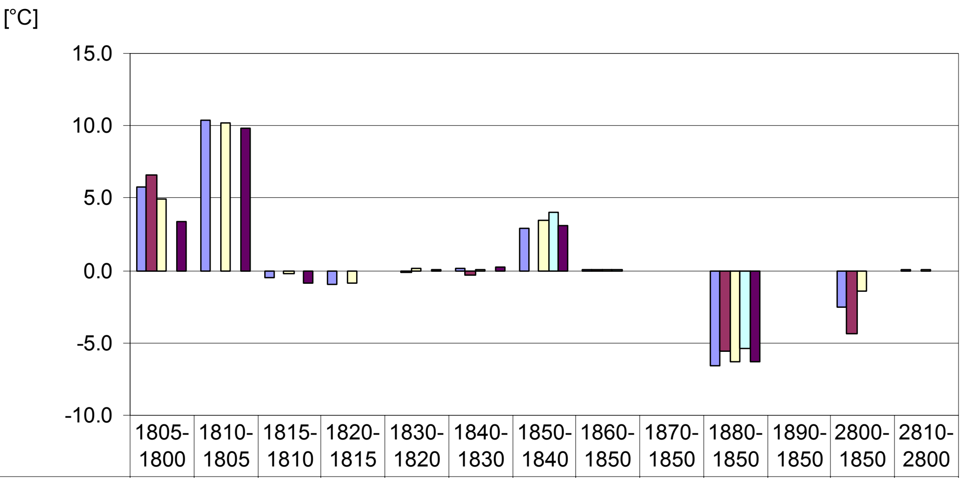
	1805-1800	1810-1805	1815-1810	1820-1815	1830-1820	1840-1830	1850-1840	1860-1850	1870-1850	1880-1850	1890-1850	2800-1850	2810-2800
TRNSYS	5.1	13.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-9.4		-5.6	0.1
DOE	4.6				0.0	0.0	0.0	0.0	0.0	-8.7	0.0	-3.4	0.0
IDA	4.1	12.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	-8.7	0.0	-4.1	0.0
CLIM2000							0.0	0.0	0.0	-10.0	0.0	-7.6	0.0
ESP	3.2	13.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-10.0	0.0		



	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	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.3		1.4	1.3
DOE	0.0				0.0	0.0	0.0	0.0	0.0	-1.8	-0.8	1.2	1.3
IDA	0.0	0.5	0.0	0.0	0.1	0.0	0.0	0.0	0.0	-1.7	1.4	1.2	1.4
CLIM2000							0.0	0.0	0.0	-2.8	2.2	1.5	1.2
ESP	0.0	1.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	-2.0	2.4		

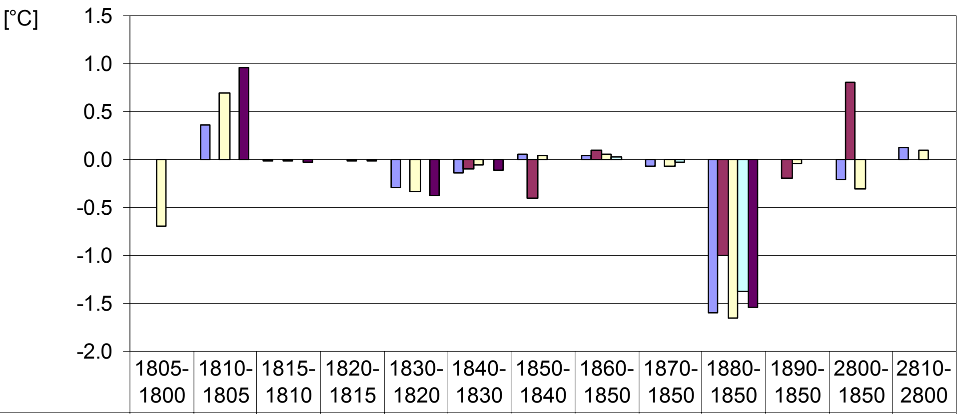
2.4.2.3 Delta floor surface temperatures active zone (case 1805 to 2810)

Delta - Max surface temperatureactive zone



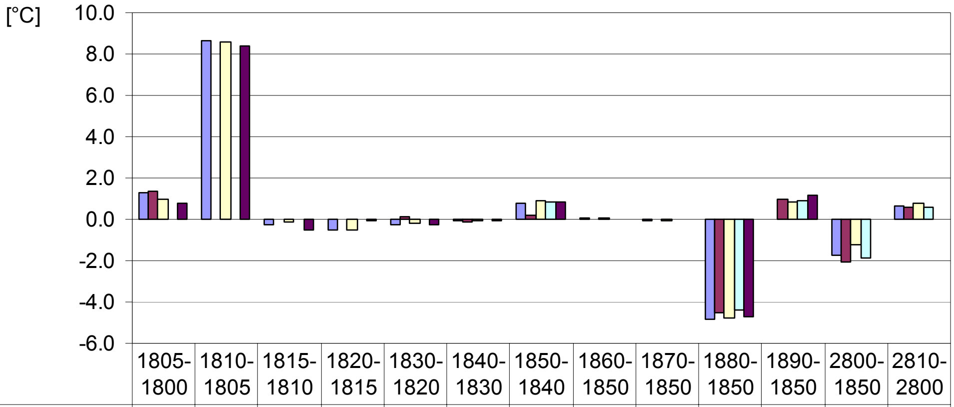
	1805-1800	1810-1805	1815-1810	1820-1815	1830-1820	1840-1830	1850-1840	1860-1850	1870-1850	1880-1850	1890-1850	2800-1850	2810-2800
TRNSYS	5.8	10.4	-0.5	-0.9	-0.1	0.2	2.9	0.0	-0.1	-6.6		-2.5	0.0
DOE	6.6				-0.1	-0.3	0.0	0.1	0.0	-5.6	0.0	-4.4	0.0
IDA	5.0	10.2	-0.3	-0.9	0.1	0.0	3.5	0.0	-0.1	-6.3	0.0	-1.4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

Delta - Minimum surface temperatureactive zone



	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	0.0	0.4	0.0	0.0	-0.3	-0.1	0.1	0.0	-0.1	-1.6		-0.2	0.1
DOE	0.0				0.0	-0.1	-0.4	0.1	0.0	-1.0	-0.2	0.8	0.0
IDA	-0.7	0.7	0.0	0.0	-0.3	-0.1	0.0	0.1	-0.1	-1.7	0.0	-0.3	0.1
CLIM2000							0.0	0.0	0.0	-1.4	0.0		
ESP	0.0	1.0	0.0	0.0	-0.4	-0.1	0.0	0.0	0.0	-1.5	0.0		

Delta - Mean surface temperature active zone



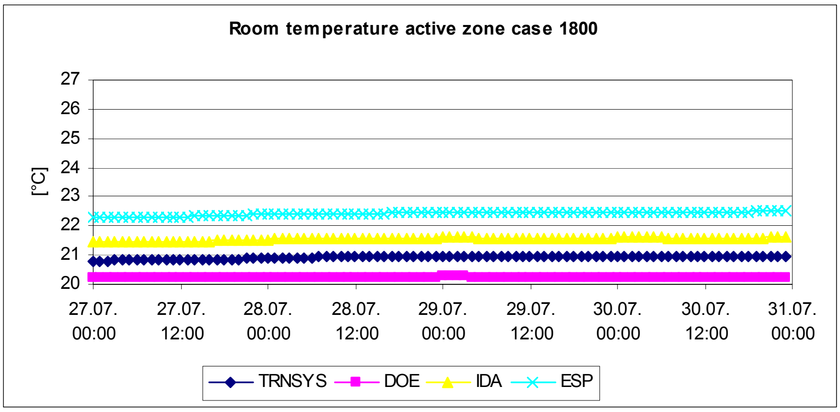
	1805-1800	1810-1805	1815-1810	1820-1815	1830-1820	1840-1830	1850-1840	1860-1850	1870-1850	1880-1850	1890-1850	2800-1850	2810-2800
TRNSYS	1.3	8.7	-0.3	-0.5	-0.3	-0.1	0.8	0.0	-0.1	-4.8		-1.7	0.7
DOE	1.4				0.1	-0.2	0.2	0.0	0.0	-4.5	0.9	-2.0	0.6
IDA	1.0	8.6	-0.1	-0.5	-0.2	-0.1	0.9	0.0	-0.1	-4.8	0.9	-1.2	0.8
CLIM2000							0.8	0.0	0.0	-4.4	0.9	-1.9	0.6
ESP	0.8	8.4	-0.5	0.0	-0.3	0.0	0.8	0.0	0.0	-4.7	1.2		

2.4.3 Detailed temperature values

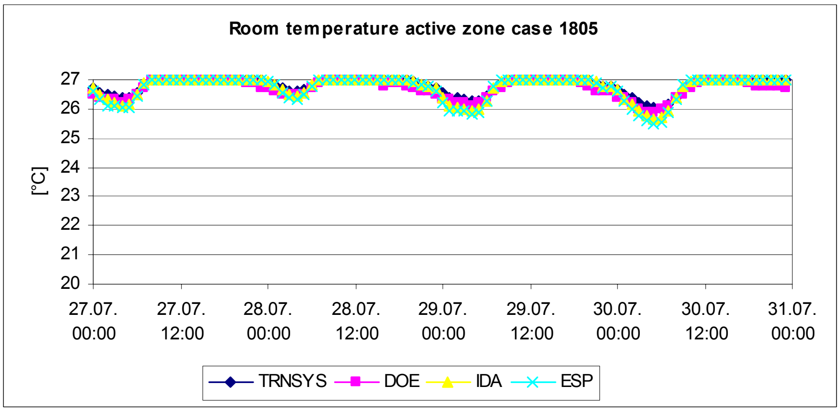
This section on the RADTEST was focused on the different temperatures:
- room temperature in the active zone
- floor surface temperature in the active zone
- return water temperature (only cases 2800 and 2810)

The temperatures are plotted for a 4 day summer and winter period. The output values for the different programs are placed in the same plot.

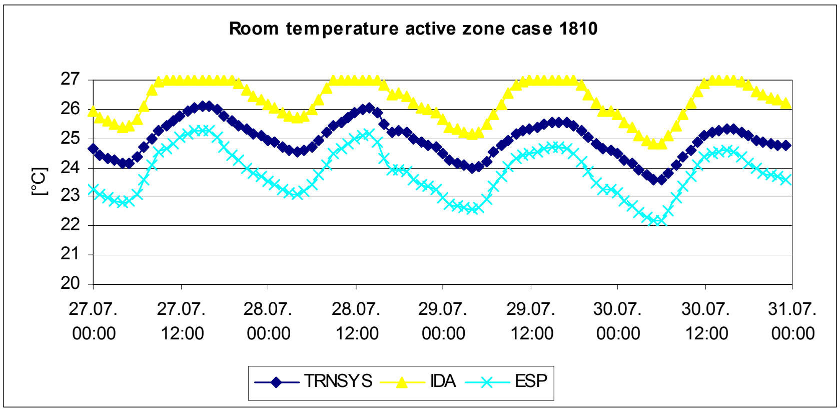
2.4.3.1 Temperatures summer period from July 27 to 30.



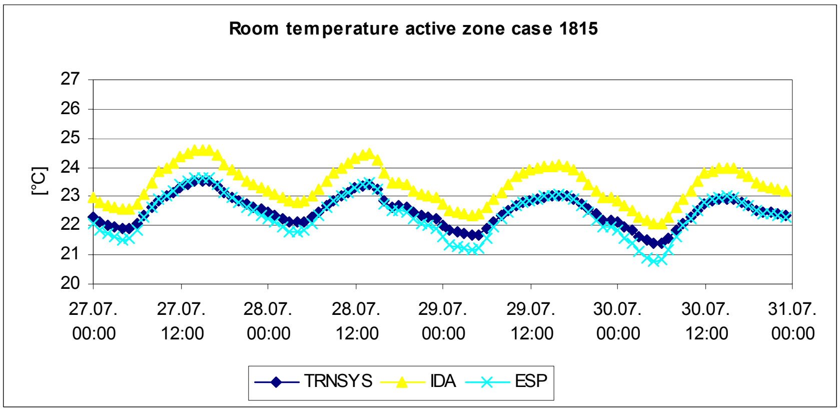
Case 1800 – highly insulated 2 zone model.



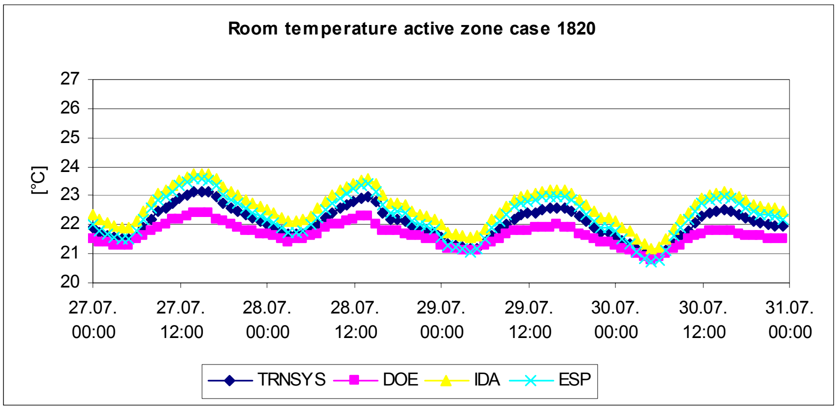
Case 1805 - Totally insulated 2 zone model.
- Infiltration Ach=1.0 1/h
- Internal loads 200 W from 1st may to 30 September (purely convective)



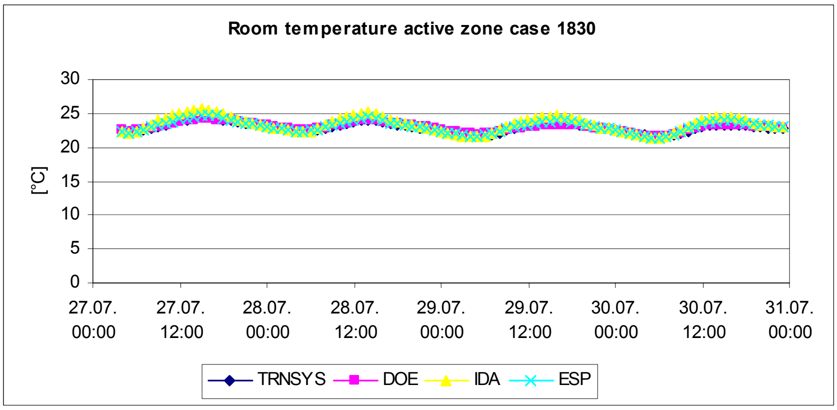
Case 1810- The constant temperature layer between the concrete layer and the insulation
- Surface coefficient on floor only convective.



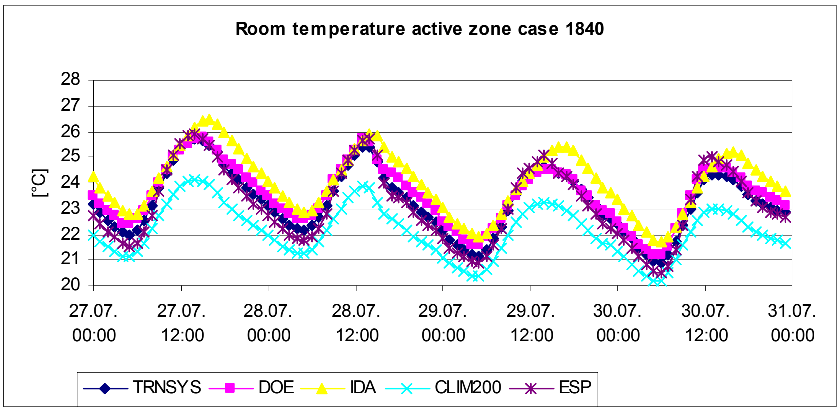
Case 1815 – Combined surface coefficient. Radiation 100% to ceiling.



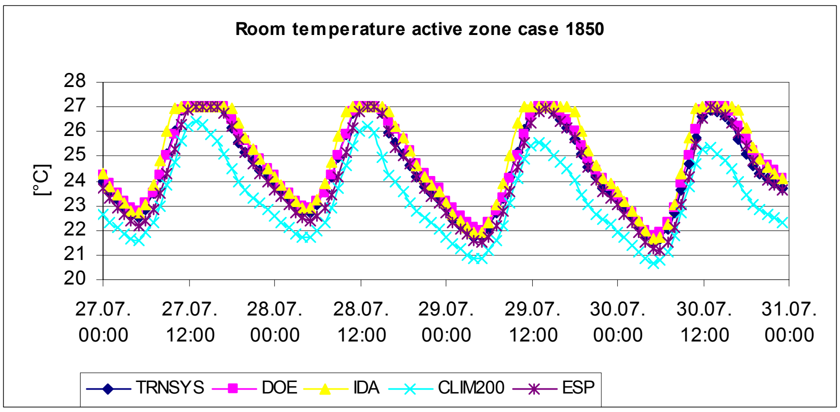
Case 1820 - Ordinary distribution of the radiation on all surfaces.



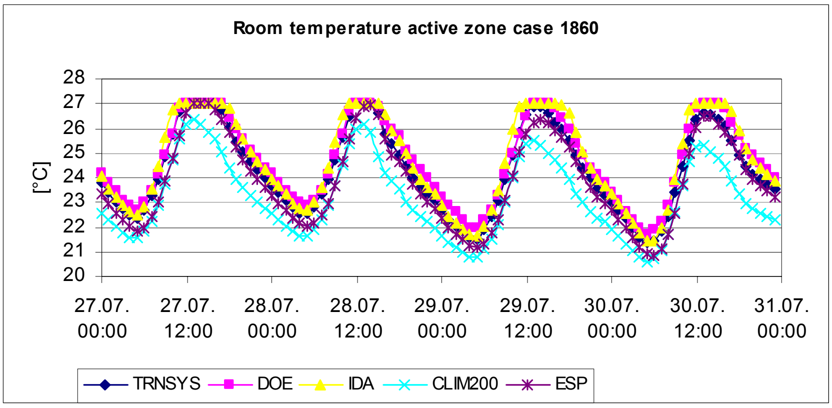
Case 1830 - Active zone with normal envelope.
- Without window
- Ach=0.5 1/h
- Internal gains only convective 365 days.



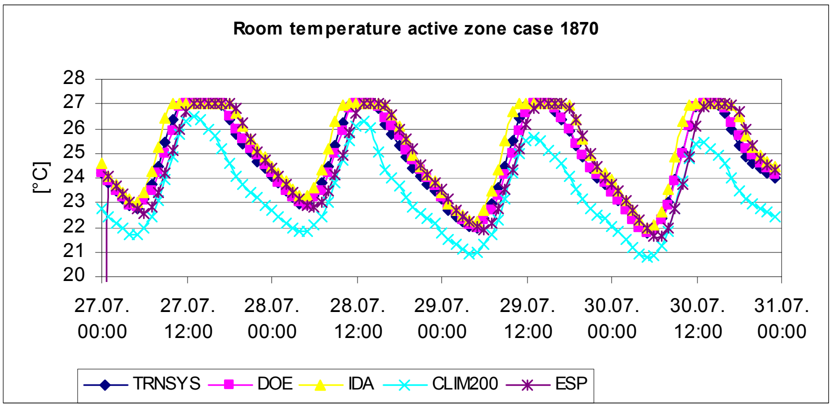
Case 1840 - Active zone with normal envelope. Highly conductive wall included



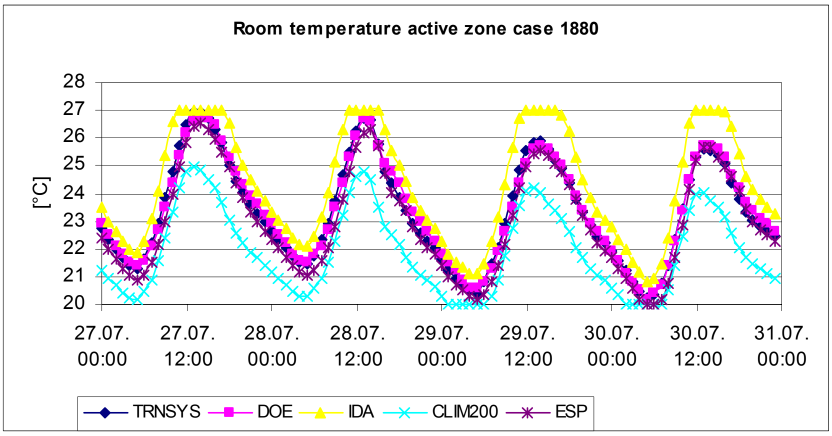
Case 1850 – real window case



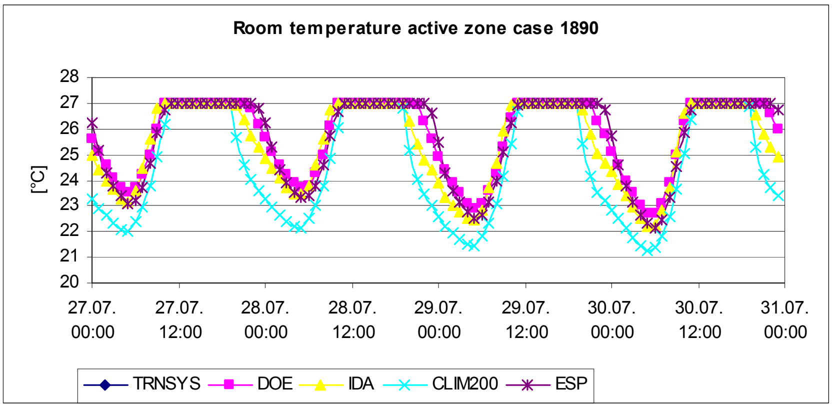
Case 1860 - internal gains purely radiative



Case 1870 - internal gains purely convective



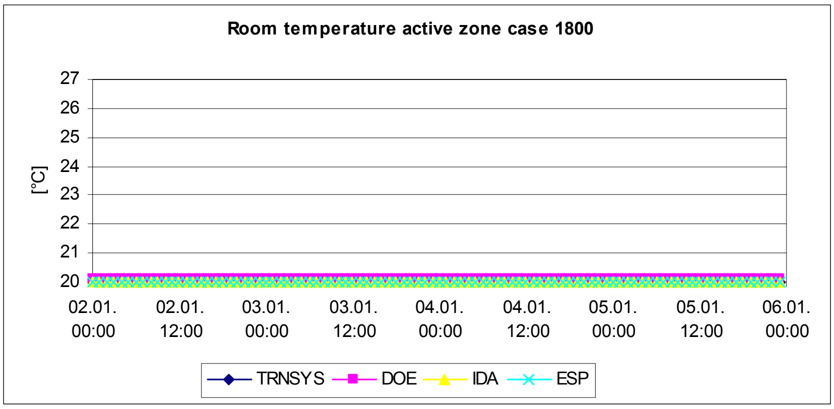
Case 1880 - layer temperatures on a lower level (summer 18°C winter 30 °C)



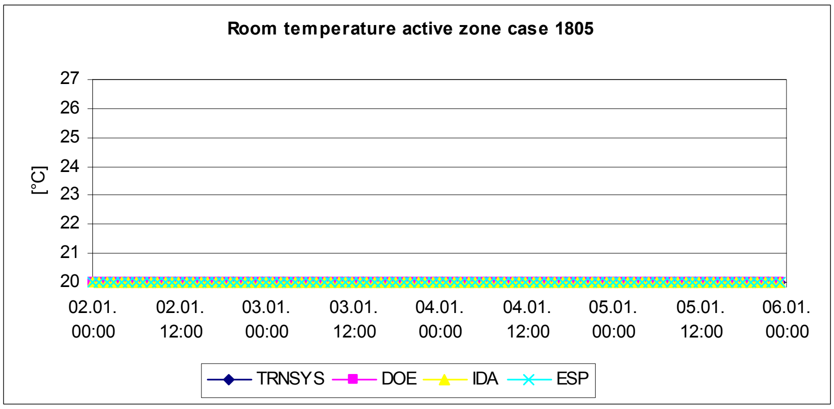
Case 1890 – Similar case as 1850, but during summer time layer is only active from 10 pm to 6 am

TRNSYS did not run this test.

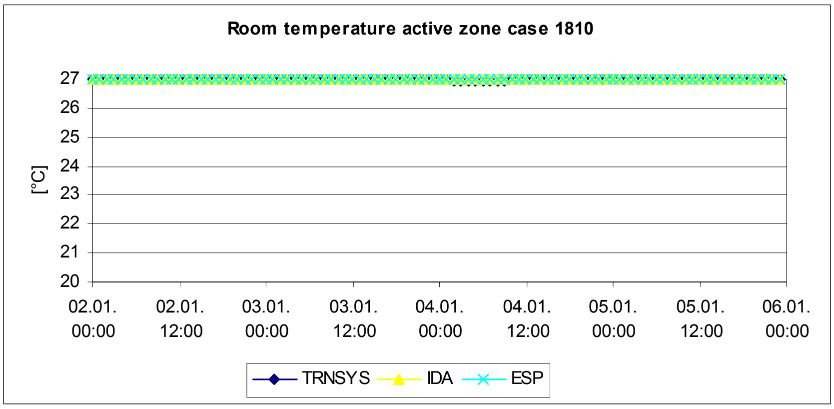
2.4.3.2 Winter cases from January 2 to 5



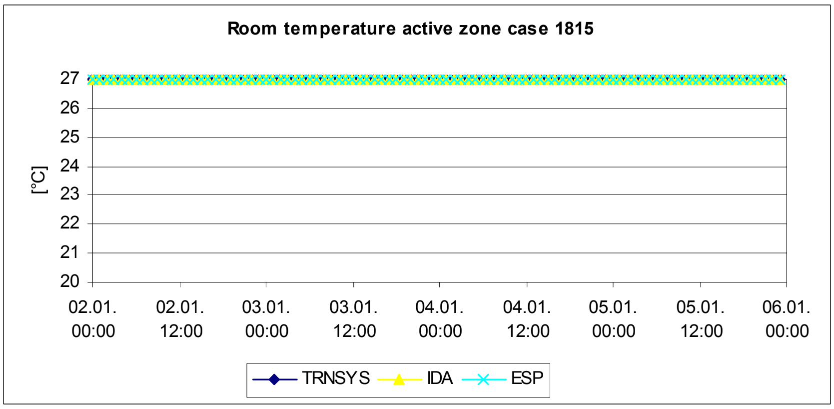
Case 1800 – highly insulated 2 zone model.



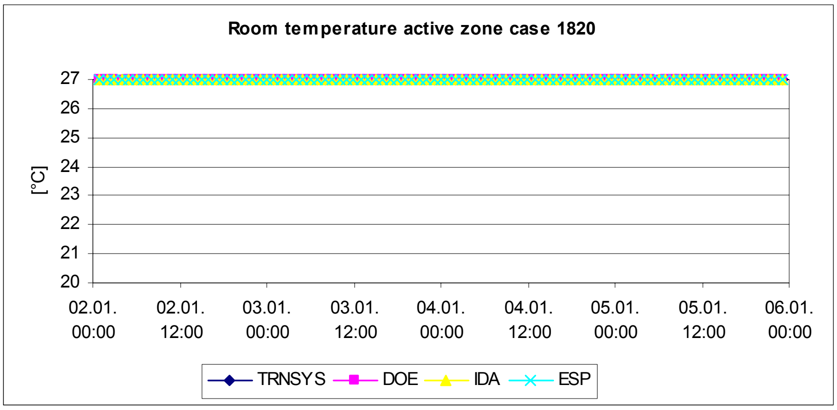
Case 1805 - Totally insulated 2 zone model.
- Infiltration Ach=1.0 1/h
- Internal loads 200 W from 1st may to 30 September. (purely convective)



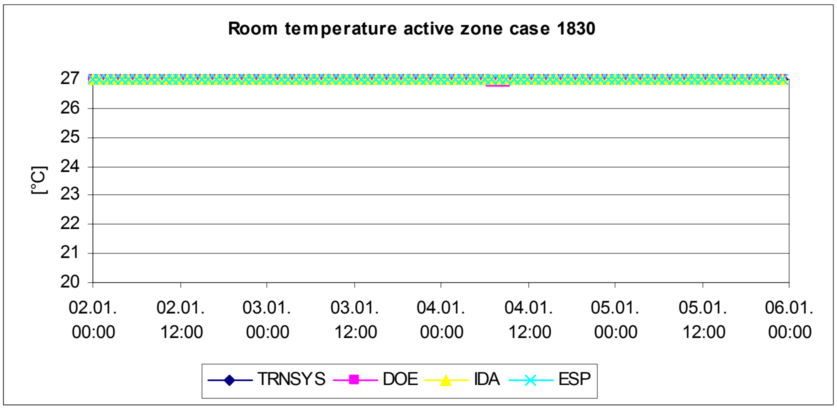
Case 1810- The constant temperature layer between the concrete layer and the insulation
- Suface coefficient on floor purely convective.



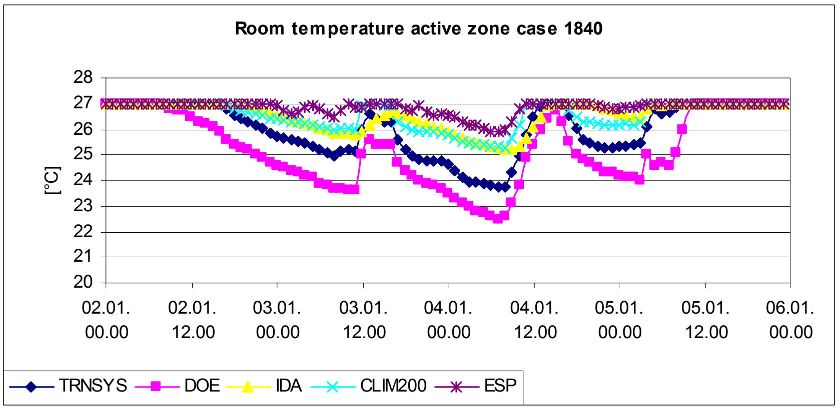
Case 1815 – Combined surface coefficient. Radiation 100% to ceiling.



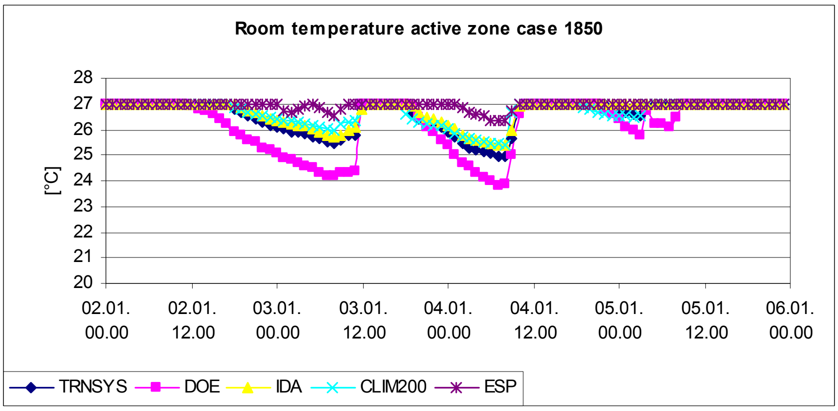
Case 1820 - Ordinary distribution of radiation on all surfaces.



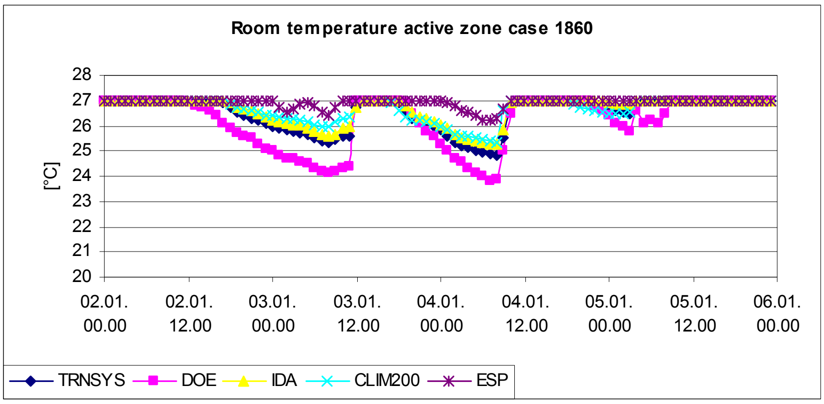
Case 1830 - Active zone with normal envelope.
- Without window
- Ach=0.5 1/h
- Internal gains purely convective 365 days.



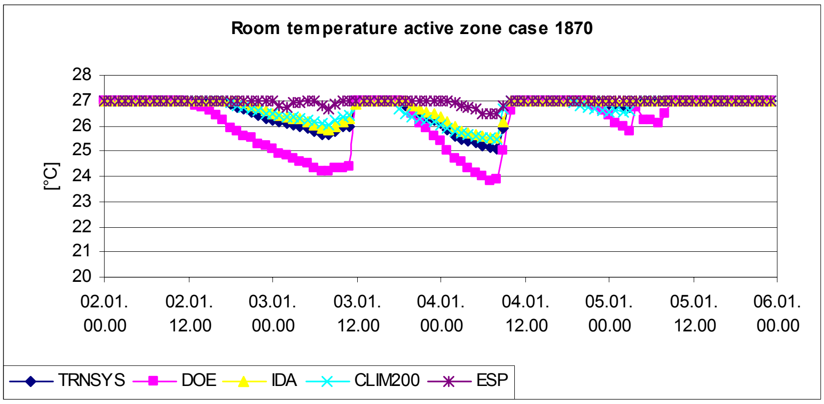
Case 1840 - Active zone with normal envelope. Highly conductive wall included



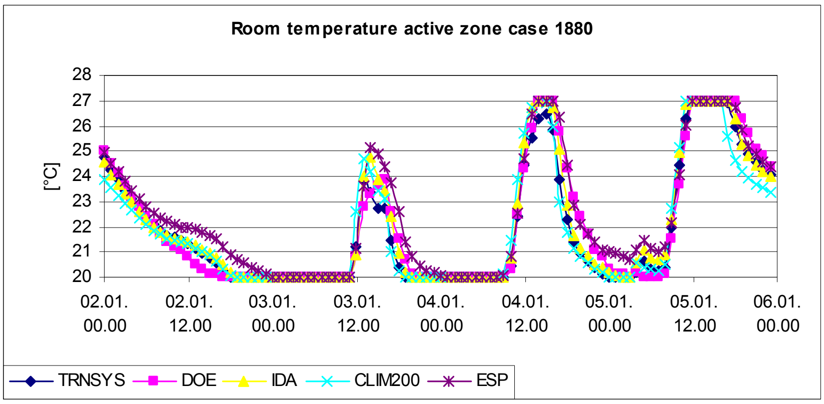
Case 1850 – real window case



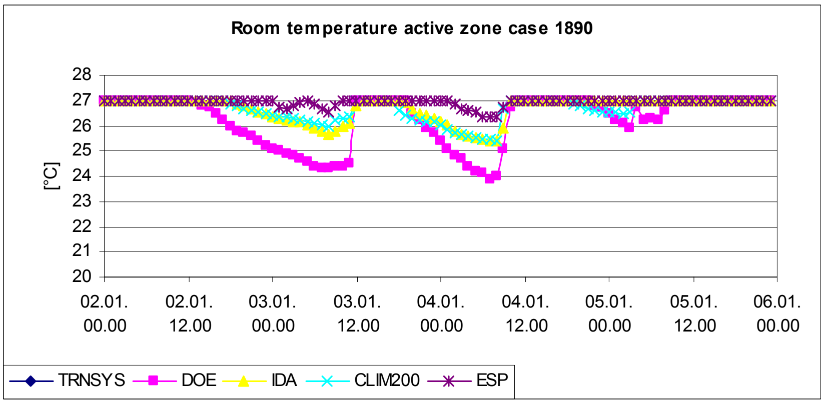
Case 1860 - internal gains purely radiative



Case 1870 - internal gains purely convective



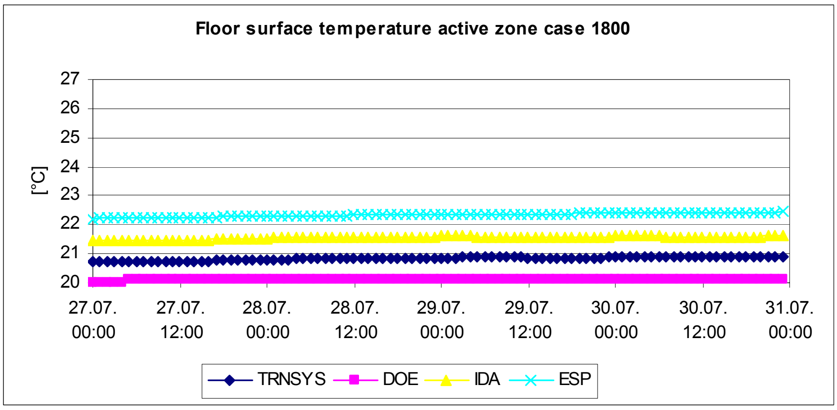
Case 1880 - layer temperatures on a lower level (summer 18°C winter 30 °C)



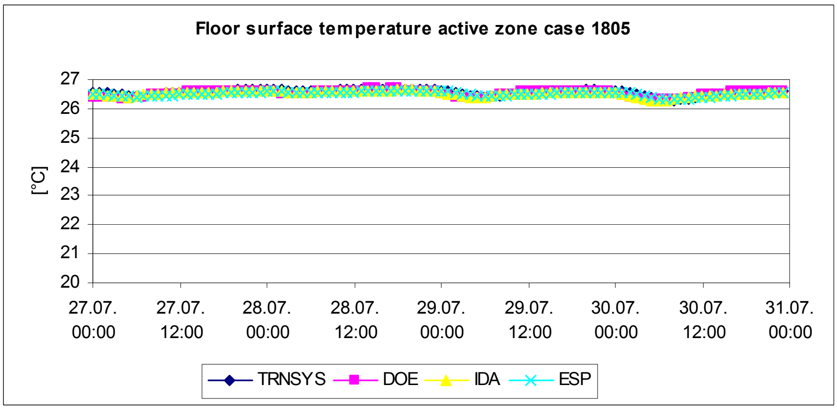
Case 1890 – Similar case as 1850 but during summer time layer only active from 10 pm to 6 am.

TRNSYS did not run this test

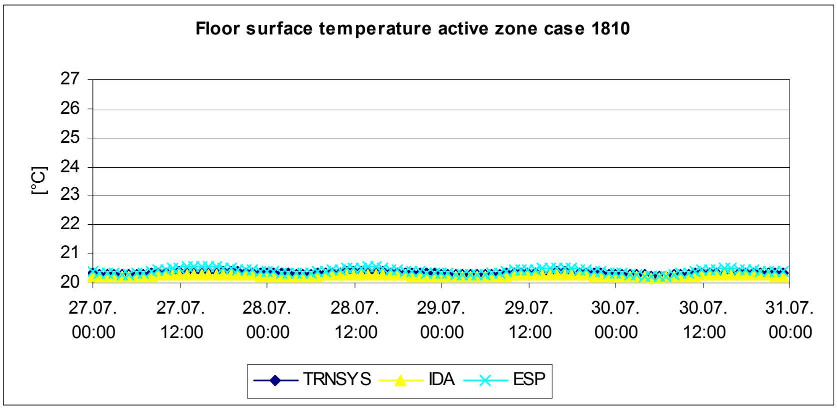
2.4.3.3 Floor surface temperatures summer period



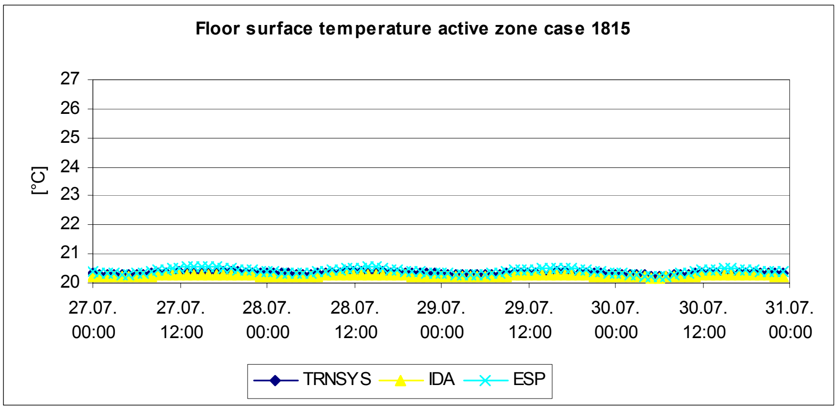
Case 1800 – highly insulated 2 zone model.



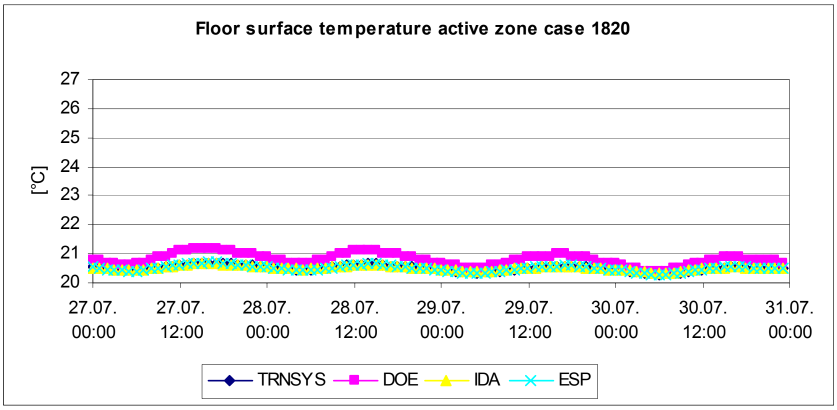
Case 1805 - Totally insulated 2 zone model.
- Infiltration Ach=1.0 1/h
- Internal loads 200 W from 1st may to 30 September. (purely convective)



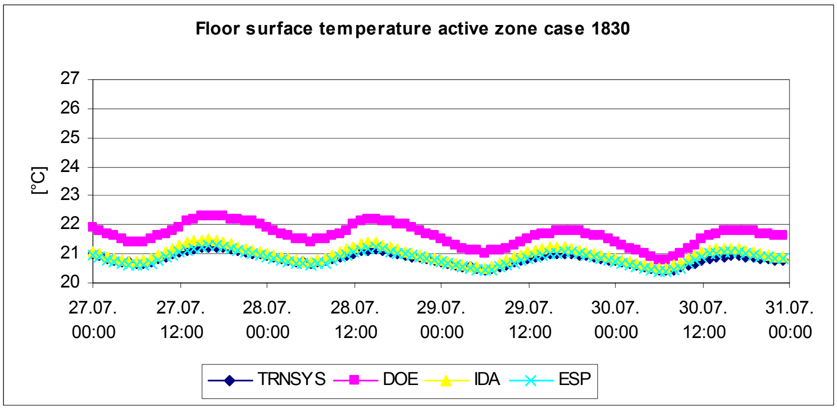
Case 1810- The constant temperature layer between the concrete layer and the insulation
- Surface coefficient on floor purely convective.



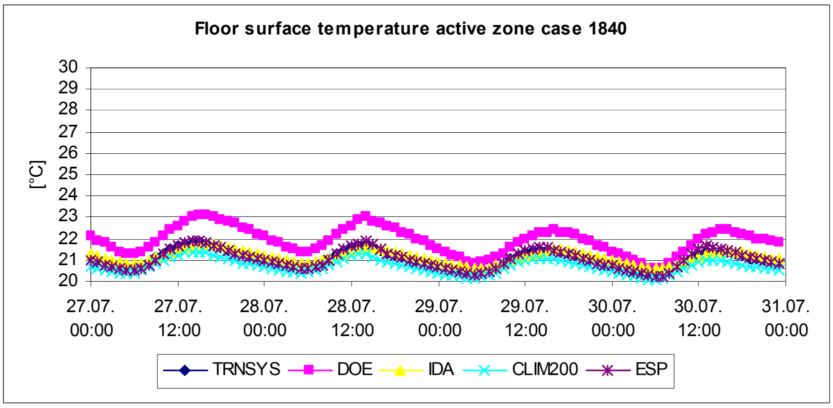
Case 1815 – Combined surface coefficient. Radiation 100% to ceiling.



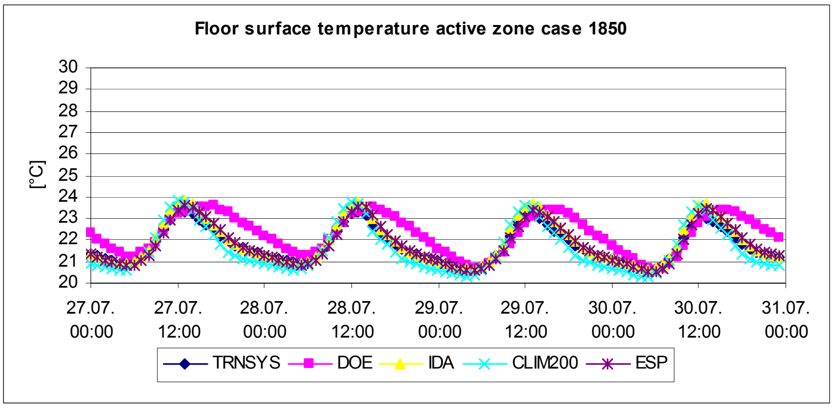
Case 1820 - Ordinary distribution of radiation on all surfaces.



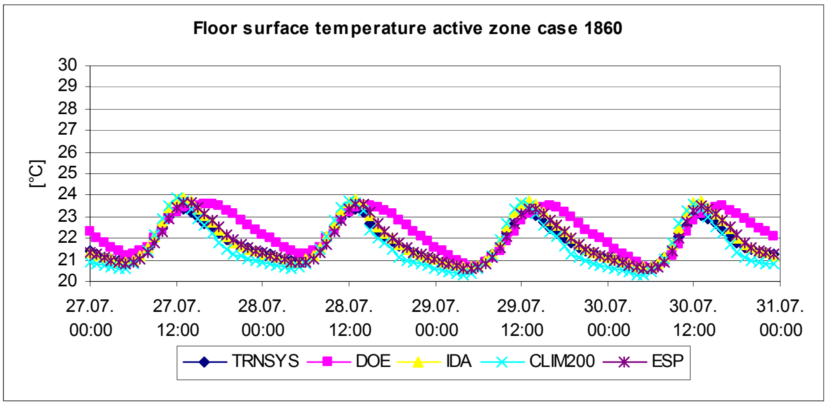
Case 1830 - Active zone with normal envelope.
- Without window
- Ach=0.5 1/h
- Internal gains only convective 365 days.



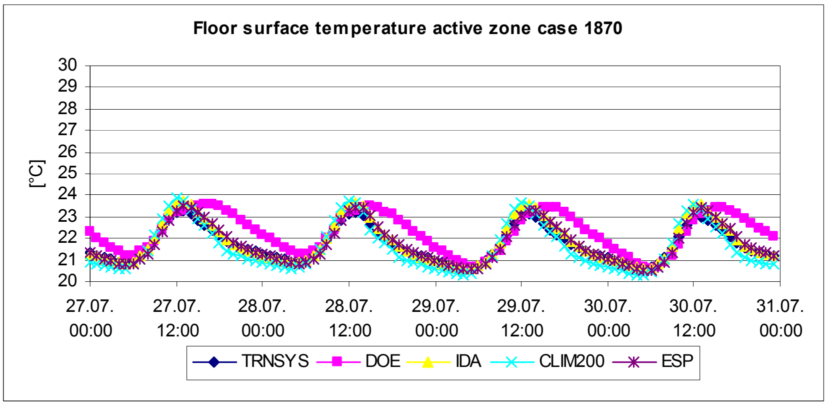
Case 1840 - Active zone with normal envelope. Highly conductive wall included



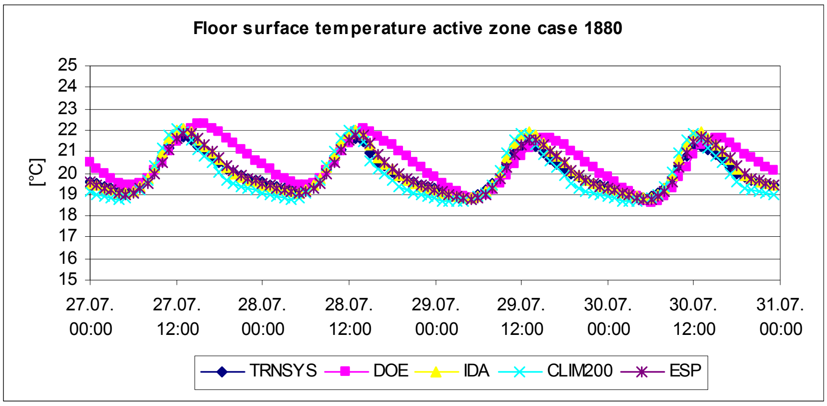
Case 1850 – real window case



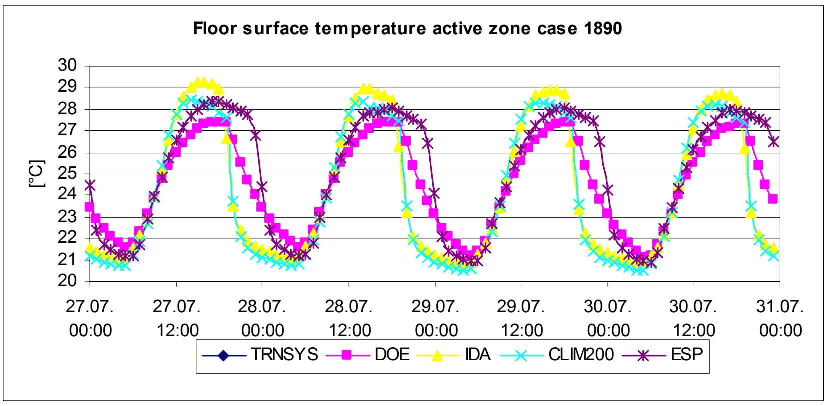
Case 1860 - internal gains only radiative



Case 1870 - internal gains only convective



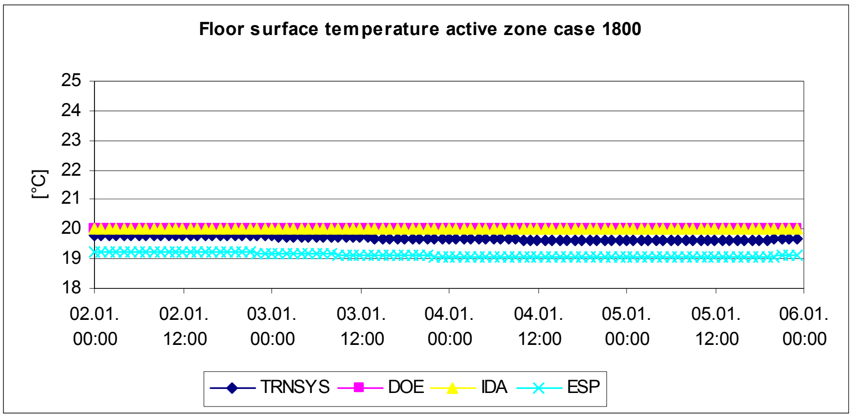
Case 1880 - layer temperatures on a lower level (summer 18°C winter 30 °C)



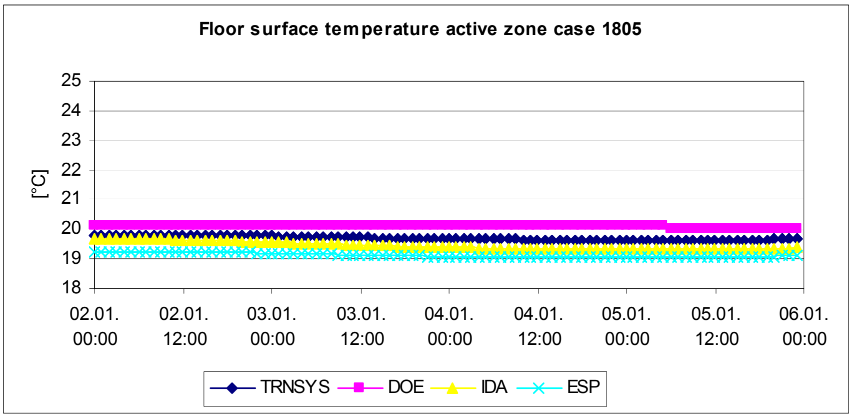
Case 1890 – Similar case as 1850 but during summer time layer only active from 10 pm to 6 am.

TRNSYS did not run this test

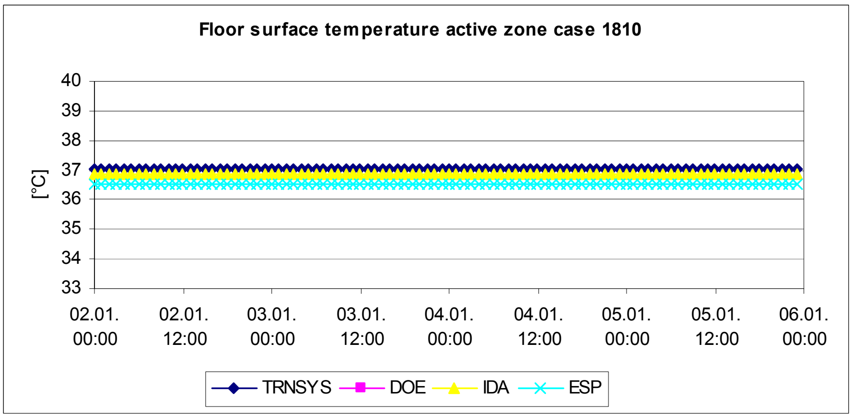
2.4.3.4 Floor surface temperatures winter period



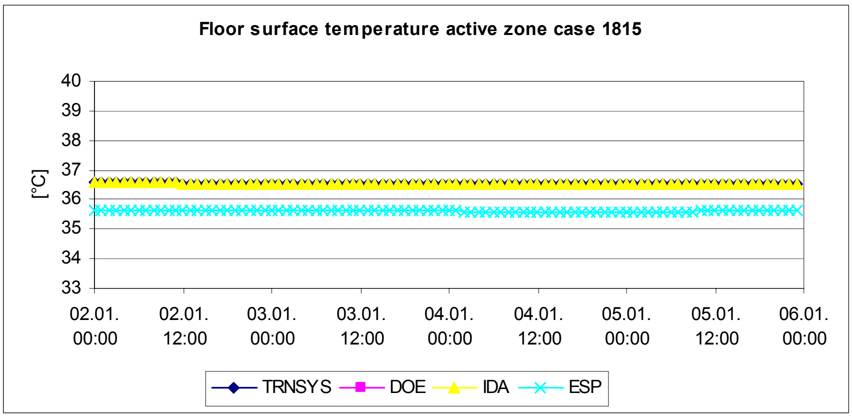
Case 1800 – highly insulated 2 zone model.



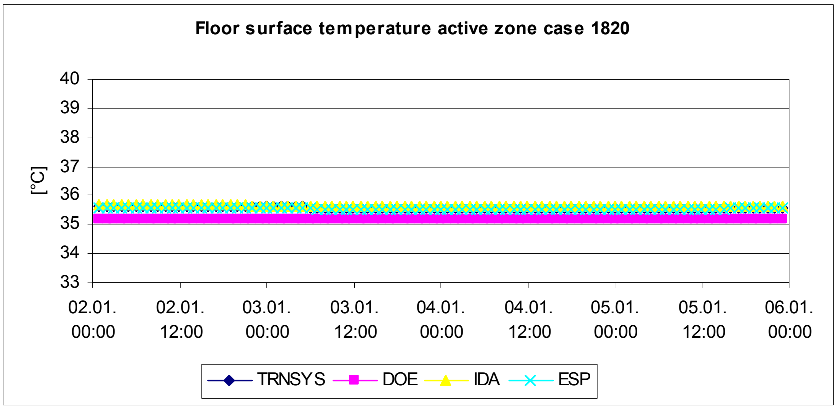
Case 1805 - Totally insulated 2 zone model.
- Infiltration Ach=1.0 1/h
- Internal loads 200 W from 1st may to 30 September. (purely convective)



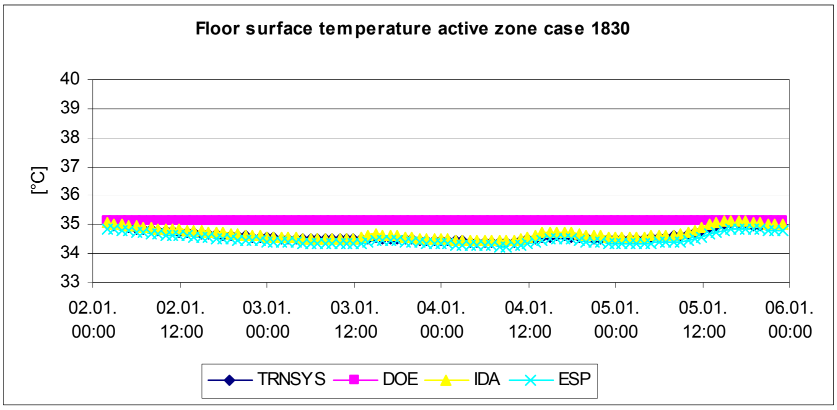
Case 1810- The constant temperature layer between the concrete layer and the insulation
- Surface coefficient on floor purely convective.



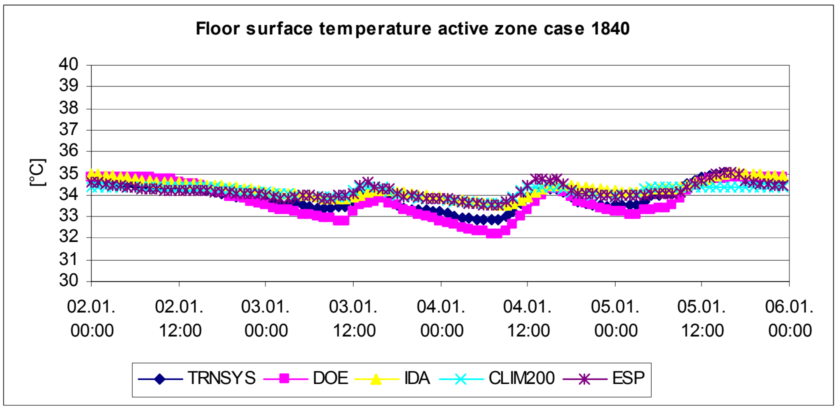
Case 1815 – Combined surface coefficient. Radiation 100% to ceiling.



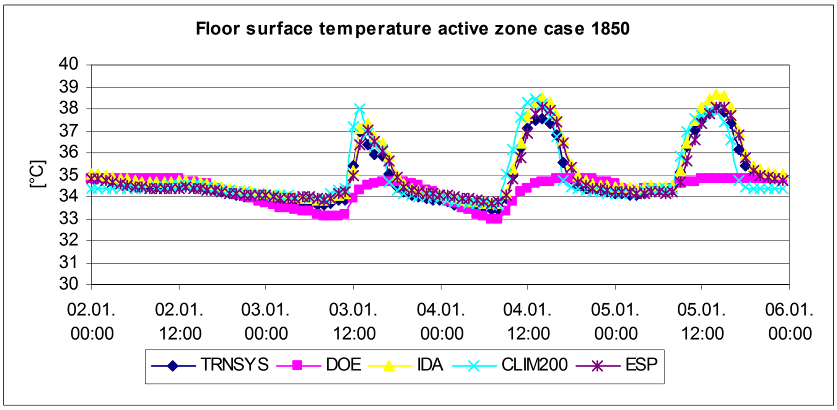
Case 1820 - Ordinary distribution of radiation on all surfaces.



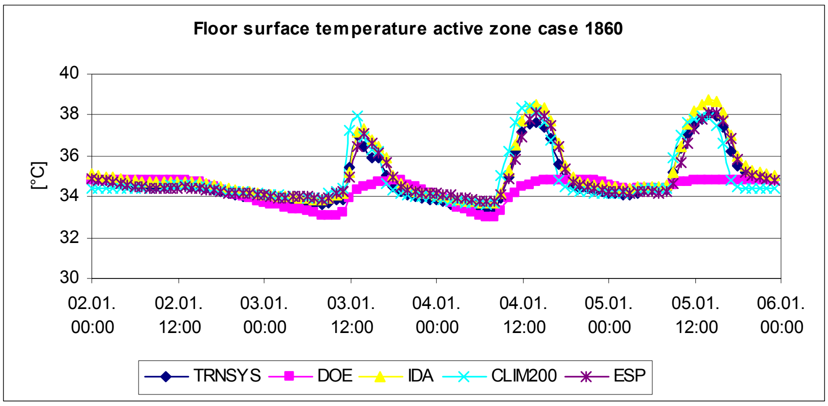
Case 1830 - Active zone with normal envelope.
- Without window
- Ach=0.5 1/h
- Internal gains purely convective 365 days.



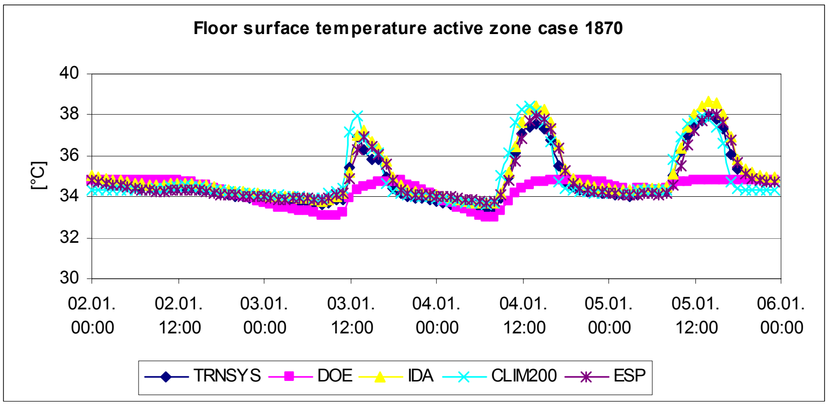
Case 1840 - Active zone with normal envelope. Highly conductive wall included



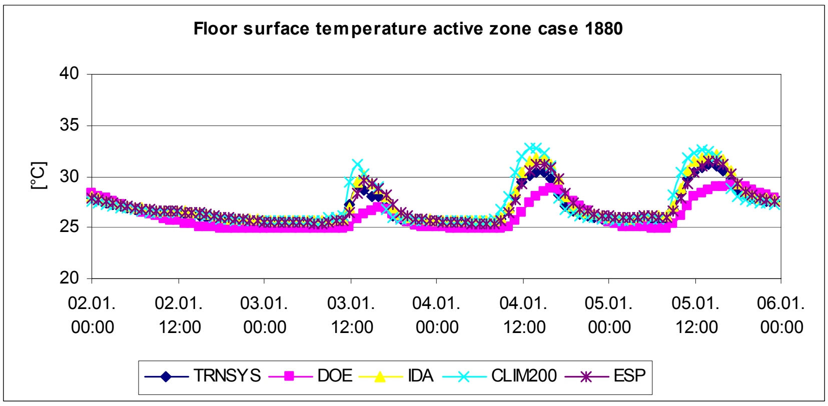
Case 1850 – real window case



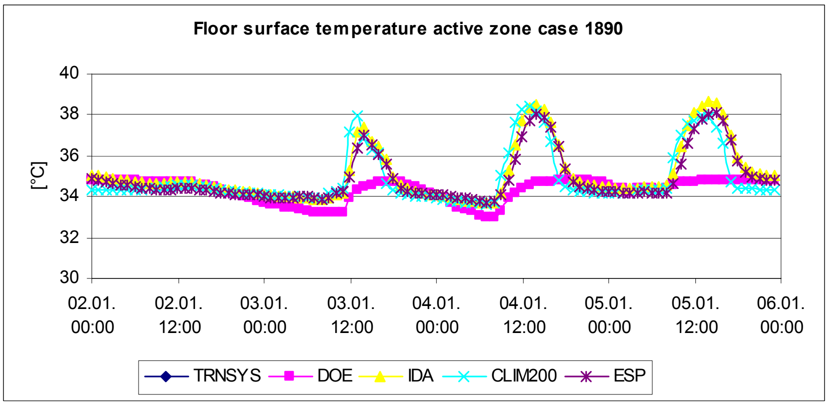
Case 1860 - internal gains purely radiative



Case 1870 - internal gains purely convective



Case 1880 - layer temperatures on a lower level (Summer 18°C winter 30 °C)

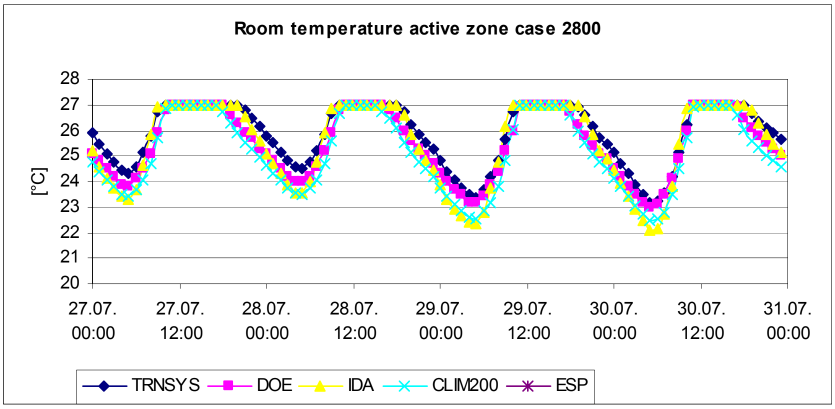


Case 1890 – Similar case as 1850 but during summer time layer only active from 10 pm to 6 am.

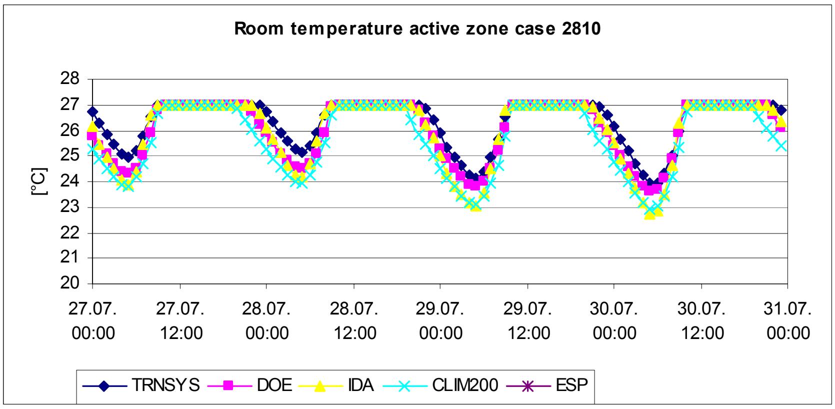
TRNSYS did not run this test

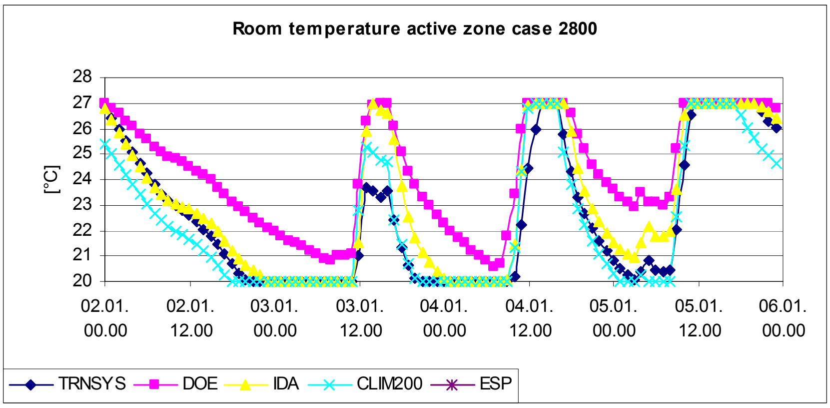
2.4.4 Detailed water loop

2.4.4.1 Room temperatures

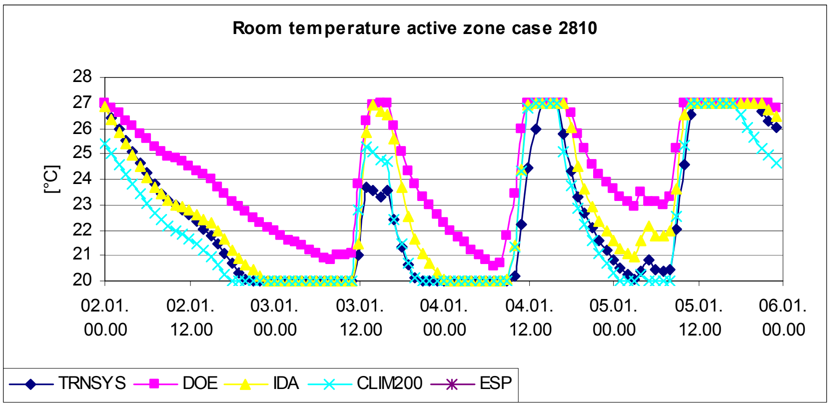


Summer period – different set point

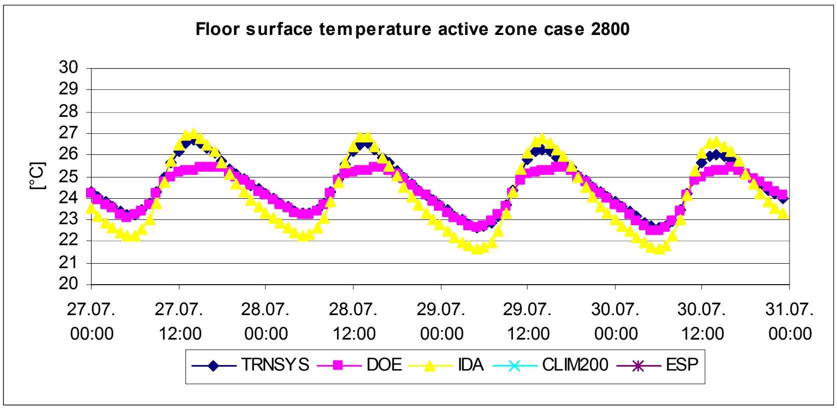




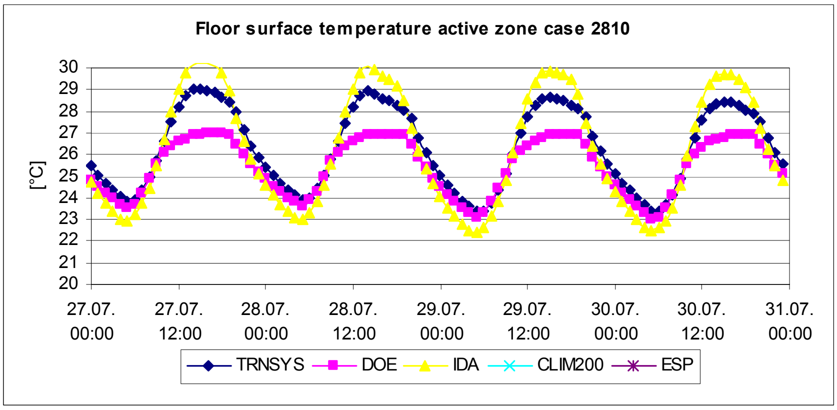
Winter period - both results similar



2.4.4.2 Floor surface temperature detailed water loop



Summer period – different set point



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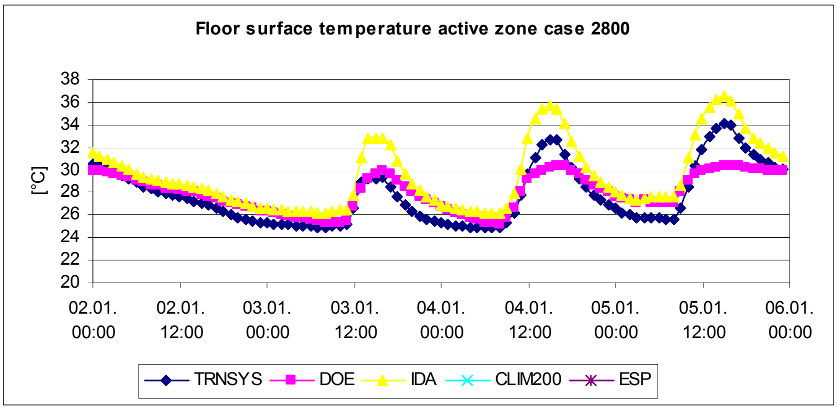
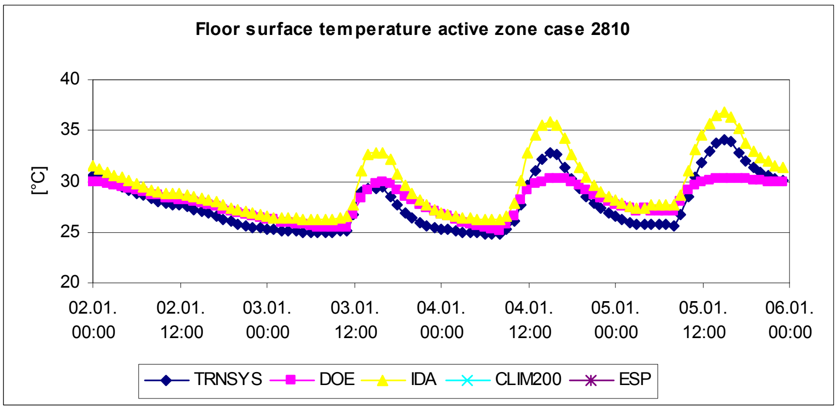
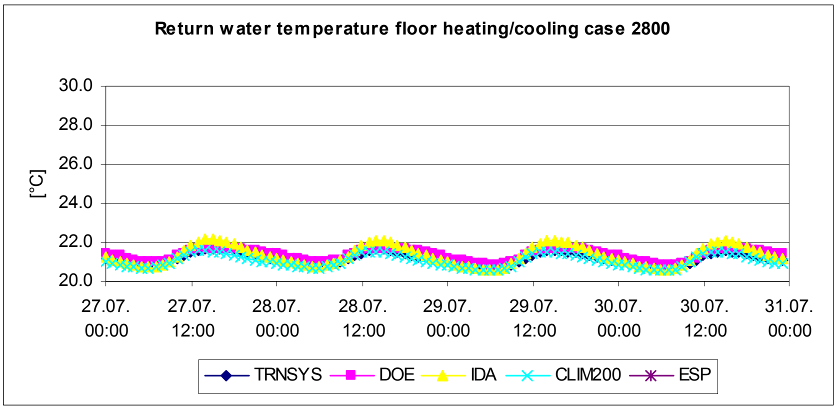


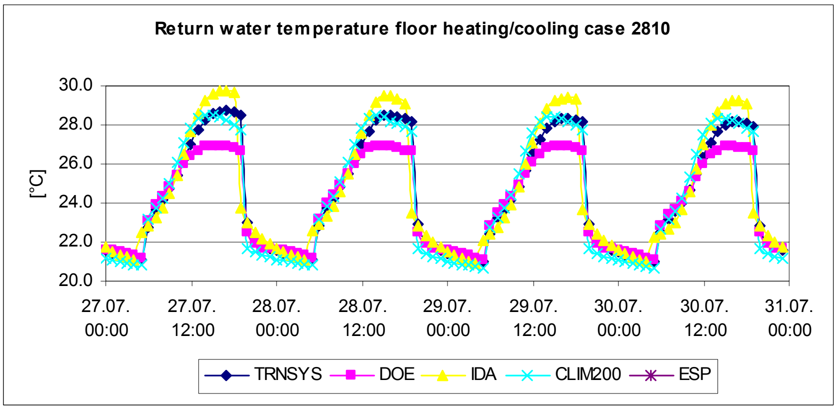
Winter period - both results similar

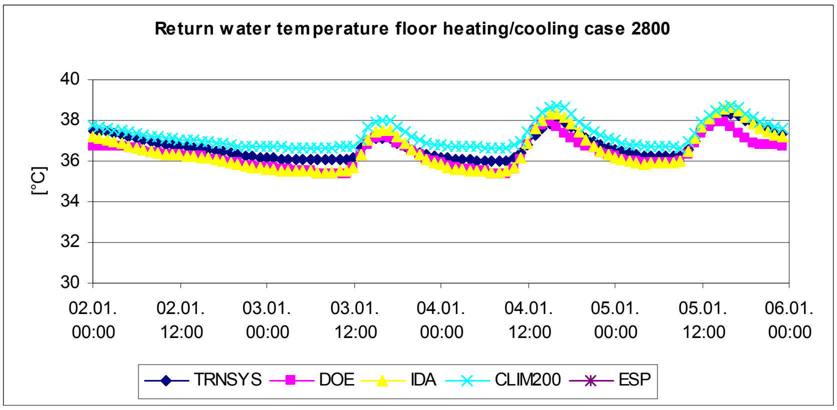


2.4.4.3 Return water temperature hydronic loop



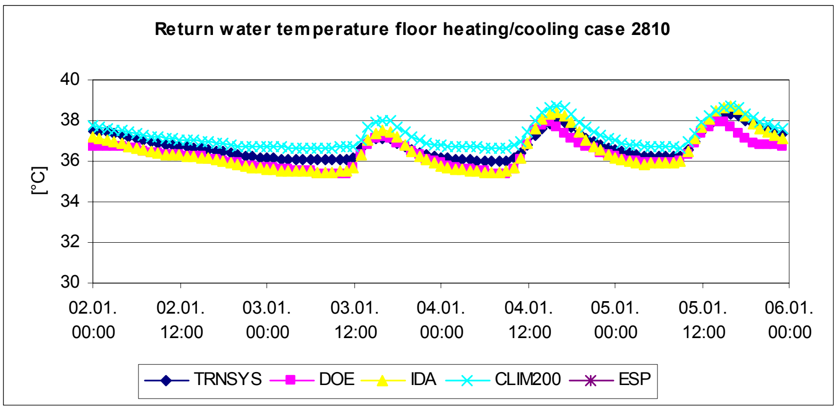
Summer period – different set point





Winter period - both similar

No problem during winter time.



2.5 Modeller Reports

2.5.1 Preliminary remark

As stated before, the tests were conducted in several steps and modified during the performance. Based of the experience, in order to clarify the suite, the user's manual (part I) was redesigned and restructured. As a consequence, chapters, tables and even cases were renumbered. This has been considered up to this place in the whole report.

In the following parts of this chapter, the modeller's reports may refer to cases, chapters and tables with numbers from earlier versions, differing from the present report. This was intentionally left as it was, because the editing authors did not want to change the original texts of the different reporting authors.

For a better navigation, the following table assigning case numbers from earlier versions to the present ones is given:

Old case number	Present case number
795	Dropped
800	800
1800	Dropped
1810	Dropped
1820	Dropped
1830	Dropped
3800	1800
3805	1805
3810	1810
3815	1815
3820	1820
3830	1830
1840	1840
1850	1850
1860	1860
1870	1870
1880	1880
1890	1890
2800	2800
2810	2810

TRNSYS

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June 2002

1. Model and simulation program

All the tests were done with TRNSYS TUD a modificated and rewritten version of TRNSYS 14.2. At Dresden university the original TRNSYS program source code was subjected to a lot of changes as well as additions to create a tool characterised by very specific properties in regard to the simulation and analysis of both operation and control of HVAC-systems in buildings.

The existing model of a underfloor heating system had to be extended to be able to run the radiant heating and cooling test cases (Radtest). Now it is possible to simulate the behavior of detailed water loops as well as simplified temperature layers within walls. The so-called active layer devides a wall into two parts each having the same boundary condition.

2. Test cases

Radtest bases on ENVELOPE BESTEST from IEA Task12 that in its high mass basic test has to be fulfilled. All test cases - simple tests as well as detailed models - are setted out in the RADTEST specifications and it is in general not very difficult to create appropriate simulation models. Nevertheless it was not possible to construct a model for test case 1890 without making a lot of changes in the TRNSYS source code. In this test case the temperature layer is shutted down partly during the summer period. Meanwhile the temperature of the active layer which is an input value of the program is undefined and a result of the simulation respectively.

The detailed model cases base on a detailed water loop model instead of a simple temperature layer. The heat transfer between the pipe system and the floor depends on the geometric layout and the thermal properties of the building element. Therefore an (equivalent) exterior heat transfer coefficient for the pipes was calculated.

3. Results

All output data required to fill out the pre-formated EXCEL-sheet are available.

4. Summary

The RADTEST is useful to validate radiant heating and cooling systems in buildings. It is hardly to find similar validation procedures.

For a more practical point of view test cases with detailed water loops are more interesting than cases with a temperature layer. It also would be really interesting to have a look at the thermal behavior of a mass flow controlled radiant heating system instead of a temperature controlled one.

DOE 2.1E

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June 2002

1 Introduction

This report is the result of the experiences made with DOE2.1e carrying out the IEA RADTEST procedure. Its aim is to outline modelling particularities when performing radiant heating and cooling calculations with DOE2. Furthermore, results in comparison to other building energy programs are commented and an overall conclusion for the use of DOE2 in the field of radiant heating and cooling calculations is made.

2 Important program capabilities of DOE2.1e concerning radiant heating and cooling

Due to its program algorithms DOE2 has certain limitations in modelling of radiant heating and cooling cases. Nevertheless, various calculations have been carried out with good results not only in this test procedure, but also for energy consultant jobs, using simulation models that take this fact into account. The major points that need special attention are described below.

surface coefficients

- **combined surface coefficients** (convection and radiation): e.g. two walls are coupled together with their combined surface coefficient having only a connection over the zone air temperature.
- **constant surface coefficients:** there is only one interior-surface coefficient (for every wall) to be defined over the whole simulation period. Thus, an average value for heating and cooling, depending on the simulation period, has to be defined.
- **one surface coefficient per wall:** only one coefficient, which is valid for both wallsides, can be defined for interior walls. Only exterior walls have an outside (which is calculated hourly by the program) and an inside surface coefficent.

Inserting a heating / cooling layer into a construction

DOE2 does not give the possibility to insert a layer for heating and cooling into a construction. Therefore, an artificial zone (in the following called DUMMY-ZONE) which represents this layer, has to be used (see also section 0).

Output variables

Because loads are calculated in the LOADS program and then passed as a whole to the SYSTEMS program which allows to simulate a floating room temperature, information of heat fluxes through individual walls of a zone are lost in the SYSTEMS program. This also affects how the model in DOE2 has to be built in order to get the desired output variables (see also section 0).

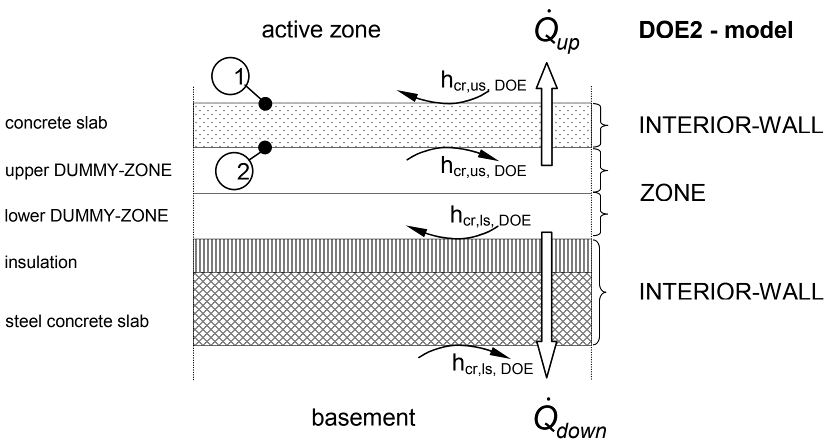
3 Model description

Floor heat model

Layer definition

The model used for the heated and cooled floor in the RADTEST cases is shown in Figure 2.5-1. Two DUMMY-ZONES are required in order to calculate both, the heat flux to the active zone (Q_{up}) and the heat flux to the basement (Q_{down}).

Each of the DUMMY-ZONES is served by an own system to hold the desired layer temperature according to the test specification. Q_{up} and Q_{down} respectively, is equal the energy consumption of the system that serves the corresponding DUMMY-ZONE.



variables		indices	
h	surface coefficient	c	convection
Q	heat flux	r	radiation
		us	upper side
		ls	lower side
		DOE	input in DOE2

Fi

gure 2.5-1: schematic representation of the floor heat model

Determination of floor surface coefficients

As mentioned in section 0 only one surface coefficient per interior wall can be defined. The calculation of the floor surface coefficient for the upper and lower side is done according to the test specification [3], section 3.4.6. The mean floor surface temperature and the room air temperature which are needed for this calculation are obtained from a first run of simulations. This floor surface coefficient calculated in that way represents an average coefficient over the whole simulation period.

Correction of floor surface coefficients for the use in DOE2

According to [1] the following approach in the weighting factor calculation is used in DOE2 to determine the radiative heat exchange between two surfaces (m and i):

$$Q_{Rim} = K_{Rim^*}(T_m - T_i)$$

Equation 2.5-1

where Q_{Rim} is the heat flow from surface i to surface m, T_i and T_m are the surface temperatures and K_{Rim} is calculated as:

$$K_{Rim} = 4 * \varepsilon_i * \sigma * (T_R^{\,3}) * F_{im} * A_i$$

Equation 2.5-2

where ε_i is the emissivity of surface i, σ is the Stefan-Boltzmann constant, T_R is a reference temperature in absolute units, F_{im} is the view factor between surfaces i and m and A_i the surface.

T_R is set to 21.1 °C (70 °F), which is too low for heating purposes. With higher surface temperatures more energy than calculated by DOE2 would be stored with radiation in ambient walls and less energy transmitted directly to the room air. To compensate for this effect, the surface coefficient determined as described in section 0 is reduced with respect to the reference temperature T_R used in DOE2:

$$f_{corr} = \left(\frac{T_R}{T_{R,eff}} \right)^3$$

Equation 2.5-3

where $T_{R,eff}$ is the effective floor surface temperature and T_R is the reference temperature used by DOE2 (21.1 °C). Both temperatures in Equation 2.5-3 are in absolute units.

It has to be emphasized that this correction is only an approximation which is made because the default surface temperatures in DOE2 for the weighting-factor calculation can not be changed.

Input of floor surface coefficient in DOE2

The film-resistance at position 2 in Figure 2.5-1 should be as small as possible, so that the surface temperature of the concrete slab on the layer side is equal the DUMMY-ZONE temperature. Therefore, the floor surface coefficient as described in section 0 must not be input directly in DOE2 because it is used on both wallsides. Following models are possible[1]:

Model 1

$h_{cr,DOE} = 0.5 * h_{cr}$

Model 2

$h_{cr,DOE}$ = 999 W/m2*K (small film-resistance). To compensate the too low film-resistance at position 1 an additional thermal resistance without thermal capacity has to be input.

Model 3

$h_{cr,DOE} = h_{cr}$

To compensate the too high film-resistance on the DUMMY-ZONE side, the layer temperature has to be set higher ($\vartheta_{Layer,\ corrected}$) so that the desired layer temperature is equal $\vartheta_{surface}$ (see following figure).

[1] The models are a compromise to find a good model that incorporates the correct surface coefficient on the active zone side and the correct temperature on the layer side. The model must not change the total resistance of the construction.

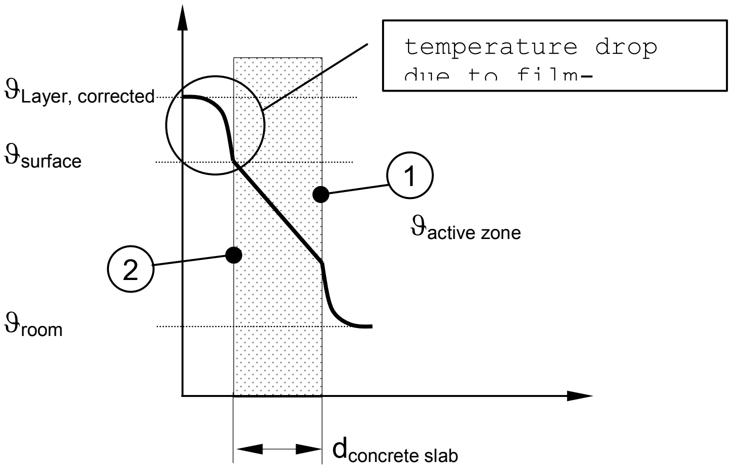


Figure 2.5-2: correction of the layer temperature
$\vartheta_{\text{Layer, corrected}}$ is chosen in order that $\vartheta_{\text{surface}} = \vartheta_{\text{Layer from test description}}$

For the RADTEST cases model 3 has been chosen as this is the best approximation to reality in this certain case.
The disadvantage of model 3, that $\vartheta_{\text{surface}}$ depends relatively strong on the temperature difference $\vartheta_{\text{Layer, corrected}} - \vartheta_{\text{active zone}}$, is not really significant in the RADTEST calculation as the temperatures are almost constant over a wide range of the simulation period.

Real case with detailed water loop
The model described in section 0 is used as well for the detailed water loop test (cases 2800 and 2810). Prior to the simulation the layer temperature has to be determined in function of the mean medium temperature and the geometrical and physical properties of the floorheating. The room temperature which is required for this calculation as well, is obtained from a first simulation.

Zone Model
The active zone is input using the SUNSPACE[2] feature of DOE2. This model incorporates a more detailed radiation calculation.

Glazing
The glazing properties from the test specification have been input in the window-4 database format for the use with DOE2. The angle dependent values from the ENVELOPE-BESTEST specification [2] have been used for this purpose.

Weather file
The binary weather file for DOE2 was made using its weather processor. The source is a TMY-file from the ENVELOPE-BESTEST [2].

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[2] The SUNSPACE feature is originally intended to use for rooms with exterior glazing that have another window adjacent to an interior room. Solar energy transmitted from the SUNSPACE-Windows though interior windows is then calculated.

4 Comments on results

Temperatures in active zone

Following observations on the room-temperatures in floating mode (temperatures between heating and cooling setpoint, i.e. 20 and 27 °C) can be made:

Whereas in the summer period (27th to 30th July) there is a good agreement with the other simulation programs, in the winter period (2nd to 5th January) the room temperature generally descends too fast. The reason for this behaviour could be that the DOE2 model underestimates the storage of radiation energy from the floor to the inner side of the ambient walls, because weighting factors are calculated at a reference temperature of 21.1 °C for the radiation calculation. This explains why better results can be observed in the summer period: at this time the floor surface temperature is closer to the reference temperature than in heating mode.

Surface temperatures

There is a good agreement in the mean surface temperatures compared to other programs. On the other hand, the plots show that there is not enough dynamical behaviour. Although, temperatures are reasonable for many of the cases in the summer period, the winter period shows a rather flat surface temperature curve. An improvement can be observed from case 1850 to case 1880 where the temperature level of the floor heating is lower (30° instead of 40 °C).
Different reasons can be considered:

- constant surface coefficient: dynamical processes such as solar radiation falling on the floor and causing a change in the floor surface temperature and therefore in the surface coefficient are neglected. Instead a constant surface coefficient for the floor has to be input.
- Radiation and convection from the floor to ambient walls are calculated with a combined surface coefficient.
- Distribution of solar radiation in the zone: the amount of solar energy falling on a surface has to be input as a constant fraction.

5 Conclusion

Although there are different limitations in modelling a radiant heating and cooling model with DOE2, the test shows good results and a good conformity to the other simulation programs.

Special attention has to be paid to the determination of the surface coefficient, which has to be input by the user. Furthermore, different models (or variations of the model described in this paper) are possible and it has to be decided by the user which one has to be chosen according to the given task. Floor surface temperatures show a poorer dynamic behaviour in winter than in summer. Better results are obtained with lower floor-heating temperatures (compare case 1850 with case 1880).

6 References

[1] DOE2, Engineers Manual

[2] IEA Task 12, Envelope BESTEST

[3] IEA Task 22, RADTEST, Radiant heating and cooling test cases

IDA-ICE

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June 2002

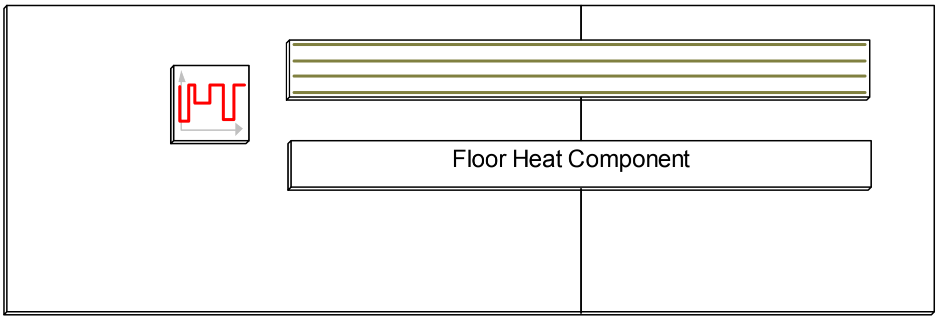
Introduction

The modeller report documents the RADTEST results calculated by IDA-ICE version 3.0. IDA-ICE is a Swedish simulation software developed and distributed by EQUA Stockholm [1].

Model approach

The building is modelled as described in the test specifications. For the cases with the active floor layer the standard floor heating model was used to provide heating and cooling power into the floor. In some cases modifications in the system parameters and/or the linkable variables were made.

The floor heating model used in IDA-ICE is macro using a floor heat component (hydronic driven layer) with two wall parts on each side (cover layer and floor construction below). The heat extraction from the water to the surface of the wall part is described by a constant surface coefficient. It is the mean heat extraction from the hydronic tubes into the floor. In that way, the heat flows into the wall parts above and below. The wall parts are developed as an infinite difference model of a multi-layer component. Each wall part is divided in several layers depending on the construction. Each layer has to be subdivided in a certain number of sub layers to get accurate storage capacity if the modeller uses heavy weight constructions. For the RADTEST the default values from IDA-ICE were used.



Pic. 1. IDA-ICE floor heat macro

Input specification

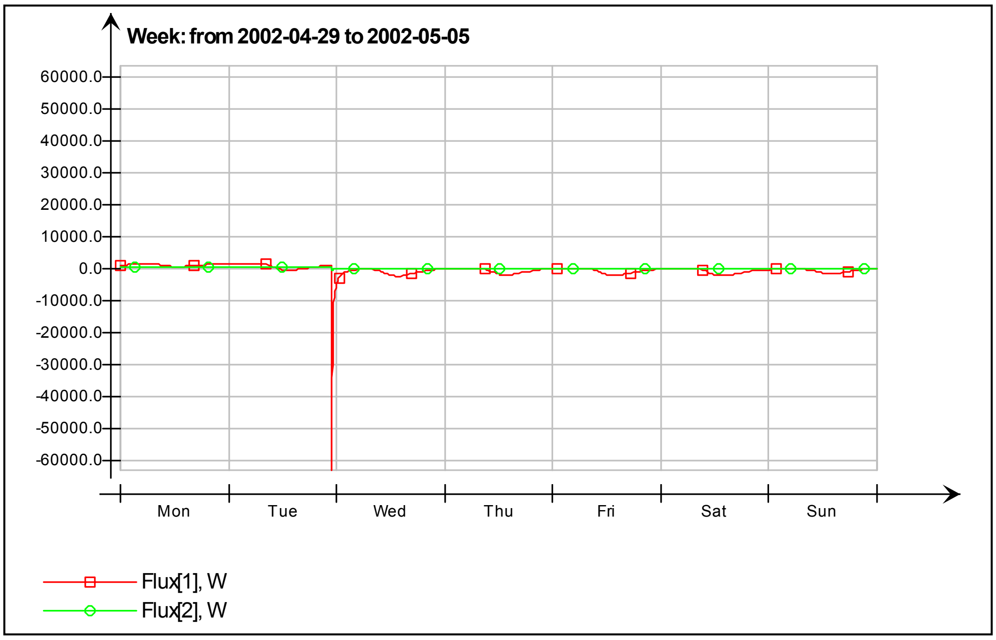
To run the RADTEST cases with the standard ICE model, the hydronic connections were disconnected. The supply mass flow was set as constant. Depending on the test case a schedule is controlling the mass flow. To get a constant floor temperature, the mass flow was set to an infinite big value. In that way, the heat extraction to the room finally depends only on the resistance of the floor construction and the surface coefficients. Surface coefficients were determined by IDA-ICE, if the modeller uses the detailed zone model.

For the cases with the detailed water loop the floor heat component was modified in same manner as the simple ones. The difference between two cases are the modified input parameters such as the mass flow which is a real designed mass flow determined by the design temperature spread. The mass flow and the temperature level of the floor heat/cool system are controlled by schedules.

Results

With the model assumptions above, IDA-ICE provides accurate results which show a good agreement with the reference programs.

At one point, the results varies from the references programs. This are the heat fluxes from the active layer to active zone and basement. The peak heat and cooling power are much higher than the other programs. A detailed analyse of this behaviour shows that, if the temperature level of the active layer changes (May 1st and October 1st) a huge heat flux is determined for a few hours. See picture 2. This behaviour only occurs in the heat flux variable – the heating and cooling energy consumption and the local zone temperatures (controlled in active zone, free floating in basement) do not react in that way. It seams, that the massive heat flux is damped by the floor construction. In fact that the big heat fluxes occurs only a few hours the influence on the annually heat fluxes is not remarkable and can be neglected.



Pic. 2. upward heatflux if setpoint changes

Conclusions

To run this test series with IDA-ICA no certain complication has occurred . The first runs (blind test) showed once more that the modeller itself can have a big influence on the accuracy of the results. Some modeller errors could be found on that way. It is important to have simple test cases to compare simple model approaches to make quick energy estimations with a good accuracy.
To compare detailed models, the variation of detailed test cases should be increased. It would be nice to have a comparison of different order of tube installation and different control strategies.

Matthias Achermann, Horw 26. June 2002

CLIM 2000

Joseph Ojalvo
EDF - Electricite de France
June 2002

Introduction

RADTEST

Radiant heating and cooling systems are known all over the globe. Radiant heating systems are in use in residential buildings as floor heating systems. The majority of radiant cooling systems are in use in commercial buildings, primarily as ceiling-based systems. In many instances, radiant system use for heating and cooling purposes based on time of the year.

To take into account the behaviour of radiant heating and cooling in dynamic simulation programs, specific models or modelling methods should be available. Some of these methods are well known, but there is a need to validate these models and methods to improve confidence in them.

The goal of this work is be sure that the tested programs are able to accurately model radiant heating and cooling systems. Additionally, the relation between the simplified approaches and the detailed floor heating and cooling models should be quantified.

The RADTEST is a uniform set of unambiguous test cases for a software to software diagnostic comparison. It has been developed in the frame work of IEA Task22.

The RADTEST cases contain 14 runs. The procedure 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.

CLIM2000

The studies were carried out with the version 2.6 of the CLIM2000 software program.

CLIM2000 allows the behaviour of a whole building to be simulated. The simulation is divided into three stages.

Firstly the building is described by means of a graphics editor providing multi-windowed dialogue in the form of a set of icons. This is called Formal Type (TF), and represents the models chosen by the user. These elementary models, about one hundred in CLIM2000, describe physical laws (conduction, convection, etc.) with a set of continuous equations.

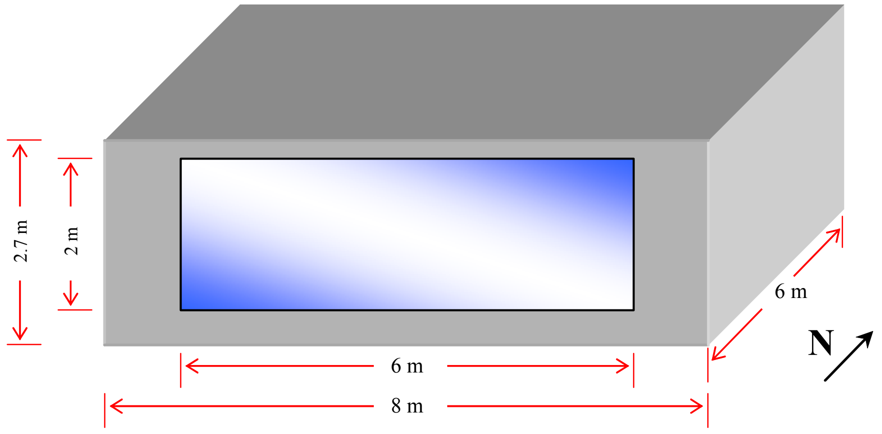
Secondly, these sets of equations are transformed into an electrical circuit representation and solved by the ESACAP solver. In order to simulate these equations, ESACAP uses a Gear's method with a variable sample time.

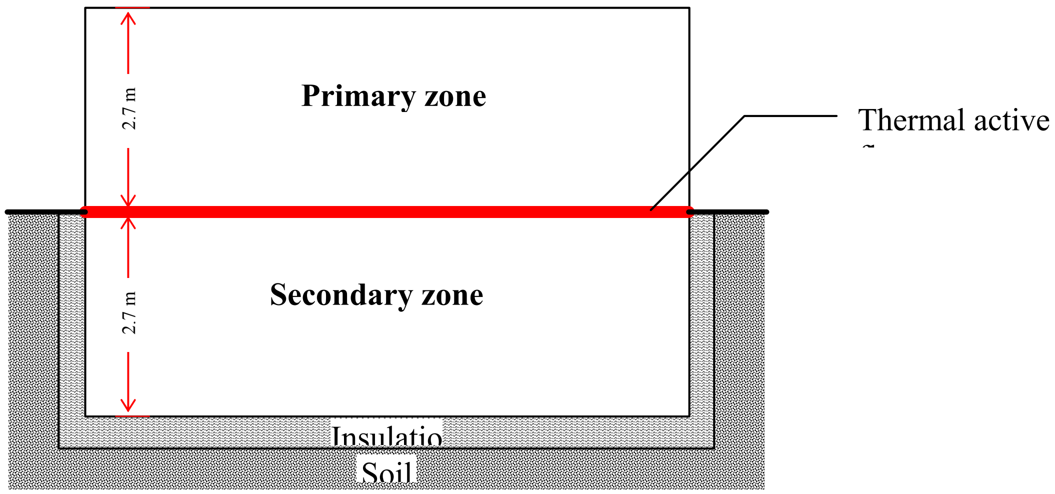
Finally, a post-treatment of the simulation data is possible via a graphic tool, as well as via a transfer to EXCEL.

Main modelling assumptions

Building envelope

Each wall is discretized by using several layers of material, in accordance with the material specifications.





Materials properties

	□ (W/m.K)	□ (kg/m^3)	Cp (J/kg.K)
Concrete block	0,510	1400	1000
Foam insulation	0,04	10	1400
Wood siding	0,14	530	900
Concrete slab	1,13	1400	1000
Fiberglas quilt	0,04	12	840

Roof deck	0,14	530	900
Plasterboard	0,16	950	840
Steel concrete	1,8	2400	1100
Soil	1,3	1500	800

Transparent Window

Double-glazed window, whose properties are :

- $U_{air\text{-}air}$ = 3.0 W/m²K
- Absorptance (direct radiation) $\square_{dir}$

angle (deg)	0	10	20	30	40	50	60	70	80	90
$\square_{dir}$	0.116	0.116	0.119	0.123	0.127	0.133	0.138	0.141	0.136	0

- Absorptance (diffuse radiation) : $\square_{diff}$ = 0.128
- Transmittance (direct radiation) : $\square_{dir}$

angle (deg)	0	10	20	30	40	50	60	70	80	90
$\square_{dir}$	0.748	0.747	0.745	0.739	0.725	0.693	0.622	0.475	0.229	0

- Transmittance (diffuse radiation) : $\square_{diff}$ = 0.644

- ❑ No solar protection

The model used (TF114) doesn't take into account any thermal inertia.

High conductance wall

We use the same model as for the transparent window. The transmittance coefficients are set to 0. The absorptance coefficients are set to 0.6.

Exterior surface coefficient

The exterior radiative exchanges are automatically calculated by CLIM2000.

Hence, the exterior surface coefficient only takes into account the convective part. It is determined by removing the radiative part (estimated to 4.63 W/m²K) from the combined coefficient.

	ε (emissivity)	**α** (abs.)	$\mathbf{h_{conv}}$
Walls and roof	0.9	0.6	24.67 W/m²K
Window and High conductive wall			16.37 W/m²K

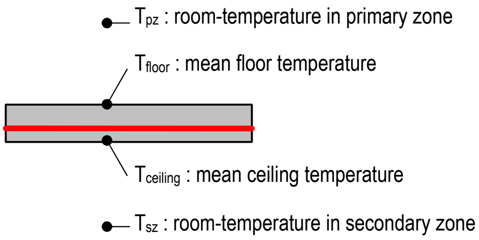
Interior surface coefficient

Single value of the combined radiative and convective surface coefficient.

	ε (emissivity)	**h_{glob}**
walls, floor, ceiling, window	0.9	8.29 W/m²K

<u>Heated and cooled floor</u>

We use here a combined radiative and convective surface coefficient. The value depends on the direction of the heat flow and the difference between the mean surface temperature and the room-temperature.



Upward heat flow

↳ $T_{pz} < T_{floor}$ or $T_{sz} > T_{ceiling}$

$$h_{glob} = 8.92 * \left| T_{air} - T_{surf} \right|^{0.1}$$

Downward heat flow

↳ $T_{pz} > T_{floor}$ or $T_{sz} < T_{ceiling}$

$$h_{glob} = 6.22 * \left| T_{air} - T_{surf} \right|^{0.1}$$

Detailed water loop model ⇨ $h_{glob} = 7.00 * \left| T_{air} - T_{surf} \right|^{0.1}$

Weather data

We used the weather file DRYCOLD.TMY provided with the RADTEST.

- Used data
  - day / month / year / hour
  - dry bulb temperature (°C) T_{ext} [TMY]
  - dew point (°C)
  - total horizontal solar radiation (kJ/m²) $\Phi_{gl\text{-}hz}$ [TMY]
  - direct normal solar radiation (kJ/m²) $\Phi_{dir\text{-}n}$ [TMY]
  - station pressure (kPa) P_{atm} [TMY]
  - wind speed (m/s)
  - wind direction (deg.)

- Adaptations to meet CLIM2000 requirements
  - CLIM2000 uses the universal time (Greenwich), while the TMY file uses the solar time.
    ▶ time [UT] = time [TMY] + 7h
  - total horizontal solar radiation converted in W/m²
    ▶ $\Phi_{gl\text{-}hz} = \Phi_{gl\text{-}hz}$ [TMY] / 3.6
  - direct normal solar radiation converted in W/m²
    ▶ $\Phi_{dir\text{-}n} = \Phi_{dir\text{-}n}$ [TMY] / 3.6
  - calculation of the diffuse horizontal solar radiation (W/m²)
    ▶ $\Phi_{diff\text{-}hz} = \Phi_{gl\text{-}hz} - \Phi_{dir\text{-}hz}$
    $\Phi_{diff\text{-}hz} = \Phi_{gl\text{-}hz} - \Phi_{dir\text{-}n} * \sin h$ avec h = solar height (rad.)

- sky temperature (°C)
  ► $T_{sky} = T_{ext} - 20$

- atmospheric pressure converted in Pa
  ► $P_{atm} = P_{atm}$ [TMY] *1000

Infiltration

The air change in the primary zone due to infiltration is modelled with a double ventilation system (mechanical exhaust and supply).

Standard conditions at sea level

- T_0 = 15°C = 288.16 K
- P_0 = 101 321 kPa
- ρ_0 = 1.201385 kg/m^3

Site specific conditions

- altitude = 1609 m
- T_{room} (room-temperature in primary zone) = 20°C = 293.16 K
- T_{ext} (mean annual outside dry-bulb temperature) = 9.7°C = 282.86 K
- ACH (exhaust) : τ_{out} = 0,5 vol/h
- Interior air volume : V_{room} = 129.6 m^3

$$P_{alt} = P_0 * e^{-1{,}219755.10^{-4} * alt} \quad \Rightarrow \quad P_{1609m} = 83\ 265.56 \text{ kPa}$$

$$\frac{P_0}{\rho_0 * T_0} = \frac{P_{1609m}}{\rho_{room} * T_{room}} \quad \Rightarrow \quad \rho_{room} = \frac{P_{1609m}}{P_0} * \frac{T_0}{T_{room}} * \rho_0 \quad \Rightarrow \quad \rho_{room} = 0.97045 \text{ kg/m}^3$$

$$\frac{P_0}{\rho_0 * T_0} = \frac{P_{1609m}}{\rho_{ext} * T_{ext}} \quad \Rightarrow \quad \rho_{ext} = \frac{P_{1609m}}{P_0} * \frac{T_0}{T_{ext}} * \rho_0 \quad \Rightarrow \quad \rho_{ext} = 1.0058 \text{ kg/m}^3$$

Calculation of the mass flow.

$$\dot{m} = \tau_{out} * V_{room} * \rho_{room} \quad \Rightarrow \quad \dot{m} = 62{,}886 \text{ kg/h}$$

The inlet mass flow is equal to the outlet mass flow, so the inlet infiltration rate can be determined as follows.

$$\dot{m} = \tau_{out} * V_{room} * \rho_{room} = \tau_{adm} * V_{room} * \rho_{ext} \quad \Rightarrow \quad \tau_{adm} = 0.4824 \text{ vol/h}$$

The heat loss due to infiltration is specified in the RADTEST at 18.440 W/K. We decided to calibrate the air *Cp* value on this heat loss value.

$$\Phi_{heat\_loss} = \frac{\dot{m}}{3600} * Cp \quad \Rightarrow \quad Cp = 1056 \text{ J/kg.K}$$

Solar loads

The solar loads transmitted through the window are distributed over the internal surfaces ($\alpha = 0.6$), according to the solar distribution fractions (S.D.F) shown in the table below. In practice, the window is divided in as many portions as internal surfaces, each portion being connected to its corresponding surface. The surface of each portion is proportional to the corresponding solar fraction, as shown in the table below. The solar radiation transmitted by each portion is assumed to be totally absorbed by its corresponding surface.

Surface	*S.D.F*	*Window portion*
Floor	0.642	7.704 m²
Ceiling	0.168	2.016 m²
North wall	0.053	0.636 m²
East wall	0.038	0.456 m²
South wall	0.026	0.312 m²
West wall	0.038	0.456 m²
Solar lost through window	0.035	0.42 m²
TOTAL	**1**	**12 m²**

Internal loads

The convective part (**80 W**) of the internal gains are totally applied to the air node.

The radiative part (**120 W**) of the internal gains is evenly distributed over the internal surfaces, as shown in the table below.

Floor	33.6 W
Ceiling	33.6 W
North wall	15.1 W
East wall	11.3 W
South wall	6.7 W
South window	8.4 W
West wall	11.3 W
TOTAL	**120 W**

This distribution is suitable for every cases except the 1860 and 1870 ones.

Case **1870** : the internal loads (**200 W**) are exclusively convective, and totally applied to the air node.

Case **1860** : the internal loads (**200 W**) are exclusively radiative, and evenly distributed over the internal surfaces, as shown in the table below.

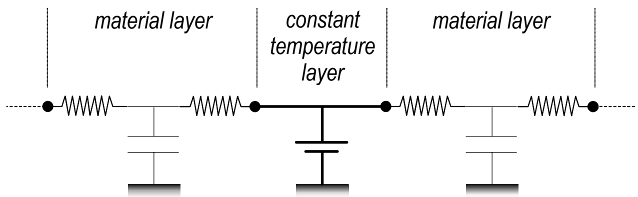
Floor	55.9 W
Ceiling	55.9 W

North wall	25.2 W
East wall	18.9 W
South wall	11.2 W
South window	14.0 W
West wall	18.9 W
TOTAL	**200 W**

Thermal active floor

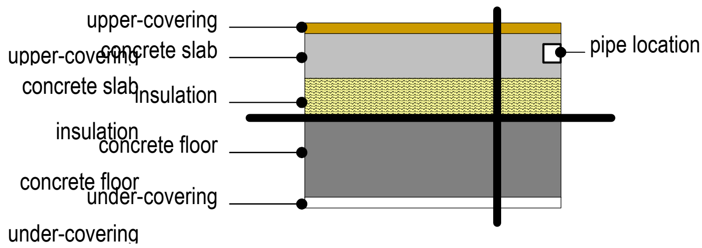
Simplified model with a constant temperature layer

The constant temperature layer is inserted in the electrical circuit representation as a source of tension.



Detailed water loop model

The reference model comprises 5 layers : upper-covering, concrete slab including the pipes, insulation, concrete floor and under-covering. The 2D conductive heat transfer is dealt with in a section perpendicular to the pipe direction, accounting for simplifications due to symmetry. The mesh is not variable ; it has been previously determined with a specific tool. The elementary section is divided in 4 major regions, as shown on the drawing below.



The water loop simplified model is then based on the thermal-electrical analogy.

The solar radiation hitting the floor is supposed to be totally absorbed.

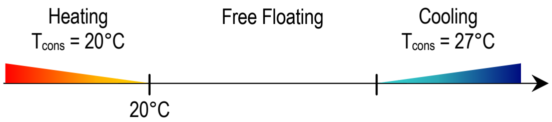
Our modelling assumes that the pipe is in contact with the insulation layer. The nonexistent under & upper-covering layers have been modelled by setting to a very low value (10^{-5}) the corresponding thickness, density and specific heat , while setting to a high value (10^{5}) the corresponding conductivity.

The water flow in the pipe is set to 0.6012 m^3/h when working, or else 0 m^3/h. The supply water temperature is set to 20°C or 40°C in accordance with the test specification.

Temperature control strategies for the primary zone

The air temperature in the primary zone is controlled by a convective heating and cooling system.

- Pure sensible heating and cooling, without capacity limitations
- Equipment characteristics
  - heating capacity : 1000 kW
  - cooling capacity : 1000 kW
  - Effective efficiency : 100 %
- Thermostat control of room-air temperature



The thermostat used is a proportional one. The proportional band was set to a very low value to approximate a non-proportional thermostat as required in the test specification.

Preconditioning period

A preconditioning period of **3 months** has been added before the 1 year simulation period.

ESP-r/HOT3000

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Introduction

This report describes the modelling strategy and assumptions used for the proposed Radiant Heating and Cooling Test Cases (RADTEST) carried out by CETC at Natural Resources Canada using a modified version of the ESP-r software (ESRU 1996) called ESP-r/HOT3000. ESP-r/HOT3000 retains ESP-r's modelling approach but includes new models for ground coupling, air infiltration, furnace, air and ground source heat pumps, DHW, and fuel cells. The simulator used was bpsh3k version 1.7 of March 2002 (based on bps version 9.21b of Jan 2002).

The RADTEST test cases description and the basis of the modeling approach are both described in the report by Achermann (2001). At this point, only the Simple Test Cases (795-1890) and the Additional Test Cases (3800-3830) are modeled using ESP-r/HOT3000. All the required characteristics of the Simple and Additional Test Cases, specified in the RADTEST report, are included in the ESP-r/HOT3000 simulation models created. Details about various aspects of these simulation models, as they are implemented in the ESP-r/HOT3000 environment, are presented in the following sections of this report.

Modeling of the Constant-Temperature Active Layer

The constant temperature layer for test cases 1820-1890 and 3800-3830 is modeled as an air zone. The temperature in this zone is controlled using an ideal controller that maintains the temperature at the desired level specified in the RADTEST Manual. The ideal controller works by injecting convectively at the air point the required amount of heat.

For Test Case 1820, the constant-temperature zone is placed on top of the floor as shown in Figure 1. For Test Case 1830, the constant-temperature zone is placed on the under side of the floor as shown in Figure 2. Figure 3 shows the placement of the constant-temperature zone between the concrete and the insulation for Test Case 1840.

It is found that the temperature of the constant-temperature zone can be maintained at the desired set point specified in the RADTEST Manual through a control law associated with the ideal controller. Whenever there is a sudden jump or drop in the temperature of the constant-temperature zone, it is found that the temperature of the basement starts to gradually approach the temperature of the active layer. After a certain period of time, the temperature of the basement becomes almost equal to the temperature of the active layer.

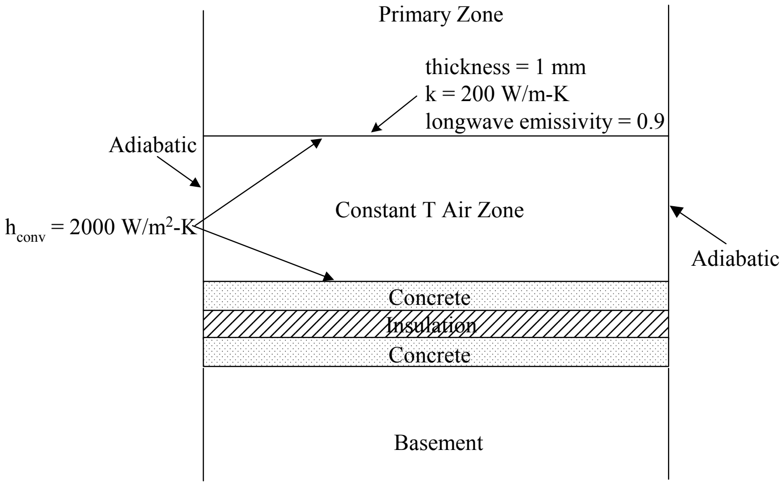

Figure 1: Placement of the constant-temperature zone for Test Case 1820

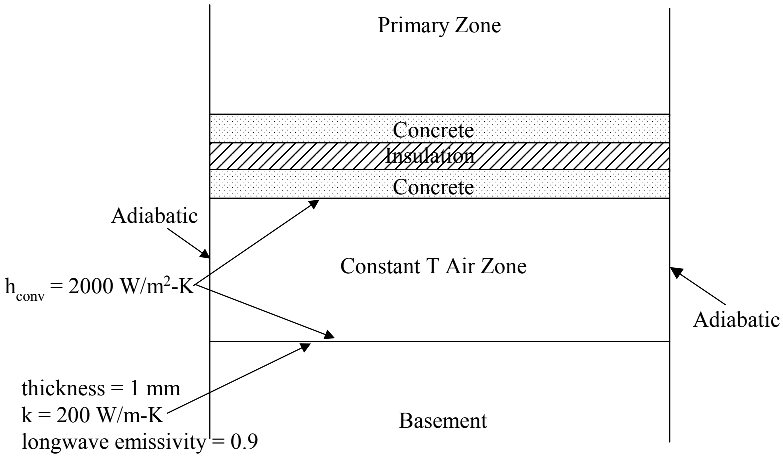

Figure 2: Placement of the constant-temperature zone for Test Case 1830

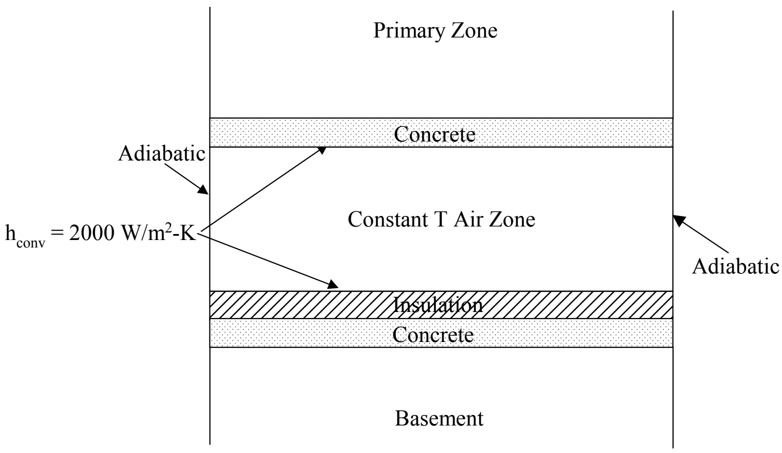

Figure 3: Placement of the constant-temperature zone for Test Case 1840

Weather File

The TMY weather data provided with the RADTEST report was used to construct the required ESP-r/HOT3000 weather file.

Infiltration

ESP-r/HOT3000 does not account for the variation of outdoor density with altitude. Therefore, the infiltration rate adjustment factor of 0.822 specified in the RADTEST Manual was used.

Heat Transfer Coefficients

Exterior Heat Transfer Coefficients:

ESP-r/HOT3000 calculates automatically the outside radiation and convection heat transfer coefficients. Therefore, the total heat transfer coefficient data given in Table 1-4 of the RADTEST Manual is not used.

Interior Heat Transfer Coefficients:

By default, the interior convection and radiation heat transfer coefficients are estimated internally in ESP-r/HOT3000. This default approach is used for all surfaces except for estimating the convection heat transfer coefficients of the heated/cooled floor and of the ceiling and floor of the constant-temperature zone used to represent the constant-temperature layer.

Interior Heat Transfer Coefficient on Top of Heated/Cooled Floor (Applies for all Test Cases Except Case 3810):

For the top surface of the heated floor of the primary zone, it is assumed that the convection heat transfer coefficient is 45% of $8.92x(T_{floor}-T_{ra})^{0.1}$. This correlation is implemented in the ESP-r/HOT3000 source code and is used every time step when the floor surface temperature is greater than that of the air inside the primary zone. The 45% value is the fraction of the total heat transfer coefficient attributed to convection for “Upward heat transfer on horizontal surfaces” based on the data in Table 1-5 of the RADTEST Manual. The longwave emissivity of the top surface of the heated floor facing the primary zone is set to 0.9, and the radiative heat transfer between this surface and the primary zone is predicted internally by ESP-r/HOT3000. The only exception to this is for Case 3810 where the longwave emissivity is set to 0.01 to suppress radiation heat transfer.

Table 1-5 of the RADTEST Manual also indicates that the fraction of the total heat transfer coefficient attributed to convection is 16% for “Downward heat transfer on horizontal surface”. It is assumed then that the convection heat transfer on top of the cooled floor of the primary zone is equal to 16% of $8.6x(T_{ra}-T_{floor})^{0.1}$. This correlation is also implemented in the ESP-r/HOT3000 source code and is used every time step when the floor surface temperature is less than the primary zone air temperature. Again in this case, the longwave emissivity of the top surface of the cooled floor facing the primary zone is set to 0.9 (except for Case 3810 where it is set to 0.01), and the radiative heat transfer between this surface and the primary zone is predicted internally by ESP-r/HOT3000.

Sensitivity of Simulation Results to Radiative/Convective Split of the Interior Heat Transfer

Coefficient on Top of the Heated/Cooled Floor:

It is to be noted that the RADTEST document does not address how to split the total heat transfer coefficient, between the heated floor and the primary zone, into convective and radiative components.

It is found that the assumed split of this total heat transfer coefficient can have a large impact on the predicted loads of the conditioned zone. For example, when the total heat transfer coefficient is treated as described in the previous two paragraphs of this report, the annual heating and cooling loads are found to be 0.255 and 17.13 MWh, respectively, for case 1820. When the total heat transfer coefficient between the heated floor and the primary zone is assumed to be 100% convective, these heating and cooling loads for case 1820 become 0.284 and 28.82 MWh, respectively. The longwave emissivity of the top surface of the heated floor is set to a very small value (0.01) in this case to suppress radiation heat transfer.

It seems then that the assumed radiative and convective split of the total heat transfer coefficient, between the heated floor and the primary zone, has a large impact on the predicted loads. This is especially true for the cooling load. It is then suggested that the RADTEST Manual be modified to give guidance as to how to treat this radiative and convective split. It is expected that this will reduce the spread in the simulation results from the various simulation programs.

<u>Interior Heat Transfer Coefficient on Top of the Heated/Cooled Floor for Test Case 3810:</u>

For this Test Case the RADTEST Manual indicates that “Surface Coefficient on Floor only Convective”. On the one hand this can mean that the total heat transfer coefficient, plotted in Diagram 1-1 and 1-2 of the RADTEST Manual, on top of the floor needs to be set in the simulation model equal to the convective heat transfer coefficient with radiation set to zero. But it can also mean that only the convective portion of the total heat transfer coefficient in Diagram 1-1 and 1-2 needs to be accounted for in the simulation. This issue then needs to be clarified in the Manual.

Table 1 then lists two sets of results for Test Case 3810. The first one (3810) is for when the total heat transfer coefficient from the Manual is set to the convective heat transfer coefficient in the simulation with radiation set to zero. The second (3810-2) is for when only the convective portion of the total heat transfer coefficient given in the Manual is accounted for in the simulation with radiation still set to zero. Again the fraction of the total heat transfer coefficient that is convective is assumed to be 45% for a heated floor and 16% for a cooled floor.

Interior Heat Transfer Coefficients for the Constant-Temperature Zone:

The convection heat transfer coefficient on the inside of the floor and ceiling of the constant-temperature zone, used to represent the constant-temperature layer, is set to a high value (2000 W/m^2-K). This is to minimize the temperature difference between the air and the interior surfaces of this zone so that the condition of a constant-temperature layer is satisfied.

Glazing Optical Properties

Values for direct-beam transmittance in Table 1-7 of the RADTEST Manual are used. Solar absorptance values for the inner and outer layers of the window are obtained from Appendix E of IEA BESTEST and Diagnostic Method Manual (Judkoff and Neymark 1995).

Annual Cooling Energy for Test Case 800

According to IEA BESTEST and Diagnostic Method Manual (Judkoff and Neymark 1995), the total annual heating and cooling energies, obtained using ESP-r, for Test Case 800 are 4.868 and 0.113 MWh respectively. Based on the simulations carried for RADTEST using ESP-r/HOT3000, it is found that total annual heating and cooling energies for Test Case 800 are 4.878 and 0.209 MWh respectively. The heating energy is almost exactly the same as that reported in the IEA BESTEST Manual. However, there is a large difference between the annual cooling energy reported in IEA

BESTEST Manual and that obtained in the course of this task. The ESP-r/HOT3000 input files used for the present task were checked again and no errors with the input were discovered. Given that the total annual heating energy obtained in this task and that reported in IEA BESTEST Manual are almost exactly the same, it is possible that there was a problem with the entry of the cooling energy data for Case 800 in IEA BESTEST.

Results

Table 1 lists values for annual heating load, annual cooling load, peak heating load, peak cooling load, maximum and minimum primary zone temperature, maximum and minimum basement temperature, and maximum and minimum temperature for the top surface of the heated/cooled floor.

Table 1: Simulation Results for Simple Test Cases (795-1890) and Additional Test Cases (3800-3830)

Case	$Q_{h,tot}$ (MWh)	$Q_{c,tot}$ (MWh)	$Q_{h,max}$ (kW)	$Q_{c,max}$ (kW)	T_{max}	T_{min}	$T_{b,max}$	$T_{b,min}$	$T_{fl,max}$	$T_{fl,min}$
795	3.925	0.153	2.50	0.56	27	20	---	---	28.32	15.28
800	4.878	0.209	3.38	0.81	27	20	---	---	28.72	13.67
1800	4.88	0.203	3.36	0.80	27	20	28.57	13.97	28.64	13.79
1810	4.849	0.190	3.33	0.77	27	20	26.98	16.28	28.50	14.07
1820	0.255	17.128	0.89	4.85	27	20	40.0	20.01	39.96	19.99
1830	2.568	0.091	2.80	0.56	27	20	40.06	19.99	28.20	18.32
1840	0.254	7.909	0.95	3.28	27	20	40.0	20.01	35.89	19.48
1850	0.121	10.980	0.78	5.39	27	20	40.0	20.01	39.00	19.58
1860	0.152	10.748	0.83	5.36	27	20	40.0	20.01	39.04	19.63
1870	0.085	11.338	0.71	5.45	27	20	40.0	20.01	38.93	19.50
1880	0.356	1.856	1.12	3.0	27	20	30.0	18.01	32.70	18.04
1890	0.045	11.414	0.69	5.39	27	20	40.0	22.41	39.0	19.61
3800	0.329	0.	0.19	0.	23.3	20	23.11	18.35	23.26	19.04
3805	3.422	0.075	1.72	0.41	27	20	26.26	18.33	26.66	19.04
3810	0.113	14.742	0.5	3.78	27	20	40.0	19.37	34.36	20
3810-2	0.090	7.083	0.48	2.27	27	20	40.0	19.37	36.54	20
3815	0.116	9.985	0.49	2.83	27	20	40.0	19.37	35.7	19.97
3820	0.118	10.212	0.49	2.87	27	20	40.0	19.37	35.63	19.96
3830	0.089	9.651	0.54	3.01	27	20	40.0	20.01	35.65	19.59

Conclusions

ESP-r/HOT3000 is successfully used to create simulation models for Test Cases 795-1890 and 3800-3830 of the IEA Radiant Heating and Cooling Test Cases. The only change to the ESP-r source code required is to implement the proper correlations, given in the RADTEST Manual, for the convection heat transfer coefficient on the heated or cooled constant-temperature floor. All the other aspects of the test cases are easily modeled using existing ESP-r/HOT3000 capabilities. The results show that it is possible to properly model the active layer using a constant-temperature air zone. Results obtained in this work also indicate that the simulation results are strongly dependent on the assumed convective/radiative split of the total heat transfer coefficient on top of the heated/cooled floor.

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