APPENDIX 2

Modeller's reports and Proforma

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I. APACHE - BRE - UNITED KINGDOM

I.1. Modellers Report

Elisabeth SILVER, Building Research Establishment, UK.

ETNA 2

1. Controllers

The controllers were modelled as proportional controllers in both REF and MES cells, with proportional band 1°C.

There are no PID controllers in APACHE so in the REF cell the controller is the same type as in the MES cell.

The sampling time was 1 minute, that is, the time step in the program, 1 minute being the minimum that APACHE will allow.

2. Shutters

The shutters were modelled very simply, ie they block off all solar radiation during the hours in question (noon April 13 to 10am April 19). Their thermal effect was approximated by an extra resistance of 0.12 m^2.K/W day and night. All the other shutter parameters were not used. This is the way APACHE models shutters on windows.

I.2. Program Proforma

APACHE – March ’98

Your name and organisation

Elizabeth Silver, BRE

● : As used in ETNA2 runs

❍ : An option.

Program status

	Public domain
●	Commercial
	Research
	Other (please specify)

Solution method

●	Explicit finite difference
	Implicit finite difference
	Weighting factors
	Response factors
	Transfer functions
	Other (please specify)

Time step

	Fixed within code (please specify time step)
●	User-specified (please specify time step) 0.01h..1h, 1 minute in ETNA2
	Other (please specify)

Timing convention for meteorological data : sampling interval

●	Fixed within code (please specify interval) 1 hour
	User-specified

Timing convention for meteorological data : period covered by first record

	Fixed within code (please specify period or time which meteorological record covers)
●	User-specified 24:30 - 01:30 or 24:00 – 01:00

Meteorological data reconstitution scheme

	Climate assumed stepwise constant over sampling interval
●	Linear interpolation used over climate sampling interval
	Other (please specify)

Output timing conventions

	Produces spot predictions at the end of each time step
	Produces spot output at end of each hour
●	Produces average outputs for each hour (please specify period to which value relates) The output at the end of each timestep is an average over the previous hour

Treatment of zone air

●	Single temperature (i.e. good mixing assumed)
	Stratified model
	Simplified distribution model
	Full CFD model
	Other (please specify)

Heater (dynamics)

●	No dynamics assumed
	Simple first order dynamics
	Detailed modelling of heat source dynamics

Heaters (output characteristics)

	Purely convective
	Radiative/Convective split fixed within code
●	Radiative/Convective split specified by user
	Detailed modelling of heat source output

Control temperature

❍	Air temperature
	Combination of air and radiant temperatures fixed within the code
●	User-specified combination of air and radiant temperatures 50:50 or 33:67 as used
	User-specified construction surface temperatures
	User-specified temperatures within construction
	Other (please specify)

Control laws

❍	Perfect control
❍	On/Off thermostatic control
❍	On/Off thermostatic control with deadband
	On/Off thermostatic control with accelerator heater
❍	Proportional control
	More comprehensive control laws (please specify)

Heat transfer within zones

	Radiation and convection combined
●	Radiation and convection treated separately

Convective heat transfer within zones

❍	Coefficients fixed within code
●	Coefficients specified by user Radiative coefficient calculated from emissivity Total coefficient specified by user. Conv. = Total – Rad.
	Coefficients calculated by code as a function of surface orientation
❍	Coefficients calculated by code as a function of temperature difference
	Coefficients calculated by code as a function of surface finishes
	Other (please specify)

Longwave radiative heat transfer within zones

●	Constant linearised coefficients $= 5.7 \cdot \Delta T$
	Linearised coefficients based on viewfactors
	Linearised coefficients based on surface emissivities
	Non-linear treatment of radiation exchange
	Other (please specify)

Number of nodes placed within each layer of walls and slabs

	Not applicable for this solution method
	Fixed number of nodes per layer (please specify)
	User-specified number of nodes per layer
●	Other (please specify) 3, 5, 7 or 9 depending on conductivity & thermal mass

Airgaps within walls and slabs

	Resistance fixed within code
●	User-specified constant resistance
	Resistance calculated within code as a function of orientation
	Resistance calculated by code as a function of temperature difference
	Radiation and convection treated separately across airgaps
	Treated as additional zones
	Other (please specify)

Windows (heat loss)

●	Fixed resitance used for window element User selected
	Dynamic treatment of window heat loss using same scheme as opaque elements
	Other (please specify)

Airgaps within windows

	Resistance fixed within code
●	User-specified constant resistance
	Resistance calculated within code as a function of orientation
	Resistance calculated by code as a function of temperature difference
	Radiation and convection treated separately across airgaps
	Treated as additional zones
	Other (please specify)

Windows (transmission of direct shortwave radiation)

	Fixed transmission used
	ASHRAE solar heat coefficients used
●	Calculated by code as a function of incidence angle
	Calculated by code from user-specified function of incidence angle
	Other (please specify)

Windows (transmission of diffuse radiation)

●	Diffuse radiation treated as direct from fixed altitude (please specify) 60°
	Other (please specify)

Distribution of solar radiation within zones

	Fixed within the code
	Constant user-specified distribution
●	Calculated once by code and used throughout (please describe algorithm) Area weighted
	Calculated as a function of solar position (please describe algorithm)

Heat transfer between external surfaces and surrounding environment

●	Radiation and convection combined
	Radiation and convection treated separately

External convection

❍	Coefficients fixed within code
❍	User-specified constant coefficients Radiative coeff. calculated from emissivity. Total coeff. Specified by user. Conv. = Total – Rad.
	Calculated within code as a function of orientation
	Calculated within code as a function of surface finish
●	Calculated within code as a function of wind speed Defaults depend on exposure of site : sheltered, normal or severe
	Calculated within code as a function of wind speed and direction
	Other (please specify)

External radiative heat transfer

	Assumed to be to ambient temperature
	Assumed to be to sky temperature read from met file
●	Based on calculated sky temperature (please specify algorithm and requirements) Fonction of sol-air temperature
	Includes view factor of surrounding obstruction

Diffuse sky model

	Isotropic
●	Other (please specify model used) Anisotropic (Hay)

II. AXBU - UNIV. DRESDEN - GERMANY

II.1. Modellers Report

IEA TASK 22, SUBTASK A3, EMPIRICAL VALIDATION

Modeller's report on ETNA and GENEC runs

Dresden University of Technology (TU Dresden)

Department of Thermodynamics and Technical Installation of Buildings

Clemens Felsmann

General

The official participation of TU Dresden in the *IEA Task22* started on January 1st, 1998 when the funding by the gouverment was available. For this reason the simulations which have been done as a 'blind test' and for the 1st round of ETNA1 just could made with a low level of effort. The program AxBU that has been used to simulate the ETNA1-'blind test' represents a linear state space model. Because of the results, which were not satisfactorily at all, the simulation program was changed. To avoid any confusion the name of the program was not changed. The simulation program that has been used afterwards is the result of considerable developments and re-writings of TRNSYS[1]. In future this program will be called TRNSYS-TUD to differ from the official TRNSYS distribution. Because of the flexible building description possibilities implemented in TRNSYS there on principle encountered no problems in modelling the test rooms.

Documentation, data and hotline

The documentations and the manuals which had been provided are clearly arranged and include the most important and necessary information. Therefore there were no fundamental problems to build the models of the ETNA and GENEC test cells. By the help of the hotline extra information were available in a short time.

The input and validation data sets had not to be transformed anyway. Because of the program's format-free reading capabilities the data could be use as they were. There only had to be payed attention to the different interpretations of the time arrangements of data. This could cause some effects of shifting.

Results and studies

'Blind test' simulation

The results from the ETNA1 'blind test', the first simulation run which was done without knowing the validation data, deviated from the results of the other TASK22 participants and from the real measurements. The evaluated air temperature was too high. The simulation has been conducted with a program AxBU that deals with a linear state space model. This program was new created shortly before with the idea to solve control and optimization problems. It never could be tested under real conditions till then. Therefore the 1st round of ETNA1 was a 'blind test' for both the program and the model.

2nd and 3rd round of simulation

The following rounds of ETNA and GENEC simulation runs were conducted with a changed version of TRNSYS, called TRNSYS TUD. Within the multizone-building type the models of the wall transfer functions and of the longwave radiation exchange had been modified above all. Modifications at the detailled window model first became necessary due to analytical tests which are also a part of the *Task22*.

After the 2nd round the results which were calculated with the changed simulation program came closer to the measurements. To minimize the differences between predictions and measurements the ETNA model had to be analysed and validated. For that a lot of sensitivity studies were made to find out which of the model's characteristics affect the results at most [2]. Some of the characteristics which were investigated are heat transfer, conductivity, solar absorption and transmission, shading and long wave radiation exchange. The most important influence was given by the conductivity of the building elements and the calculation of the solar incident radiation. That is why some additional heat losses possibly caused by thermal bridges were implemented into the model. The solar processor was improved in some details as well. The validation of the ETNA model was made to match the profile of the air temperature within the MEASURE test cell. The predicted temperatures deviate from the measured values as listed in the following table.

	Mean error [K]	Standard error [K]
Air temperature	0.08	0.64
Mean radiant temperature	-0.75	0.95
Enclosure temperature	-0.34	0.73

Table 1 : Mean and standard error, MEASURE test cell, 3rd round ETNA1

The simulation results of the 3rd round are documented in the final report of *Task22*. For the REFERENCE test cell the mean difference was bigger considering the air temperature and smaller considering the radiant and enclosure temperatures. This is in accord with ETNA2 simulation runs where a smaller energy consumption was caused by higher air temperatures possibly infected by smaller heat losses of the envelope. For the GENEC test cell similar investigations were conducted but with a very small level of effort. The prediction of the GENEC air temperature is also higher than the measurements.

Latest results

With the help of several analytical tests which are available as a *Task22* working document [3] some parts of the simulation program were revised and modified after the 3rd round of ETNA was already finished. These modifications concern the detailled window model, the internal longwave radiation exchange as well as the handling of solar radiation. It was necessary to change the program source code. The changes were really small but influence the predictions in a considerable way. The investigations represented now were made with this modificated and bugfixed simulation program.

At first the original model of the ETNA and GENEC test cells were used for a quasi 'blind test', i. e. the building input description corresponds to the test cell manual. No additional heat losses were taken into account as it was done for the 2nd and 3rd round. For ETNA1 two results are displayed: the solar vertical radiation flux on the outside surface of the south wall (Fig. 1) and the air temperature profile of the MEASURE test cell (Fig. 2).

Figure 1 shows the estimation of the solar heat flux on an vertical outside surface. In spite of some deviation the difference of the mean values between measured data and simulation results is about -2.9 W/m². The global energy flux has an error of –4.1%.

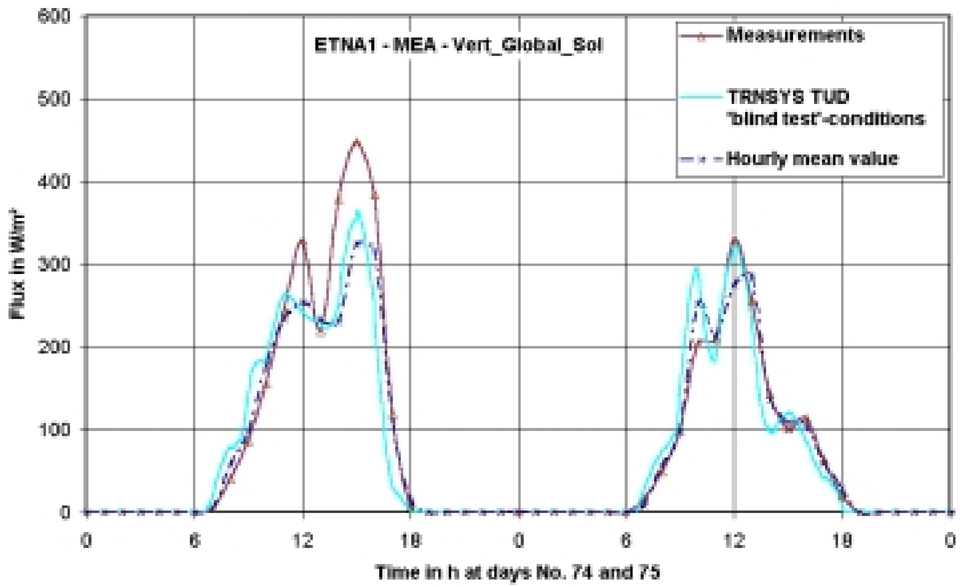


Figure 1 : Vertical radiation flux. ETNA1

In order to estimate solar heat flux in a similar right way it is very important to avoid any kind of shift between solar time, local standard time and simulation time. Shifting the time scale causes unwanted effects on every output.

Figure 2 presents the predicted air temperature in the MEASURE test cell. The measurements are compared with both the results from TRNSYS TUD in a 0.1 h step size and a hourly averaged profile of this result.

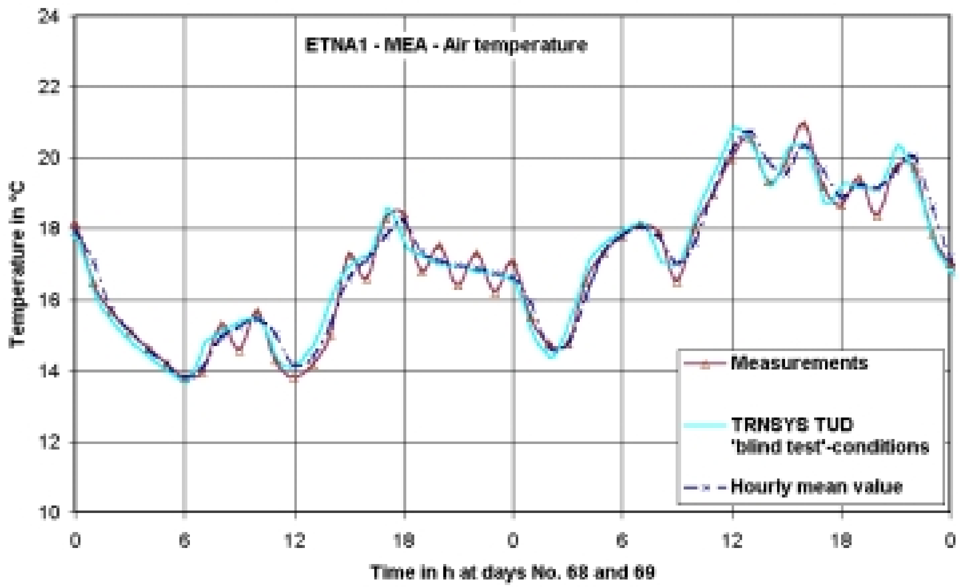


Figure 2 : Air temperature for MEASURE test cell. ETNA1

As to see there is a significant improvement of the calculated air temperature. The quasi 'blind test' simulation calculated with the bugfixed program matches the measurements better than the results of the first two rounds of ETNA1. The mean errors referring to the MEASURE test cell temperatures are listed in Table 2.

	Mean error [K]
Air temperature	0.26
Mean radiant temperature	-0.68
Enclosure temperature	-0.21

Table 2 : Mean error, MEASURE test cell, quasi 'blind test' ETNA1

The mean errors roughly correspond to the error values of the 3rd round of ETNA1 (Tab. 1). The modificated TRNSYS TUD program also leads to an improvement of the 3rd round results for the ETNA2 experiment. The quasi 'blind test' comes to a predicted value for the energy consumption that is about 10% closer to the measurements. The difference of the means could be reduced by 26%. There is the same effect of improvement referring to the temperature profiles. Figure 3 shows the measured and predicted air temperature for the MEASURE test cell. The mean air temperature calculated with TRNSYS TUD in the quasi 'blind test' is 17.14°C compared to 17.02°C from the measured values.

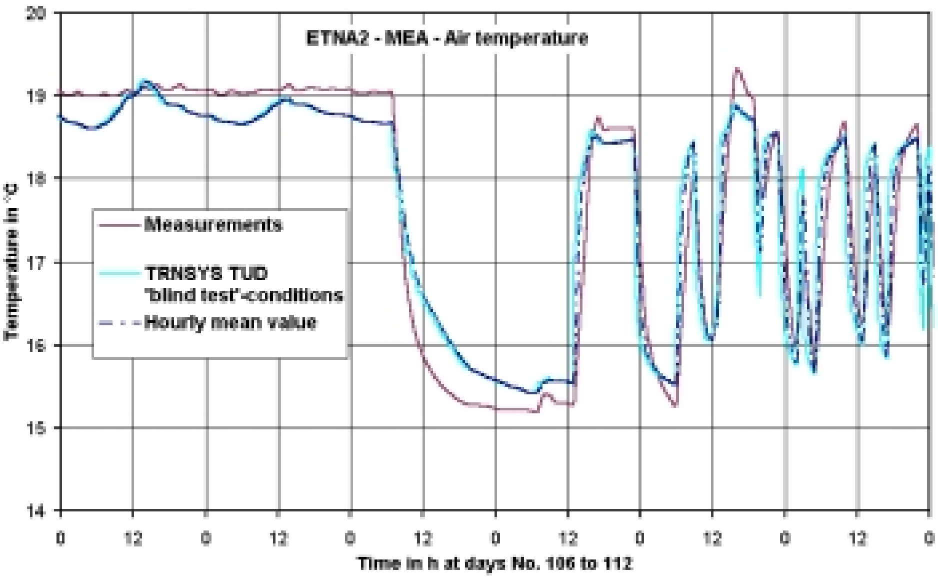


Figure 3 : Air temperature for MEASURE test cell. ETNA2

Results and studies

If there are bugs within the program which are not fixed anyway a validation of the model could cover such bugs and both modelling errors as well as errors in the program source code are compensated. Therefore it is really difficult to detect bugs with only empirical validation procedures. For that analytical tests are very useful.

All in all it can be concluded that it is possible to minimize the deviations between measured and simulated temperatures round by round if there is enough time and sufficient skill to deal with the model's characteristics.

[1] Solar Energy Laboratory; University of Wisconsin-Madison: TRNSYS – A transient system simulation program; Manual TRNSYS14.2; Madison USA, July 1996

[2] Schwanz, Christian: Untersuchungen zur Simulation des thermischen Verhaltens von Gebäuden mit dem Programm TRNSYS; DA 97-115, TU Dresden 1997

[3] Tuomaala, Pekka: Subtask A.1 Analytical Tests. Working document of IEA Task22; VTT Building Technology, April 1997

II.2. Program Proforma

Program name (please include version number)

AxBu

Your name and organisation

Mr. C. Felsmann, Technical University of Dresden

Program status

	Public domain
❍	Commercial
●	Research
	Other (please specify)

Solution method

	Explicit finite difference
	Implicit finite difference
	Weighting factors
	Response factors
❍	Transfer functions
●	Other (please specify) solving differential equations

Time step

	Fixed within code (please specify time step)
●	User-specified (please specify time step) 0.01h.....1h
	Other (please specify)

Timing convention for meteorological data : sampling interval

	Fixed within code (please specify interval)
●	User-specified

Timing convention for meteorological data : period covered by first record

	Fixed within code (please specify period or time which meteorological record covers)
●	User-specified

Meteorological data reconstitution scheme

❍	Climate assumed stepwise constant over sampling interval
●	Linear interpolation used over climate sampling interval
	Other (please specify)

Output timing conventions

	Produces spot predictions at the end of each time step
	Produces spot output at end of each hour
●	Produces average outputs for each hour (please specify period to which value relates) the output at the end of each timestep is an average of this timestep

Treatment of zone air

●	Single temperature (i.e. good mixing assumed)
	Stratified model
	Simplified distribution model
	Full CFD model
	Other (please specify)

Heater (dynamics)

	No dynamics assumed
●	Simple first order dynamics
❍	Detailed modelling of heat source dynamics

Heaters (output characteristics)

❍	Purely convective
	Radiative/Convective split fixed within code
●	Radiative/Convective split specified by user
❍	Detailed modelling of heat source output

Control temperature

●	Air temperature
	Combination of air and radiant temperatures fixed within the code
❍	User-specified combination of air and radiant temperatures
	User-specified construction surface temperatures
	User-specified temperatures within construction
	Other (please specify)

Control laws

❍	Perfect control
❍	On/Off thermostatic control
❍	On/Off thermostatic control with deadband
	On/Off thermostatic control with accelerator heater
●	Proportional control
❍	More comprehensive control laws (please specify) PID-controler

Heat transfer within zones

❍	Radiation and convection combined
●	Radiation and convection treated separately

Convective heat transfer within zones

	Coefficients fixed within code
❍	Coefficients specified by user
❍	Coefficients calculated by code as a function of surface orientation
●	Coefficients calculated by code as a function of temperature difference
❍	Coefficients calculated by code as a function of surface finishes
	Other (please specify)

Longwave radiative heat transfer within zones

❍	Constant linearised coefficients
	Linearised coefficients based on viewfactors
	Linearised coefficients based on surface emissivities
●	Non-linear treatment of radiation exchange
	Other (please specify)

Number of nodes placed within each layer of walls and slabs

	Not applicable for this solution method
●	Fixed number of nodes per layer (please specify) one node at inside/outside surface
	User-specified number of nodes per layer
	Other (please specify)

Airgaps within walls and slabs

	Resistance fixed within code
●	User-specified constant resistance
	Resistance calculated within code as a function of orientation
	Resistance calculated by code as a function of temperature difference
	Radiation and convection treated separately across airgaps
	Treated as additional zones
	Other (please specify)

Windows (heat loss)

	Fixed resitance used for window element
	Dynamic treatment of window heat loss using same scheme as opaque elements
●	Other (please specify) user specified window properties corrected by temperature differences

Airgaps within windows

	Resistance fixed within code
	User-specified constant resistance
	Resistance calculated within code as a function of orientation
●	Resistance calculated by code as a function of temperature difference
●	Radiation and convection treated separately across airgaps
	Treated as additional zones
	Other (please specify)

Windows (transmission of direct shortwave radiation)

	Fixed transmission used
	ASHRAE solar heat coefficients used
	Calculated by code as a function of incidence angle
●	Calculated by code from user-specified function of incidence angle
	Other (please specify)

Windows (transmission of diffuse radiation)

	Diffuse radiation treated as direct from fixed altitude (please specify)
	Other (please specify)

Distribution of solar radiation within zones

	Fixed within the code
●	Constant user-specified distribution
	Calculated once by code and used throughout (please describe algorithm)
	Calculated as a function of solar position (please describe algorithm)

Heat transfer between external surfaces and surrounding environment

	Radiation and convection combined
●	Radiation and convection treated separately

External convection

	Coefficients fixed within code
❍	User-specified constant coefficients
	Calculated within code as a function of orientation
	Calculated within code as a function of surface finish
	Calculated within code as a function of wind speed
	Calculated within code as a function of wind speed and direction
●	Other (please specify) User-specified as function of wind speed and temperatures

External radiative heat transfer

	Assumed to be to ambient temperature
●	Assumed to be to sky temperature read from met file
❍	Based on calculated sky temperature (please specify algorithm and requirements)
	Includes view factor of surrounding obstruction

Diffuse sky model

❍	Isotropic
	Other (please specify model used)

III. CA-SIS - EDF - FRANCE

III.1. Modellers Report

Modeller's report for ETNA and GENEC simulations runs

CA-SIS 2.1 UNIX

Luc TABARY & Gilles GUYON, Electricité De France, France

1) Introduction

The studies were carried out with the version 2.1 of the CA-SIS software program, under UNIX operating system.

The CA-SIS (Conditionnement d'Air-SImulation des Systèmes) software environment was developed by Electricity Applications in Residential and Commercial Buildings Branch in Research and Development Division of the French utility company EDF (Electricité De France). This software program focuses on commercial buildings and HVAC systems. It is based on the TRaNsient SYstem Simulation (TRNSYS) solver, and a specific model library has been developed to simulate HVAC systems and allow easy comparisons between them. This software seems to be an answer to the problems of engineering offices enabling analysis and accurate previsions of energy consumption in buildings within relatively short time scale. This software offers also a three-step approach corresponding to the different levels of knowledge in a project : sketch, basic and advanced.

For EDF, IEA Task22 is a good opportunity to compare theirs programs (CLIM2000 v2.1.6 and CA-SIS 2.1) results with others building energy analysis tools available, as done in the past in the framework of IEA Annex 21. It was also a good experience because EDF managed the three validation exercises (documentation, empirical data, hot-line and reporting). It was really an exciting work to do.

To be " honest ", EDF team was shared into groups especially during the blind phases i.e. with no knowledge of experimental data. The first group was in charge of simulation runs and the second one was in charge of the management of the exercises, so that blind runs were effectively blind.

I would like to thank all participants who performed the simulation runs and who exchanged knowledge and experience during the different rounds of the validation exercises.

2) Problems concerning the modelling

Because CA-SIS is more dedicated to commercial buildings and HVAC systems, this validation exercise was not very obvious. Nevertheless, due to the capabilities offered by the software, we did not encounter any problem in modelling ETNA cells. No changes and no modifications were needed to represent ETNA and GENEC cells into CA-SIS.

Due to lack of time, we have just carried out simulations for ETNA1 experiment. We only used the models available in the CA-SIS standard library. No modifications were needed tu run the simulations.

For ETNA1 cells, we made the following assumptions :

- The heating system in the REFERENCE cell was supposed to be purely convective, as described in the documentation provided. Then, the elevation of walls is just due to convection (Modelling 1)

- Gains simulated with CA-SIS can be convective and radiative whereas heating is always considered as purely convective (the energy being transferred to the air mass). In a first step, we studied the heating sequences as gains which enabled us to differentiate both kinds of emittor. Therefore, we avoided a supplementary error source in the analysis of the partly radiative case. The heating system in the MEASURE cell is supposed to be radiative (15%) and convective (85%) (Modelling 2). The radiative part is applied to the surfaces uniformly as a weighted function. In a second time, to behave like most of the CA-SIS end-users, we simulated a heating system (the convector is supposed to be purely convective) (Modelling 3). These two different modellings are dedicated to evaluate the influence of the radiative part of the heater.
- The used film coefficients are the French regulations ones.
- To model the floor, we have calculated a virtual wall by using the standard values given in the French regulations.
- Due to the set-back window, we have modelled a shading device. The sunlit fraction is calculated by sharing the window plane in 16 elementary surfaces. Then, the incoming solar flux is calulated by analysing the number of elementary surfaces shaded and unshaded.
- The West window in contact with thermal guard is represented as an opaque wall with the same U-factor.
- The incoming solar fluxes is distributed uniformly on all interior surfaces.
- The time step is one hour.

3) Problems encountered with the documentation provided and hot-line

It is difficult to write a lot of things on these subjects because EDF managed the validation exercises. We have tried to do our best for the documentation and the hot-line. Further to the different meetings we had during this work and the different modeller's report included here, it seems the documentation needs some minor changes. The totality of asked questions on the documentation provided were resolved via the hot-line. Obviously, if any information is given to one of the participant, it is given to each other participant. So that, each participant did have all the material necessary to perform the simulation runs. Finally, it seems absolutely necessary to have such an hot-line for this kind of validation exercises.

4) Were any bugs found in the model as a result of this exercise ?

No bugs in CA-SIS were found.

5) Results obtained

All the simulation runs for this validation exercise were carried out in blind way with no knowledge of experimental data. We only produced one set of simulated results for this exercise, the same from the first round to the final round.

One odd result obtained by EDF team and by each participant, was that in the first experiment carried out in ETNA cells, mean air temperature is less for the MEASURE cell than for the REFERENCE one. Because the ideal reference heat source installed in the REFERENCE cell is closer to the model used in most software programs, we could expect a better agreement between simulation and experiment in that cell.

Regarding the different modelling used to represent the convector in the MEASURE cell, the results in terms of air temperature are the following :

Modelling	MeanDT	STDERR
Modelling 1 REFERENCE cell purely convective	0.54	0.63
Modelling 2 MEASURE cell, radiative and convective	0.17	0.58
Modelling 3 MEASURE Cell, purely convective	0.29	0.63

We can see that the results are always satisfying in terms of MeanDT (Mean difference between simulation and experiment) and Stderr (Standard error) Not taking into account the radiative part of heating in the MEASURE cell induces a greater simulation error which can however be admitted and remains inferior to the purely convective case. This last one presents clearly difficulties which are not correctly modelled (variable heat exchange coefficients with air turbulence inside zone, ..) and a closer scrutiny is required to perform more precise simulations.

III.2. Program Proforma

Program name (please include version number)

CA-SIS 2.1 (UNIX)

Your name and organisation

Gilles GUYON, Electricité De France, Division Recherche & Développement

Program status

	Public domain
○	Commercial (A PC version of CA-SIS will be diffused in 1999)
●	Research
	Other (please specify)

Solution method

	Explicit finite difference
	Implicit finite difference
	Weighting factors
	Response factors
●	Transfer functions
	Other (please specify)

Time step

●	Fixed within code (please specify time step) 1 hour
	User-specified (please specify time step)
	Other (please specify)

Timing convention for meteorological data : sampling interval

●	Fixed within code (please specify interval) : 1 hour
	User-specified

Timing convention for meteorological data : period covered by first record

	Fixed within code (please specify period or time which meteorological record covers)
	User-specified

Meteorological data reconstitution scheme

●	Climate assumed stepwise constant over sampling interval
	Linear interpolation used over climate sampling interval
	Other (please specify)

Output timing conventions

	Produces spot predictions at the end of each time step
●	Produces spot output at end of each hour
	Produces average outputs for each hour (please specify period to which value relates)

Treatment of zone air

●	Single temperature (i.e. good mixing assumed)
	Stratified model
	Simplified distribution model
	Full CFD model
	Other (please specify)

Heater (dynamics)

●	No dynamics assumed
	Simple first order dynamics
	Detailed modelling of heat source dynamics

Heaters (output characteristics)

	Purely convective
	Radiative/Convective split fixed within code
●	Radiative/Convective split specified by user
	Detailed modelling of heat source output

Control temperature

●	Air temperature
	Combination of air and radiant temperatures fixed within the code
	User-specified combination of air and radiant temperatures
	User-specified construction surface temperatures
	User-specified temperatures within construction
	Other (please specify)

Control laws

●	Perfect control
	On/Off thermostatic control
	On/Off thermostatic control with deadband
	On/Off thermostatic control with accelerator heater
	Proportional control
	More comprehensive control laws (please specify)

Heat transfer within zones

	Radiation and convection combined
●	Radiation and convection treated separately

Convective heat transfer within zones

	Coefficients fixed within code
●	Coefficients specified by user
	Coefficients calculated by code as a function of surface orientation
	Coefficients calculated by code as a function of temperature difference
	Coefficients calculated by code as a function of surface finishes
	Other (please specify)

Longwave radiative heat transfer within zones

●	Constant linearised coefficients
	Linearised coefficients based on viewfactors
	Linearised coefficients based on surface emissivities
	Non-linear treatment of radiation exchange
	Other (please specify)

Number of nodes placed within each layer of walls and slabs

	Not applicable for this solution method
	Fixed number of nodes per layer (please specify)
	User-specified number of nodes per layer
	Other (please specify)

Airgaps within walls and slabs

	Resistance fixed within code
●	User-specified constant resistance
	Resistance calculated within code as a function of orientation
	Resistance calculated by code as a function of temperature difference
	Radiation and convection treated separately across airgaps
	Treated as additional zones
	Other (please specify)

Windows (heat loss)

●	Fixed resitance used for window element
	Dynamic treatment of window heat loss using same scheme as opaque elements
	Other (please specify)

Airgaps within windows

	Resistance fixed within code
●	User-specified constant resistance
	Resistance calculated within code as a function of orientation
	Resistance calculated by code as a function of temperature difference
	Radiation and convection treated separately across airgaps
	Treated as additional zones
	Other (please specify)

Windows (transmission of direct shortwave radiation)

●	Fixed transmission used
	ASHRAE solar heat coefficients used
	Calculated by code as a function of incidence angle
	Calculated by code from user-specified function of incidence angle
	Other (please specify)

Windows (transmission of diffuse radiation)

	Diffuse radiation treated as direct from fixed altitude (please specify)
●	Other (please specify) : Fixed direct and diffuse coefficient

Distribution of solar radiation within zones

	Fixed within the code
	Constant user-specified distribution
●	Calculated once by code and used throughout (please describe algorithm) : The incoming solar radiation is distributed to the envelope walls proportionally to their surfaces.
	Calculated as a function of solar position (please describe algorithm)

Heat transfer between external surfaces and surrounding environment

●	Radiation and convection combined
	Radiation and convection treated separately

External convection

	Coefficients fixed within code
	User-specified constant coefficients
	Calculated within code as a function of orientation
	Calculated within code as a function of surface finish
	Calculated within code as a function of wind speed
	Calculated within code as a function of wind speed and direction
	Other (please specify)

External radiative heat transfer

	Assumed to be to ambient temperature
	Assumed to be to sky temperature read from met file
	Based on calculated sky temperature (please specify algorithm and requirements)
	Includes view factor of surrounding obstruction

Diffuse sky model

	Isotropic
	Other (please specify model used)

IV. CLIM2000 - EDF - FRANCE

IV.1. Modellers Report

Modeller's report for ETNA and GENEC simulations runs

CLIM2000 V2.1.6

Gilles GUYON, Electricité De France, France

1) Introduction

The studies were carried out with the version 2.1.6 of the CLIM2000 software program.

The CLIM2000 software environment was developed by Electricity Applications in Residential and Commercial Buildings Branch in Research and Development Division of the French utility company EDF (Electricité De France). This software operational since June 1989, allows the behaviour of an entire building to be simulated. Its main objective is to produce economical studies, pertaining to energy balances over long periods as well as more detailed physical behaviour studies including stiff non-linear problems and varied dynamics. The building is described by means of a graphics editor in the form of a set of icons representing the models chosen by the user and taken from a library containing about 150 elementary models.

For EDF, IEA Task22 is a good opportunity to compare theirs programs (CLIM2000 v2.1.6 and CA-SIS 2.1) results with others building energy analysis tools available, as done in the past in the framework of IEA Annex 21. It was also a good experience because EDF managed the three validation exercises (documentation, empirical data, hot-line and reporting). It was really an exciting work to do.

To be " honest ", EDF team was shared into groups especially during the blind phases i.e. with no knowledge of experimental data. The first group was in charge of simulation runs and the second one was in charge of the management of the exercises, so that blind runs were effectively blind.

I would like to thank all participants who performed the simulation runs and who exchanged knowledge and experience during the different rounds of the validation exercises.

2) Problems concerning the modelling

Because of the modularity and flexibility of CLIM2000 software program, no problems were encountered in representing the test rooms within the model. No changes and no modifications were needed to represent ETNA and GENEC cells into CLIM2000.

For ETNA1 and ETNA2 experiment, we used the same quite the same modelling except boundary conditions. We used the basic family of elementary models available in the CLIM2000 library.

For GENEC cells, we have used an interesting feature of CLIM2000 : the solar patch modelling. For each time step, the model calculates the position of sun, the position of solar patch into the cell (determines the walls impacted by the sun) and evaluates the fraction of incoming solar radiation to be taken into account for each wall. In such cells with large window areas on South facade, it was necessary to take into account the real effect of sun.

This modelling allow us to produce very precise surface temperatures and a good prediction of operative temperature.

3) Problems encountered with the documentation provided and hot-line

It is difficult to write a lot of things on these subjects because EDF managed the validation exercises. We have tried to do our best for the documentation and the hot-line. Further to the different meetings we had during this work and the different modeller's report included here, it seems the documentation needs some minor changes. The totality of asked questions on the documentation provided were resolved via the hot-line. Obviously, If any information is given to one of the participant, it is given to each other participant. So that, each participant did have all the material necessary to perform the simulation runs. Finally, it seems absolutely necessary to have such an hot-line for this kind of validation exercises.

4) Were any bugs found in the model as a result of this exercise ?

No bugs in CLIM2000 were found.

5) Results obtained

5.1) Simulated results

One surprising result obtained by EDF team and by each participant, was that in the first experiment carried out in ETNA cells, mean air temperature difference and mean operative temperature difference are less for the MEASURE cell than for the REFERENCE one. Because the ideal reference heat source installed in the REFERENCE cell is closer to the model used in most software programs, we could expect a better agreement between simulation and experiment in that cell.

All the simulation runs for the three validation exercises were carried out in blind way with no knowledge of experimental data. We only produced one set of simulated results for each exercise, the same from the first round to the final round.

5.2) Measured results

As explained in the main body of this final report of analysis, the measured surface temperatures have to be considered carefully. Indeed, the measured value used for the comparison with simulated results is the mean of two temperatures located at mid-height of each wall. Then, these two different sensors do not represent precisely the surface temperature of each wall (they did not take into account the solar patch effect and the effect of corners). Then, it is difficult to say that these measured values represent the standard of truth, i.e. the real surface temperature.

Discussion with others measuring teams that we met before this IEA project lead to say that measuring surface temperatures is the one of the most difficult measurement to do in a cell or a room. If we want to have a “ real ” surface temperature i.e. a measurement representing the mean temperature observed on the considered surface, two different possibilities are offered :

- to install a lot of surface temperature sensors (at least 20) with some of them close to the corners to evaluate the 2D effects and to calculate a mean value of all measurements coming from these sensors, or
- to measure the surface temperature by using infra-red thermography. The main disadvantage of this technique is that it is difficult to record the data in real time.

Then, taking into account the above comments, it seems difficult to use the measured surface temperatures given in the main body of this report for calculating another mean radiant temperature. Such a calculated value will be one value not a real measured mean radiant temperature. Another point has to be mentioned ; how calculating a mean radiant temperature without any knowledge of measured glazing temperature ? No glazing temperature were provided : too difficult to do for providing a good measured temperature of glass panels. In addition, it is for us impossible to compare a mean radiant temperature calculated on the basis of measured surface temperatures (even if they are precise enough, see previous comment) with mean radiant temperature measured with a black globe because the time constants are very different (black globe and wall materials). At the end, the measured surface temperatures should not be utilised here to calculate a measured mean radiant temperature.

In the MEASURE cell, there was not any stirring of air. So that, the black globe temperatures were not affected by air velocity. Even in the REFERENCE cell with stirring of air, the air velocity was low and did not affect the black globe temperatures.

IV.2. Program Proforma

Program name (please include version number)

CLIM2000 V2.1.6 ○: possibility of the code and ●:used in the exercises

Your name and organisation

Gilles GUYON, Electricité De France, Division Recherche & Développement

Program status

	Public domain
	Commercial
●	Research
	Other (please specify)

Solution method

●	Explicit finite difference
●	Implicit finite difference
	Weighting factors
	Response factors
	Transfer functions
●	Other (please specify) : Gear's method with detection of instability + BDF (order and time step variable)

Time step

	Fixed within code (please specify time step)
	User-specified (please specify time step)
●	Other (please specify) : Time step variable, chosen by the solver

Timing convention for meteorological data : sampling interval

	Fixed within code (please specify interval)
●	User-specified

Timing convention for meteorological data : period covered by first record

	Fixed within code (please specify period or time which meteorological record covers)
●	User-specified

Meteorological data reconstitution scheme

	Climate assumed stepwise constant over sampling interval
	Linear interpolation used over climate sampling interval
●	Other (please specify) : user-specified : linear or parabolic interpolation, or stepwise constant

Output timing conventions

●	Produces spot predictions at the end of each time step
	Produces spot output at end of each hour
	Produces average outputs for each hour (please specify period to which value relates)

Treatment of zone air

●	Single temperature (i.e. good mixing assumed)
○	Stratified model
○	Simplified distribution model
	Full CFD model
	Other (please specify)

Heater (dynamics)

●	No dynamics assumed
	Simple first order dynamics
	Detailed modelling of heat source dynamics

Heaters (output characteristics)

●	Purely convective
	Radiative/Convective split fixed within code
○	Radiative/Convective split specified by user
	Detailed modelling of heat source output

Control temperature

○	Air temperature
	Combination of air and radiant temperatures fixed within the code
●	User-specified combination of air and radiant temperatures
	User-specified construction surface temperatures
	User-specified temperatures within construction
	Other (please specify)

Control laws

	Perfect control
	On/Off thermostatic control
○	On/Off thermostatic control with deadband
	On/Off thermostatic control with accelerator heater
●	Proportional control
○	More comprehensive control laws (please specify) PID controller

Heat transfer within zones

●	Radiation and convection combined
○	Radiation and convection treated separately

Convective heat transfer within zones

	Coefficients fixed within code
●	Coefficients specified by user
○	Coefficients calculated by code as a function of surface orientation
○	Coefficients calculated by code as a function of temperature difference
	Coefficients calculated by code as a function of surface finishes
	Other (please specify)

Longwave radiative heat transfer within zones

●	Constant linearised coefficients
	Linearised coefficients based on viewfactors
	Linearised coefficients based on surface emissivities
○	Non-linear treatment of radiation exchange
	Other (please specify)

Number of nodes placed within each layer of walls and slabs

	Not applicable for this solution method
	Fixed number of nodes per layer (please specify)
●	User-specified number of nodes per layer
	Other (please specify)

Airgaps within walls and slabs

	Resistance fixed within code
●	User-specified constant resistance
	Resistance calculated within code as a function of orientation
	Resistance calculated by code as a function of temperature difference
	Radiation and convection treated separately across airgaps
	Treated as additional zones
	Other (please specify)

Windows (heat loss)

●	Fixed resistance used for window element
○	Dynamic treatment of window heat loss using same scheme as opaque elements
	Other (please specify)

Airgaps within windows

	Resistance fixed within code
●	User-specified constant resistance
○	Resistance calculated within code as a function of orientation
○	Resistance calculated by code as a function of temperature difference
○	Radiation and convection treated separately across airgaps
	Treated as additional zones
	Other (please specify)

Windows (transmission of direct shortwave radiation)

	Fixed transmission used
	ASHRAE solar heat coefficients used
●	Calculated by code as a function of incidence angle
○	Calculated by code from user-specified function of incidence angle
	Other (please specify)

Windows (transmission of diffuse radiation)

	Diffuse radiation treated as direct from fixed altitude (please specify)
●	Other (please specify) : Treated as if coming from all directions isotropically + user-specified transmission coefficient

Distribution of solar radiation within zones

	Fixed within the code
●	Constant user-specified distribution
	Calculated once by code and used throughout (please describe algorithm)
○	Calculated as a function of solar position (please describe algorithm) : for each time step, detailed geometrical projections of each corner of the total window (or sunlit fraction) on each zone wall. The algorithm considers the first reflection (one part is absorbed and the remaining part is reflected as diffuse).

Heat transfer between external surfaces and surrounding environment

○	Radiation and convection combined
●	Radiation and convection treated separately

External convection

	Coefficients fixed within code
●	User-specified constant coefficients
	Calculated within code as a function of orientation
	Calculated within code as a function of surface finish
	Calculated within code as a function of wind speed
○	Calculated within code as a function of wind speed and direction
	Other (please specify)

External radiative heat transfer

	Assumed to be to ambient temperature
	Assumed to be to sky temperature read from met file
●	Based on calculated sky temperature (please specify algorithm and requirements)
	Includes view factor of surrounding obstruction

Diffuse sky model

●	Isotropic
	Other (please specify model used)

V. DOE-2 - CIEMAT - SPAIN

V.1. Modellers Report

IEA TASK 22

CIEMAT DOE-2 SIMULATION EXPLANATION

ENERGÍA SOLAR EN LA EDIFICACIÓN

DEPARTAMENTO DE ENERGÍAS RENOVABLES

JUAN TRAVESÍ CABETAS

DECEMBER 1997

IEA TASK 22: CIEMAT´S DOE-2 SIMULATIONS EXPLANATION

1. Introduction

The main objective of this report is to explain the results obtained at the ETNA and GENEC experiments simulations used for this validation exercise.

As DOE-2 is not able to output the surface temperature data, those results have not been obtained in any case. Neither have been obtained the wall surface heat fluxes, because although the program is able to give some results, those results are calculated at the LOADS program, and they are not accurate enough.

The DOE-2 program is a set of 4 differents subprograms, LOADS, SYSTEMS, PLANT and ECONOMICS. The LOADS program simulator calculates the hourly heating and cooling loads considering:

1. A constant space temperature for the room.
2. A constant temperature for the unconditioned spaces.

The SYSTEM adjust the LOADS program results by considering the temperature for each space every hour but there are not surface heat fluxes results available.

The results analysis to quantify the difference between the measurements and the predictions will be done using the same statistical measures than in previous results analysis.

2. ETNA TEST CELLS. FIRST STAGE

This first validation exercise intends to analyze how the programs predict the temperature evolution of the cell, knowing the internal gains.

2.1. Problems Encountered to Develop the Input File

- As you know we had an error at the weather file. We made a mistake calculating the sum position, so we did not calculate accurately the direct radiation. This mistake has been solved at this second run.
- To simulate the floor we have considered three differents kinds of cross section. The first one with a beam of 0.07+0.05 m width. The second one with 0.07 m of polystyrene + 0.05 m of beam. An the third one considering 0.07+0.05 of polystyrene. The areas of each kind of floor have been calculated.
- No thermal bridges have been considered.
- The program is not prepared to consider this experiment. It is not able to simulate the heating system output as a random function. The system output must be controlled by a thermostat. To simulate the test, we have considered an internal heating source, with the heating power schedule given by EDF. This heating source is not a classical convector and neither an academic convective source. To simulate the stirred air we have introduce a fan on the reference cell.

It seems like if those tricks did work pretty good.

			MEASURE CELL		REFERENCE CELL	
	Vert_glob_sol	Flux_inside_cell	Puis_mes	air_temp_mes	Puis_mes	air_temp_mes
dtmin	-248.18		-0.5	-0.18	-0.5	-0.26
dtmax	133.18		0.5	4.59	0.5	4.51
meandt	-1.647587719		-0.023903509	1.640789474	-0.007236842	1.787609649
min	0		2	14	2	15.5
max	828.56		521	25.9	578	25
mean	94.98153509		240.3092105	18.93618421	261.6688596	19.64627193
abdmeandt	18.26482456		0.269078947	1.642412281	0.202850877	1.793004386
rsqmeandt	43.38319403		0.303524617	1.848200049	0.251006745	2.091903618
stderr	43.35189706		0.302581915	0.850678155	0.2509024	1.086513915
sum	43311.58	26262.51387	109581	8634.9	119321	8958.7

Figure 1. Statistical analysis.

As previous figure shows, DOE-2 overestimated the air temperature.

3. ETNA TEST CELLS. SECOND STAGE

This second validation exercise was planned to quantify the differences between the energy consumption measured an predicted for a test cell having a heating system.

When I tried to define those heating equipments in my input file, I found out that I did not have enough data for a detailed definition. If an accurate prediction is desired, we need to know:

For the reference cell:

1. Maximum supply temperature of the heating fan system.
2. Fan flow and power.
3. Partial load efficiency curve. As you know, each equipment has its own partial load efficiency curve. The program has its own default curve, but it might be different to the real equipment used.

For the measure cell:

1. Partial load efficiency curve.
2. Besides this problem, I had a different one. The DOE-2 program does not include a routine to simulate a classical convector (most common heater type used in France, but not in USA or Spain). The system that I considered for the

simulation is a baseboard one, because it is quite similar to the convector.

Assuming possible errors, I tried to predict the air temperatures and energy consumption for both test cells.

Considering that the dynamic effect due to a difference in the initial conditions is negligible since day 100 (April 10th) the results obtained were:

	MEASURE CELL		REFERENCE CELL	
	Pref	Airref	Pref	Airref
dtmin	-501.9	-2.96	-509.9	-3
dtmax	506.6	6.45	382.9	4
meandt	-52.08371809	0.32654828	-53.42372919	0.370532741
min	0	11.3	0	11.4
max	507	21.9	454	21.5
mean	123.3473918	17.1891232	125.6903441	17.26625971
abmeandt	123.2135738	0.93700333	124.5175583	0.922874584
rsqmeandt	192.9400893	1.223355586	193.5300795	1.180413357
stderr	185.7771901	1.178967816	186.0102063	1.120750276
stderr/mean	1.506129861	0.068588014	1.479908482	0.064909847
sum	111136	15487.4	113247	15556.9

Figure 2. Statistical analysis.

As you can see, the results for the energy prediction are not very good. I think that it is mainly due to that the partial load efficiency curve is very different to the real one. As you can see in the figure 4, the real and the predicted equipments have different behavior at partial load.

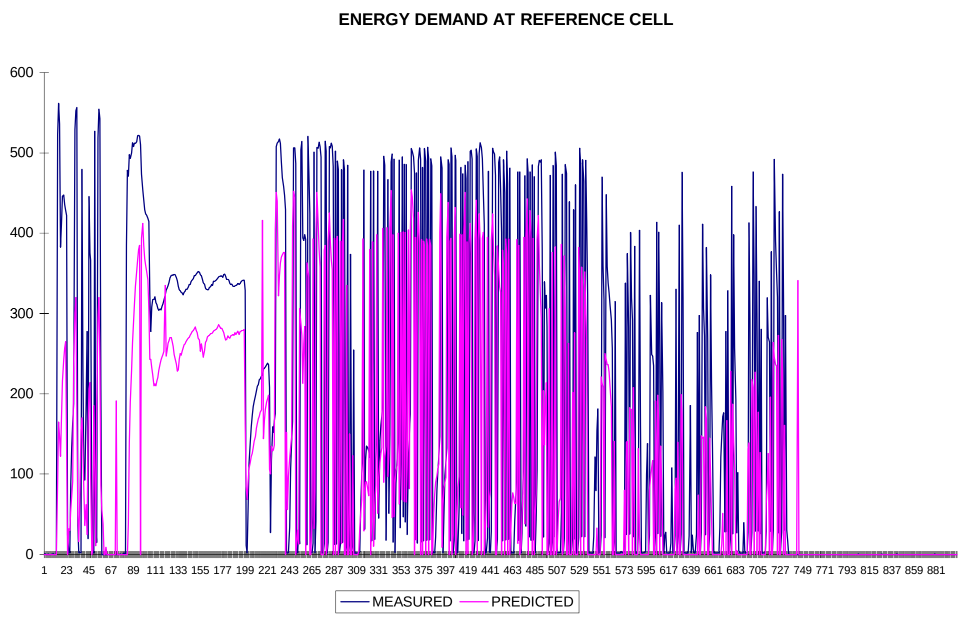


Figure 3. Graphical analysis for energy consumption. Reference cell.

As figure 3 shows, the program underestimate the energy consumption.

4. GENEC TEST CELLS

As I did not have data about humidity, wet bulb temperature, dew point or any parameter that let us know the outside air humidity conditions, we have "created" those measures whose are needed for an accurate prediction. Those measures are needed for a latent heat balance at those hours where some outside air is infiltrated to the cell.

V.2. Program Proforma

Program name (please include version number)

DOE-2.1E-088

Your name and organisation

Juan Travesí. CIEMAT, Spain.

Note: As we are not developers of this prgram, there are few questions that we cannot answer. There are few that we answer but we are jnot totally sure about this answer.

Program status

●	Public domain
	Commercial
	Research
	Other (please specify)

Solution method

	Explicit finite difference
	Implicit finite difference
●	Weighting factors. **To calculate loads from heat gains.**
●	Response factors. **Heat transfer by conduction and radiation through the building skin.**
	Transfer functions
	Other (please specify)

Time step

●	Fixed within code (please specify time step). **1 hour**
	User-specified (please specify time step)
	Other (please specify)

Timing convention for meteorological data : sampling interval

I am not very sure about what are you asking about. I supose that you mean what is the time interval of data demanded by the program

●	Fixed within code (please specify interval). **1 hour**
	User-specified

Timing convention for meteorological data : period covered by first record

●	Fixed within code (please specify period or time which meteorological record covers). **January 1, 1 A.M.**
	User-specified

Meteorological data reconstitution scheme

●	Climate assumed stepwise constant over sampling interval
	Linear interpolation used over climate sampling interval
	Other (please specify)

Output timing conventions

DOE-2 produces hourly values outputs of all variables specified by user.

	Produces spot predictions at the end of each time step
●	Produces spot output at end of each hour
●	Produces average outputs for each hour (please specify period to which value relates)

Treatment of zone air

The program outputs just one zone air temperature, but it must consider some distribution model because the results are different with and without air moving.

●	Single temperature (i.e. good mixing assumed).
	Stratified model
	Simplified distribution model
	Full CFD model
	Other (please specify)

Heater (dynamics)

I cannot answer this question because I am not sure about it. I think that the program considers the dynamics but I am not sure how and wich model does it use.

	No dynamics assumed.
	Simple first order dynamics
	Detailed modelling of heat source dynamics

Heaters (output characteristics)

	Purely convective
●	Radiative/Convective split fixed within code
	Radiative/Convective split specified by user
	Detailed modelling of heat source output

Control temperature

At the ETNA case 1 test there was not any air temperature control. We calculated this temperature using a pseudo-random heating system with a nominal values of 500 W.

●	Air temperature
	Combination of air and radiant temperatures fixed within the code
	User-specified combination of air and radiant temperatures
	User-specified construction surface temperatures
	User-specified temperatures within construction
	Other (please specify)

Control laws

	Perfect control
❍	On/Off thermostatic control
❍	On/Off thermostatic control with deadband
	On/Off thermostatic control with accelerator heater
❍	Proportional control
	More comprehensive control laws (please specify)

Heat transfer within zones

●	Radiation and convection combined
	Radiation and convection treated separately

Convective heat transfer within zones

	Coefficients fixed within code
●	Coefficients specified by user
	Coefficients calculated by code as a function of surface orientation
	Coefficients calculated by code as a function of temperature difference
	Coefficients calculated by code as a function of surface finishes
	Other (please specify)

Longwave radiative heat transfer within zones

	Constant linearised coefficients
	Linearised coefficients based on viewfactors
	Linearised coefficients based on surface emissivities
	Non-linear treatment of radiation exchange
	Other (please specify)

Number of nodes placed within each layer of walls and slabs

	Not applicable for this solution method
	Fixed number of nodes per layer (please specify)
	User-specified number of nodes per layer
	Other (please specify)

Airgaps within walls and slabs

	Resistance fixed within code
●	User-specified constant resistance
	Resistance calculated within code as a function of orientation
	Resistance calculated by code as a function of temperature difference
	Radiation and convection treated separately across airgaps
❍	Treated as additional zones
	Other (please specify)

Windows (heat loss)

●	Fixed resitance used for window element
	Dynamic treatment of window heat loss using same scheme as opaque elements
	Other (please specify)

Airgaps within windows

	Resistance fixed within code
●	User-specified constant resistance
	Resistance calculated within code as a function of orientation
	Resistance calculated by code as a function of temperature difference
	Radiation and convection treated separately across airgaps
❍	Treated as additional zones
	Other (please specify)

Windows (transmission of direct shortwave radiation)

	Fixed transmission used
●	ASHRAE solar heat coefficients used
❍	Calculated by code as a function of incidence angle. **If the glass is one of the window library.**
	Calculated by code from user-specified function of incidence angle
	Other (please specify)

Windows (transmission of diffuse radiation)

	Diffuse radiation treated as direct from fixed altitude (please specify)
	Other (please specify)

Distribution of solar radiation within zones

I am not sure if the program considers it, but as it ca calculates daylighting, it might be able to calculate the distribution solar radiation as a function of solar position.

	Fixed within the code
	Constant user-specified distribution
	Calculated once by code and used throughout (please describe algorithm)
	Calculated as a function of solar position (please describe algorithm)

Heat transfer between external surfaces and surrounding environment

●	Radiation and convection combined
	Radiation and convection treated separately

External convection

	Coefficients fixed within code
	User-specified constant coefficients
	Calculated within code as a function of orientation
●	Calculated within code as a function of surface finish
	Calculated within code as a function of wind speed
●	Calculated within code as a function of wind speed and direction
	Other (please specify)

External radiative heat transfer

	Assumed to be to ambient temperature
	Assumed to be to sky temperature read from met file
	Based on calculated sky temperature (please specify algorithm and requirements)
	Includes view factor of surrounding obstruction

Diffuse sky model

●	Isotropic
	Other (please specify model used)

VI. ZTL - SWITZERLAND

VI.1. Modellers Report

TASK22, COUNTRY CODE REPORT

This country code report describes the most important problems, experiences and results made with DOE 2.1e for the ETNA–cells, Test 1 and Test 2. The simulations were carried out by the engineering school of Lucerne, Switzerland.

Problems in representing the room with the model

The possibilities with DOE 2.1e allow a good modelation of the test-cells. However there are some problems to be solved and restrictions in representing the cell with the model placed at the user's disposal:

- Modelling of the heater: DOE assumes a 70 % radiative part of the heater-output. An additional function allows to represent a heater with a radiative part of 15 % and a convective one of 85 %.
- It is not possible to calculate the reflection of the incoming (in the room) solar-radiation to the different surfaces. The user has to define a SOLAR-FRACTION, which defines the part of absorbed solar-radiation by a component (for example the floor). If no SOLAR-FRACTION is entered by the user, a default value is being used.
- The program allows to define only a combined radiative and convective inside air film resistance, which is constant over the whole simulation period. This method has to be used because the DOE cannot calculate the surface temperatures of the walls (method of weighting factors).

Problems with the documentation

The documentation gives all important informations about the geometry, the materials and the constructions. It would have been helpful when the aim of the experimental sequence were discribed more accuracy.

Otherwise we did not have serious problems with the documentation. It was possible to get all the informations in it to create the input-file.

Hotline

Because we did not have problems with the documentation, we did not need the hotline. So it was not useful for us. Nevertheless we profited from it by using the informations that were given to other participants in form of answers.

Bugs in the model

After we have compared our simulation-results with the measured-results, we checked our input-file. There was found one bug in it:

- The solar absorption of the outside surface of the south wall was set to 0.9 instead to 0.3. This causes a test-cell air-temperature, which is about 0.3 to 0.5 °C to high (Test1). In test 2 the simulated performances are to low.

Although we eliminated this error, the simulated air-temperature is still to high (1 to 2°C). So we assume that there is either a bug in the physical model of DOE-2 or there must be an inaccuracy in the measured data.

Results

The simulated air temperatures in test 1 are to high, and the simulated heating performance in test 2 is too low (see explanation in point 4).

As a matter of fact, the graph of the simulated air temperature has the same form as the measured one, but it has a shift to higher temperatures. The conclusion of this fact is, that there is made a systematic error or the the calculated heating loss by DOE-2 is too low.

Results and conclusions of sensitivity studies

In DOE-2 it is necessary to define a SOLAR-FRACTION (see point 1). Because we did not know the influence to the result of this parameter, we varied its value from 0.2 to 0.8 (default value = 0.6 for floor).

The conclusion of this little experiment is, that the influence of the SOLAR-FRACTION can be neglected in this case.

Also the influence of an air-change (it was original assumed to have no air-change) was analized: an air-change of 0.1 h^{-1} (that is quite high for this cell!) causes an average air-temperature that is 0.1 K deeper than before.

We think, that this two effects are not responsible for the too high simulated temperatures.

Solar radiation

While we were searching for mistakes in our simulation, we discovered a problem that concerns the measuring of the solar radiation:

Mainly in the hours after sunrise and and before sunset there are measured data of global and diffus solar radiation with very little differences in their value. To get the direct solar radiation (that is necessary for DOE-2 weather-input) it is required to divide the difference of global and diffus solar radiation through the cosine of the current angle of sun height. So in the evening and in the morning very strange results are produced with this method (a little number is divided by a very little cosine ⇒ the direct solar radiation seems to be very strong in these hours).

$$direct\_rad = \frac{global\_rad - diffuse\_rad}{\cos(angle\ of\ incidence)}$$

To avoid such mistakes, we corrected the weather file as follow:

We only calculate a direct solar-radiation when the difference between global and diffuse radiation is at least 10 W/m^2.

We detected that there is a problem with this correction in the weather file of ETNA test 1: in a few hours there occurs a negative solar radiation of -0.7 to -69.85 [W/m^2] on the south wall, although all values in the weather file give a positive solar radiation. These values appear only at hour 8 of the day. Up to now we did not find the reason of this problem. Due to the little influence (it appears only four times in the hole simulation period) we did not make any further work to correct it.

Thermal bridges

Our results from the first runs show that there must be an underestimation of heating loss (see points above). So the next improvement of the model was taking into account the effect of thermal bridges. Especially in buildings with a good insulation the effect of thermal bridges is significant and therefore can not be neglected.

Our approach was the use of a program that uses the finite elements method for calculating heat fluxes. The calculation was done under the following conditions:

- Two dimensional calculation
- Stationary heat fluxes

As described in [1] it is allowed to replace the two-dimensional model (thermal bridge) by a one dimensional (e.g. ‚wall‘) if the heating loss under stationary conditions is equal and in none part of the surface lower temperatures occur than in the 2/3-dimensional problem.

In the following part the calculation of the **window-wall junction** is shortly presented:

picture 1

The overall heating loss of the defined construction is:

$\dot{Q}_{TOT} = 14.25$ [W/m]

The arrows in the drawing define the heating loss of the undisturbed elements, that means the heating loss of each element without considering the effect of thermal bridges as it is defined in the originally simulation input.

That means that we get the effect of this thermal bridge by subtracting the undisturbed heat flux from the total heat flux:

$\dot{q}_{TB} = 14.25 - 2.3 - 4.1 - 4.7 = 3.15$ [W/m]

related to the temperatue difference:

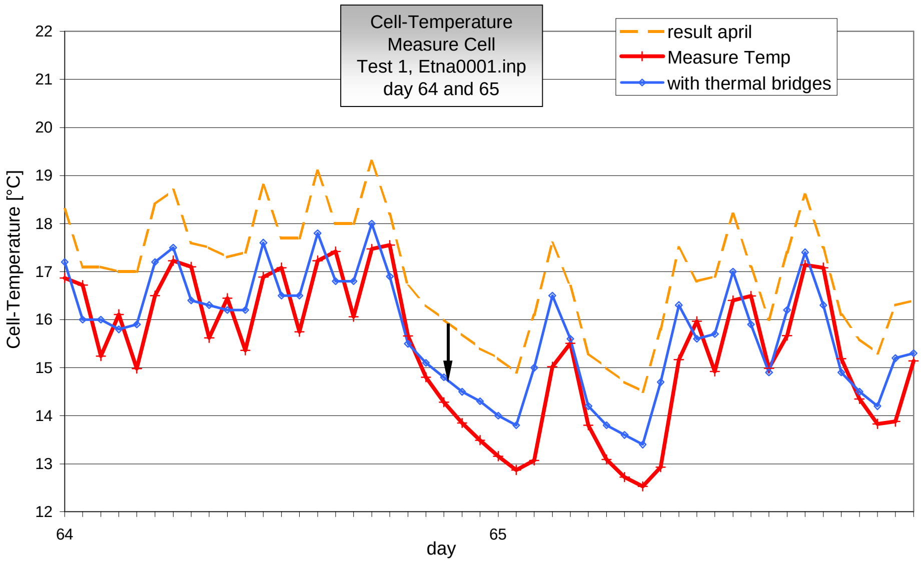
$$k_{lin} = \frac{\dot{q}_{TB}}{\Delta\vartheta} = \frac{3.15}{20-0} = 0.158 \text{ [W/m*K]}$$

All the relevant thermal bridges for the ETNA-Cell have been calculated in this way. The additional heating loss due to the several thermal bridges has then been additioned to the walls by increasing the conductivity of the insulation. The new U-values due to these corrections are listed below:

Wall	Original U-value [W/m^2*K]	Corrected U-value [W/m^2*K]	Change [%]
South-wall	0.413	0.626	+ 51.6
West-wall	0.401	0.549	+ 36.9
North-wall	0.461	0.598	+ 29.7
East-wall	0.222	0.282	+ 27.0

Chart 1

This change causes a shift of the temperature curve down to lower temperatures as shown in the diagram below. The dynamic behavior of the space does not change significantly.



Surface temperatures

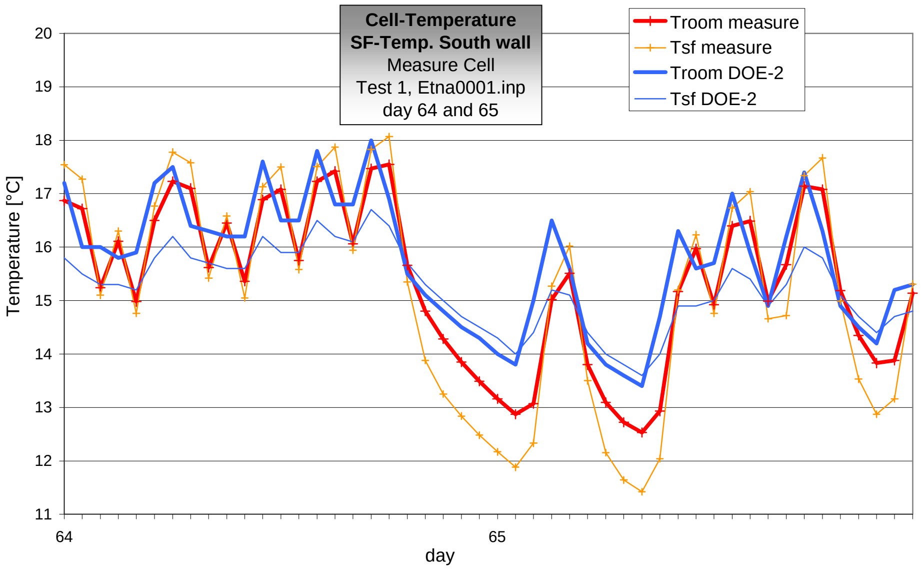
In the original Version of DOE-2 (Version DOE2.1e) a calculation of the surface temperatures is not possible. M. Koschenz performed at EMPA[1] a calculation routine (see also: [2]) for that purpose which is based on the following calculation method:

- Heat transfer on the wall surface with a combined radiative and convective film coefficient.
- The calculation of the surface temperatures is then made with an energy balance on each side of the wall. The required data such as conduction heat fluxes are known from previous time steps. The zone air temperature and the radiative heat flux to the wall are calculated in the current time step.

This routine was compiled for a PC-Version by EMPA. The simulation runs with the new DOE-2 version have been carried out and the surface temperatures have been calculated with it.

The results for the day 64 and 65 of the ETNA-Measure cell (Test 1) are shown below:

[1] Swiss Federal Laboratories for Materials Testing and Research



$T_{sfmeasure}$	measured inside surface temperature of the south wall
$T_{sfDOE-2}$	inside surface temperature calculated with DOE-2
$T_{room\ measure}$	measured room air-temperature
$T_{room\ DOE-2}$	room air-temperature calculated with DOE-2

The comparison between the measurement and the calculation shows that in the last hours of day 64 the calculated surface temperature is above the room air-temperature. The measurement shows that the surface temperature should be *below* the air-temperature. In addition to that the surface temperature does not react quick enough.

The reason for this behaviour is still unknown. There are also some uncertainties about the calculation routine of the surface temperature: it has to be tested, if the calculation is still done correctly after the compilation for the PC-version.

As a matter of fact the results of the surface temperature calculation of the reference cell is closer to the measurements than in the measure cell. This is due to the circumstance that in the reference cell the measured air temperature is given as a schedule. So the surface temperatures which are quite close to the air temperature are calculated in good accordance with the measurements.

In test 1 the heater energy is given as input. With this constellation a precise prediction of the surface temperature is more difficult (storage of radiative part).

Horw, 29. March. 99
M. Dürig

VI.1.1.1.References

[1] Thermische Gebäudesimulation, *Wolfgang Feist*
Verlag C.F. Müller, ISBN 3-7880-7486-8

[2] *Surface temperature calculation in DOE 2.1e*, M. Koschenz
IB9503MK

Program name (please include version number)

DOE 2.1e

Your name and organisation

G. Zweifel / M. Dürig, Zentralschweizerisches Technikum Luzern, Switzerland

Please note, that the following answers are only valid for the Test 1 !

Program status

	Public domain
●	Commercial
	Research
	Other (please specify)

Solution method

	Explicit finite difference
	Implicit finite difference
●	Weighting factors: storage of radiation from internal and external loads in the building-mass
●	Response factors: instationary heating transfer through components between inside and outside climate
	Transfer functions
	Other (please specify)

Time step

●	Fixed within code (please specify time step) time step = 1 hour
	User-specified (please specify time step)
	Other (please specify)

Timing convention for meteorological data : sampling interval

●	Fixed within code (please specify interval) interval = 1 hour
	User-specified

Timing convention for meteorological data : period covered by first record

	Fixed within code (please specify period or time which meteorological record covers)
	User-specified

Meteorological data reconstitution scheme

●	Climate assumed stepwise constant over sampling interval
	Linear interpolation used over climate sampling interval
	Other (please specify)

Output timing conventions

	Produces spot predictions at the end of each time step
	Produces spot output at end of each hour
●	Produces average outputs for each hour (please specify period to which value relates)

Treatment of zone air

●	Single temperature (i.e. good mixing assumed)
	Stratified model
	Simplified distribution model
	Full CFD model
	Other (please specify)

Heater (dynamics)

●	No dynamics assumed
	Simple first order dynamics
	Detailed modelling of heat source dynamics

Heaters (output characteristics)

	Purely convective
❍	Radiative/Convective split fixed within code
●	Radiative/Convective split specified by user: That's only possible with an additional function and when the heater is defined as "EQUIPMENT".
	Detailed modelling of heat source output

Control temperature

●	Air temperature
	Combination of air and radiant temperatures fixed within the code
	User-specified combination of air and radiant temperatures
	User-specified construction surface temperatures
	User-specified temperatures within construction
	Other (please specify)

Control laws

	Perfect control
	On/Off thermostatic control
❍	On/Off thermostatic control with deadband
	On/Off thermostatic control with accelerator heater
❍	Proportional control
❍	More comprehensive control laws (please specify) Following control laws are available: on / off, proportional-control with off -hour offset, proportional-control with seasonal temperature reset and off -hour temperature offset

Heat transfer within zones

●	Radiation and convection combined (film-resistance is a combination of radiation and convection)
	Radiation and convection treated separately

Convective heat transfer within zones

	Coefficients fixed within code
●	Coefficients specified by user: default value used
	Coefficients calculated by code as a function of surface orientation
	Coefficients calculated by code as a function of temperature difference
	Coefficients calculated by code as a function of surface finishes
	Other (please specify)

Longwave radiative heat transfer within zones

	Constant linearised coefficients
	Linearised coefficients based on viewfactors
	Linearised coefficients based on surface emissivities
	Non-linear treatment of radiation exchange
	Other (please specify)

Number of nodes placed within each layer of walls and slabs

●	Not applicable for this solution method
	Fixed number of nodes per layer (please specify)
	User-specified number of nodes per layer
	Other (please specify)

Airgaps within walls and slabs

	Resistance fixed within code
●	User-specified constant resistance
	Resistance calculated within code as a function of orientation
	Resistance calculated by code as a function of temperature difference
	Radiation and convection treated separately across airgaps
	Treated as additional zones
	Other (please specify)

Windows (heat loss)

	Fixed resitance used for window element
	Dynamic treatment of window heat loss using same scheme as opaque elements
●	Other (please specify): resistance in function of wind –speed (see ASHRAE-procedure)

Airgaps within windows

	Resistance fixed within code
	User-specified constant resistance
	Resistance calculated within code as a function of orientation
	Resistance calculated by code as a function of temperature difference
	Radiation and convection treated separately across airgaps
	Treated as additional zones
●	Other (please specify): see ASHRAE-procedure

Windows (transmission of direct shortwave radiation)

	Fixed transmission used
	ASHRAE solar heat coefficients used
●	Calculated by code as a function of incidence angle
	Calculated by code from user-specified function of incidence angle
	Other (please specify)

Windows (transmission of diffuse radiation)

	Diffuse radiation treated as direct from fixed altitude (please specify)
●	Other (please specify): hemisphere

Distribution of solar radiation within zones

	Fixed within the code
●	Constant user-specified distribution: default value used
	Calculated once by code and used throughout (please describe algorithm)
	Calculated as a function of solar position (please describe algorithm)

Heat transfer between external surfaces and surrounding environment

	Radiation and convection combined
●	Radiation and convection treated separately

External convection

	Coefficients fixed within code
	User-specified constant coefficients
	Calculated within code as a function of orientation
	Calculated within code as a function of surface finish
●	Calculated within code as a function of wind speed
	Calculated within code as a function of wind speed and direction
	Other (please specify)

External radiative heat transfer

	Assumed to be to ambient temperature
	Assumed to be to sky temperature read from met file
●	Based on calculated sky temperature (please specify algorithm and requirements) Sky temperature in function of dewpoint and cloud-amount
	Includes view factor of surrounding obstruction

Diffuse sky model

	Isotropic
●	Other (please specify model used): unisotropic (perez-model).

VII. ICE - KTH - SWEDEN AND FINLAND

VII.1.Modellers Report

IEA TASK 22, SUBTASK A3, EMPIRICAL VALIDATION

IDA Indoor Climate and Energy, version 2.0, beta, build 28

The studies were carried out with beta versions of the software. Several of the models have since then been revised. With the exception of models for solar processing, the impact of these changes on simulation results should be small.

The models library that is used in IDA ICE (www.brisdata.se/ice/), is a deliverable of IEA Task 22. They are available in the public domain as NMF (Neutral Model Format) source code with accompanying documentation (www.brisdata.se/nmf/simone.htm). Their implementation in IDA is an automated procedure. The third round of tests were conducted with just the model library and IDA Solver, manually setting up the system description file. At the time of the last round, a beta version of IDA ICE was available for interactive system description.

With the exception of the heater with intermittent air stirring, the given problem was readily accommodated within ICE.

Were any bugs found in the model as a result of this exercise?

- There was a problem with solar irradiation on a vertical surface, mostly at the end of the day. The problem was not rectified within the exercise, but the models for solar processing have later been revised.
- We discovered and fixed a bug in the calculation of convection in the back of a wall-mounted radiator.
- In the third round, ICE showed a problem with time-synchronisation between climate data and simulation results. These problems were rectified in the last round.

Odd results obtained

- There is a significant discrepancy in the static response of the model. This is indicated by a systematic over-prediction of temperatures in ETNA1 and, equivalently, an under-prediction of the required heating power in ETNA2. This problem is likely to be attributable to thermal bridges. Due to time constraints, no effort was made to make more detailed calculations of thermal bridges and to take account of these in the present round of tests.
- It seems that there will be a discrepancy in simulation results even after an adjustment of the static response (purely based on a visual inspection). There is a problem with both the radiant temperature and to some extent fast dynamics. (The radiant temperature happens to be fairly well predicted, but if the model was to be compensated for thermal bridges, they

would be under-predicted.) This is most likely due to problems with film coefficients, which are calculated automatically by the model but for a case with lower indoor air speeds (more typical European office conditions). The fan used to create well-mixed conditions in the reference case is likely to have significant impact on film coefficients and thereby fast transient time constants and surface temperatures relative to air.

- The same argument is also valid for the case with the convective heater and no fan (measure case) but to a lesser extent. The convective plume from such a heater has significant impact on average film coefficients, in comparison to more normal office conditions where there is no need for such heating. There was no attempt made in the scope of the present study to change the algorithms for calculation of film-coefficient, but this is clearly an area that deserves further investigation.
- The exposed surface temperature of the convector gets rather high in our calculations, but there was no measurement data to compare this result with.

VII.2.Program Proforma

Program name (please include version number)

IDA Indoor Climate and Energy, v. 2.00, beta, build 28

Your name and organisation

Mika Vuolle and Per Sahlin, KTH, Sweden

Program status

●	Public domain *The mathematical models used are a free deliverable of IEA Task 22*
●	Commercial *The user interface that was used for the last round is commercial, as is IDA Solver, which was used in both rounds.*
	Research
	Other (please specify)

Solution method

	Explicit finite difference
●	Implicit finite difference
	Weighting factors
	Response factors
	Transfer functions
●	Other (please specify) *The wall models use a modal reduction method to reduce the number of nodes*

Time step

	Fixed within code (please specify time step)
	User-specified (please specify time step)
●	Other (please specify) *Variable, selected by solver during integration. Varies 2 min - 2 hours*

Timing convention for meteorological data : sampling interval

	Fixed within code (please specify interval)
	User-specified

IDA uses instantaneous values with variable timestep for all input and output signals. There was a shift in time in the third round in the results because of this.

Timing convention for meteorological data : period covered by first record

	Fixed within code (please specify period or time which meteorological record covers)
	User-specified

See previous comment

Meteorological data reconstitution scheme

	Climate assumed stepwise constant over sampling interval
	Linear interpolation used over climate sampling interval
●	Other (please specify) *Linear or higher order (automatically selected) interpolation is used*

Output timing conventions

●	Produces spot predictions at the end of each time step
	Produces spot output at end of each hour
❍	Produces average outputs for each hour (please specify period to which value relates) *Hourly, daily or monthly averages of all signals are available in the user interface*

Treatment of zone air

●	Single temperature (i.e. good mixing assumed)
❍	Stratified model
	Simplified distribution model
	Full CFD model
	Other (please specify)

Heater (dynamics)

●	No dynamics assumed
	Simple first order dynamics
	Detailed modelling of heat source dynamics

Heaters (output characteristics)

	Purely convective
	Radiative/Convective split fixed within code
❍	Radiative/Convective split specified by user
●	Detailed modelling of heat source output

Control temperature

●	Air temperature
	Combination of air and radiant temperatures fixed within the code
❍	User-specified combination of air and radiant temperatures
❍	User-specified construction surface temperatures
❍	User-specified temperatures within construction
	Other (please specify)

Control laws

	Perfect control
	On/Off thermostatic control
❍	On/Off thermostatic control with deadband
	On/Off thermostatic control with accelerator heater
❍	Proportional control
●	More comprehensive control laws (please specify*) ICE enables the user to chose among several different types of controllers (and to add her own). A PI controller, with tracking time anti-windup, was used in the test.*

Heat transfer within zones

	Radiation and convection combined
●	Radiation and convection treated separately

Convective heat transfer within zones

	Coefficients fixed within code
	Coefficients specified by user
●	Coefficients calculated by code as a function of surface orientation
●	Coefficients calculated by code as a function of temperature difference
	Coefficients calculated by code as a function of surface finishes
	Other (please specify)

Longwave radiative heat transfer within zones

❍	Constant linearised coefficients *In the simplified zone model*
	Linearised coefficients based on viewfactors
	Linearised coefficients based on surface emissivities
●	Non-linear treatment of radiation exchange
	Other (please specify)

Number of nodes placed within each layer of walls and slabs

	Not applicable for this solution method
	Fixed number of nodes per layer (please specify)
❍	User-specified number of nodes per layer
●	Other (please specify) An automatic modal reduction method is used, which usually generates 2 or 3 layers.

Airgaps within walls and slabs

	Resistance fixed within code
●	User-specified constant resistance
	Resistance calculated within code as a function of orientation
	Resistance calculated by code as a function of temperature difference
	Radiation and convection treated separately across airgaps
❍	Treated as additional zones
	Other (please specify)

Windows (heat loss)

●	Fixed resistance used for window element
	Dynamic treatment of window heat loss using same scheme as opaque elements
	Other (please specify)

Airgaps within windows

	Resistance fixed within code
●	User-specified constant resistance
	Resistance calculated within code as a function of orientation
	Resistance calculated by code as a function of temperature difference
	Radiation and convection treated separately across airgaps
	Treated as additional zones
	Other (please specify)

Windows (transmission of direct shortwave radiation)

	Fixed transmission used
	ASHRAE solar heat coefficients used
●	Calculated by code as a function of incidence angle
	Calculated by code from user-specified function of incidence angle
	Other (please specify)

Windows (transmission of diffuse radiation)

	Diffuse radiation treated as direct from fixed altitude (please specify)
●	Other (please specify) *Treated as if coming from all directions isotropically.*

Distribution of solar radiation within zones

	Fixed within the code
	Constant user-specified distribution
●	Calculated once by code and used throughout (please describe algorithm) *Based on view factors from a diffusely radiating window*
	Calculated as a function of solar position (please describe algorithm)

Heat transfer between external surfaces and surrounding environment

	Radiation and convection combined
●	Radiation and convection treated separately

External convection

	Coefficients fixed within code
	User-specified constant coefficients
	Calculated within code as a function of orientation
	Calculated within code as a function of surface finish
	Calculated within code as a function of wind speed
●	Calculated within code as a function of wind speed and direction
	Other (please specify)

External radiative heat transfer

	Assumed to be to ambient temperature
	Assumed to be to sky temperature read from met file
●	Based on calculated sky temperature (please specify algorithm and requirements) `tsky = tair -5`
	Includes view factor of surrounding obstruction

Diffuse sky model

	Isotropic
●	Other (please specify model used) *Therkeld's model was used (and gave poor results), several others are presently available, e.g. Perez and ASHRAE.*

VIII. PROMETHEUS - KST - GERMANY

VIII.1.Modellers Report

Modeller's report for ETNA and GENEC simulation runs

Martin Behne, KLIMASYSTEMTECHNIK, Berlin, Germany

VIII.1.1.Introduction

The German participant KLIMASYSTEMTECHIK (KST), Berlin, uses the simulation program PROMETHEUS which has been developed within the company. For more than 20 years, PROMETHEUS has been improved and adapted to the needs in modern building and system simulation. The program is used to assess building's energy demand, heating and cooling loads and temperatures. In many cases, it is the companies base for consulting architects and building owners.

For KST, the IEA Task 22 is a very comprehensive opportunity to test and compare the program's capabilities with other simulation tools available and to improve it's agreement with real, i.e., measured data (validation), and to exchange knowledge and experiences with other modeller's or users of models.

VIII.1.2.Problems concerning the modelling and the documentation provided

The room description in PROMETHEUS makes it possible to model and investigate almost each kind of space. Thus, no problems occurred with modelling the ETNA and GENEC test chambers. A characteristic of PROMETHEUS, the input file with the weather data has a unique format therefore, weather data in, e.g., TMY format, has to be transformed. However, this is not a special problem within the ETNA and GENEC tests but a typical routine when working with PROMETHEUS.

The documentations provided by EDF about the ETNA and GENEC test set-ups were almost perfect. The descriptions were clear, the Figures and Tables very well organized.

Only one little restriction regarding the documentation could be mentioned. The original description of the heater control (ETNA) has not been sufficient enough for modelling and some minor details were missing, too.

VIII.1.3.Hotline

The hotline has been used to get some details missing in the descriptions. The contact with EdF via e-mail worked out fine.

VIII.1.4.Bugs

There were no bugs detected in PROMETHEUS.

Comparing the results of the blind-test, a problem regarding the solar radiation flux inside the test cells calculated by PROMETHEUS occurred : The values of the flux inside were remarkably lower than those of the other modellers. However, PROMETHEUS calculated the heat gain of the test cells correctly which becomes clear when comparing all simulation results of the temperatures inside. As the flux inside is not an standard output of PROMETHEUS, this value has to be determined „manually“. Thus, the low value of the flux inside is a result of a wrong interpretation of the definiton rather than a result of a bad simulation.

VIII.1.5.Results and conclusions of the sensitivity study

Comparing the simulation results of the empirical validation on ETNA test-cells (ETNA I) showed that the air, radiant and operative temperatures calculated by the models involved are higher than the measured values.

The average deviations seem to be mainly due to underestimated heat losses of the test-cells. This assumption was confirmed by a sensitivity analysis conducted by KST with PROMETHEUS, which showed that only the variations with an increased heat transfer to the exterior (Figure 1: conductivity + 10%; window area + 10%) ended up with remarkably reduced temperatures.

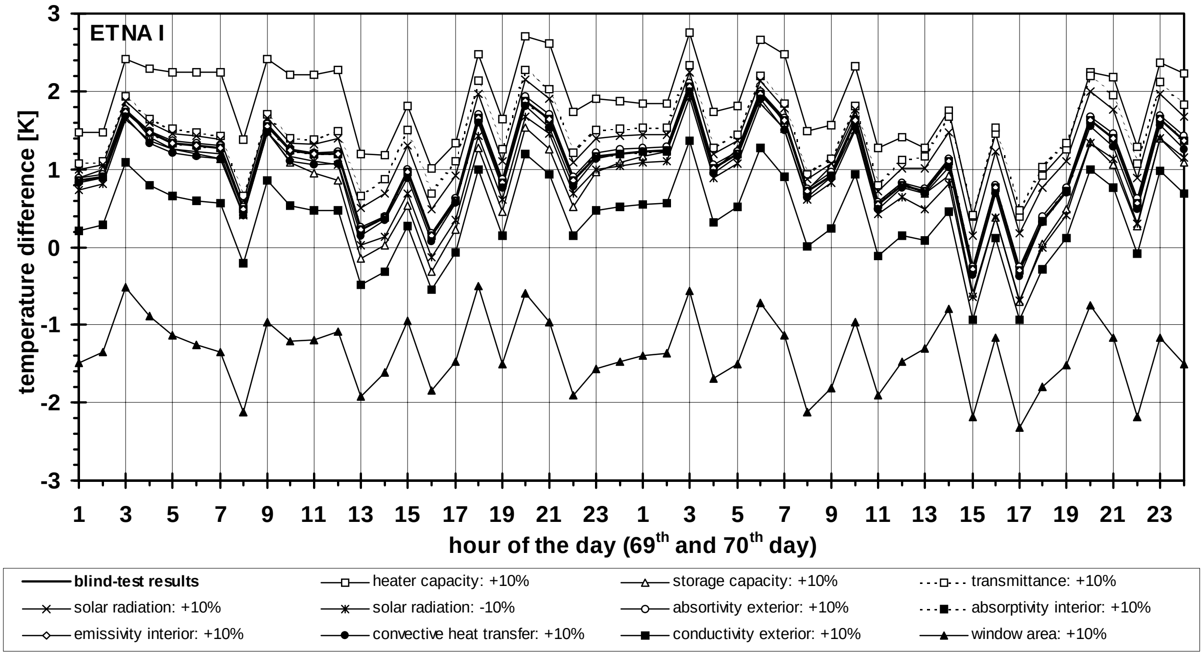


Figure 1 : Results of sensitivity analysis with PROMETHEUS

VIII.1.6.Improvement of heat transfer model

As a consequence of the blind-test and the sensitivity study, two different effects involved in heat transfer in rooms have been analyzed and implemented to improve the heat transfer model of PROMETHEUS:

- **Thermal bridges** increase the heat transfer, i.e., heat losses to colder spaces
- **Re-reflection of solar radiation** to the exterior reduces the heat gains and thus, reduces the inside temperatures

VIII.1.6.1.Thermal bridges

The heat flux via thermal brigdes can be determined considering the construction details of walls and windows or doors. Values for the heat flux via thermal brigdes can be found in, e.g., /1/. This data was used to adjust the heat losses through exterior and interior walls by changing the conductivity of the respective walls (interior and exterior) according to the additional heat losses via thermal bridges (Table 1). The film coefficients and storage capacities have not been changed.

Table 1 : Adjustment of U-values due to heat losses via thermal bridges

surface	original U-value W/m²K	area m²	additional heat losses due to thermal bridges W/K	adjusted U-value W/m²K
external wall South	0.42	7.23	2.36	0.75
internal wall North	0.42	7.00	0.85	0.54
internal wall West	0.40	10.15	1.91	0.59
internal wall East	0.22	11.81	0.59	0.27

VIII.1.6.2.Re-reflection of solar radiation

Solar radiation penetrates a space through transparent surfaces causing heat gains and as a consequence higher inside temperatures. Re-reflection of short wave radiation through a window to the exterior reduces the heat gains in a space. Depending on the view factors and the emissivities of the respective surfaces, a certain part is reflected from the surfaces back to the ambient. If this „re-reflection“ is not taken into account the room air temperatures calculated might be too high.

This problem can be solved by firstly analyzing the space's geometry (surface areas, size of windows) and the material's properties (viewfactors and emissivities of walls, floors and ceiling). Secondly, the reflection from the room to the ambient has to be calculated analytically. Finally, an additional layer in front of the windows has to be added. The reflection coefficient of this layer represents the re-reflection of the space. This additional layer of the window must neither have a storage capacity nor a heat resistance. With PROMETHEUS it and can easily be added to the definition of the windows used. As a result, the solar radiation entering the space gets reduced while the heat transmission is not changed and lower room air temperatures are calculated.

VIII.1.6.3.Simulation results with the expanded PROMETHEUS model

The improvements of the PROMETHEUS model additionally considering thermal bridges and re-reflection of solar radiation are presented in the following by comparing the simulation results with the measured data provided by EdF after the blind-test results had been submitted by the modellers.

VIII.1.6.3.1.Comparison with the measured data of the blind-test

According to the instructions for the ETNA blind-test, PROMETHEUS calculated the operative or room temperature t_R as mean of air and mean radiant temperature:

$$t_R = 0.5 \cdot (t_{air} + t_{radiant}) \tag{1}$$

Figure 2 compares the room temperatures calculated with the original PROMETHEUS model used in the blind-test, the improved model and measured data for two consecutive days with high solar radiation (72th and 73th day: $I_{sun,max}$ > 800 W/m²).

Taking into account the whole simulation period (60th through 78th day), the mean error Δt_{mean}[2] for the air temperatures calculated with the optimized model can be reduced significantly (compare Table 2). However, the radiant temperatures calculated with the improved model are below the measured data and the mean difference is about twice as high

[2] $\Delta t_{mean} = t_{mean,simulation} - t_{mean, measurement}$

when compared with the blind-tests. The mean of the air and radiant temperatures, the operative temperatures calculated with the expanded model, match the measured data better than within the blind-test. However, at times of highest solar radiation, i.e., between approximately 13^{00} and 16^{00} h, the simulation results still deviate more from the measured data than, e.g., at night time (Figure 2).

Table 2 : Comparison of mean temperatures calculated and measured (day 60 through 78; t : mean temperature; Δt : mean temperature difference)

variation	air temperature		radiant temperature		operative temperature	
	t [°C]	Δt [K]	t [°C]	Δt [K]	t [°C]	Δt [K]
measured data	17.29	-	17.31	-	17.30	-
blind-test PROMETHEUS	18.90	1.61	17.73	0.42	18.32	1.01
optimized PROMETHEUS model	17.53	0.24	16.36	-0.95	16.95	-0.36

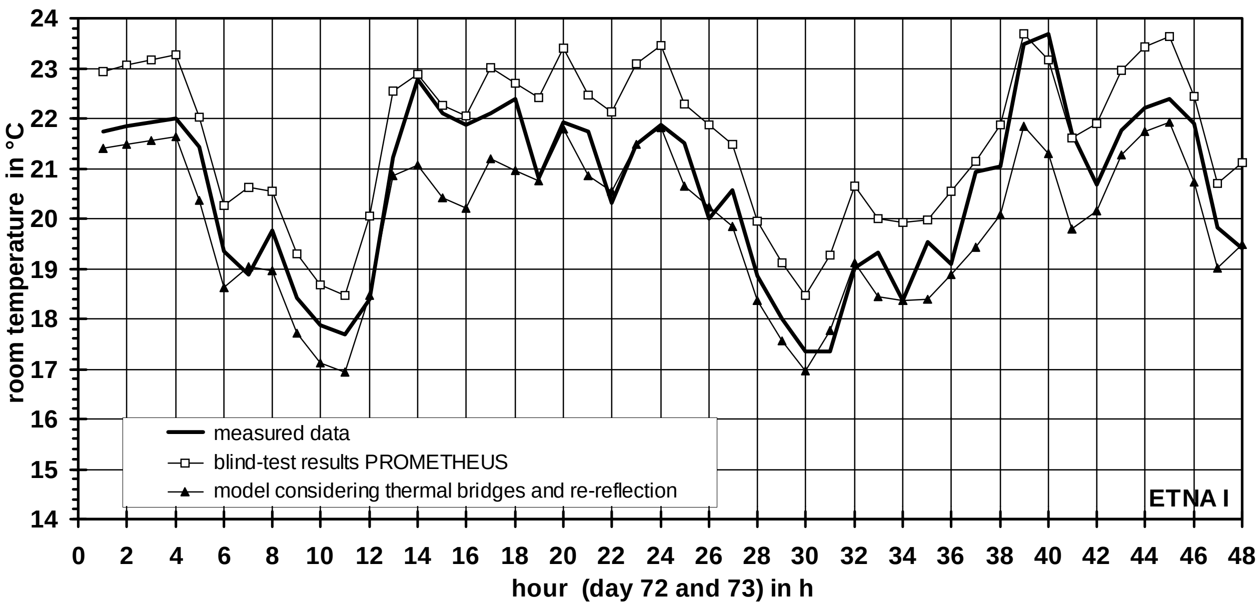


Figure 2 : Comparison of measured room temperature and results of the optimized PROMETHEUS model (only 72^{th} and 73^{th} day)

VIII.1.6.3.2.Evaluation of measured data

To find an explanation for the deviations at times with high solar radiation, the radiant temperature was also determined from the measured surface temperatures provided by EdF. As the surface temperature of the window (south wall) was not provided, the temperature rise of the inner window surface due to solar radiation absorbed was estimated. The mean radiant temperature in the test-cells is not significantly influenced therefore, this issue has not been taken into further consideration. Theoretically, the radiant temperature measured with sensors should not deviate significantly from the radiant temperature calculated according Equation 2:

$$\bar{t}_{radiant,surfaces} = \frac{1}{A_{total}} \cdot \sum_{i=1}^{n} (A_i \cdot t_{surface,i}) \qquad (2)$$

with A_{total} : sum of surface areas m²

A_i : area of surface i in m²

$t_{surface,i}$: mean temperature of surface i (measured data from EdF)

In fact, there are remarkable differences between the two measured radiant temperatures. Between 12^{00} and 17^{00} h, the difference is significantly higher than at other times, which seems to prove that solar radiation directly influenced the radiant sensors, i.e., the black-globe thermometers used by EdF. However, even at times with no solar radiation a difference of more than 1 K can be observed indicating other systematical errors which might be caused by the influence of the air flow pattern on the black-globe temperature and the accuracy of the measurement.

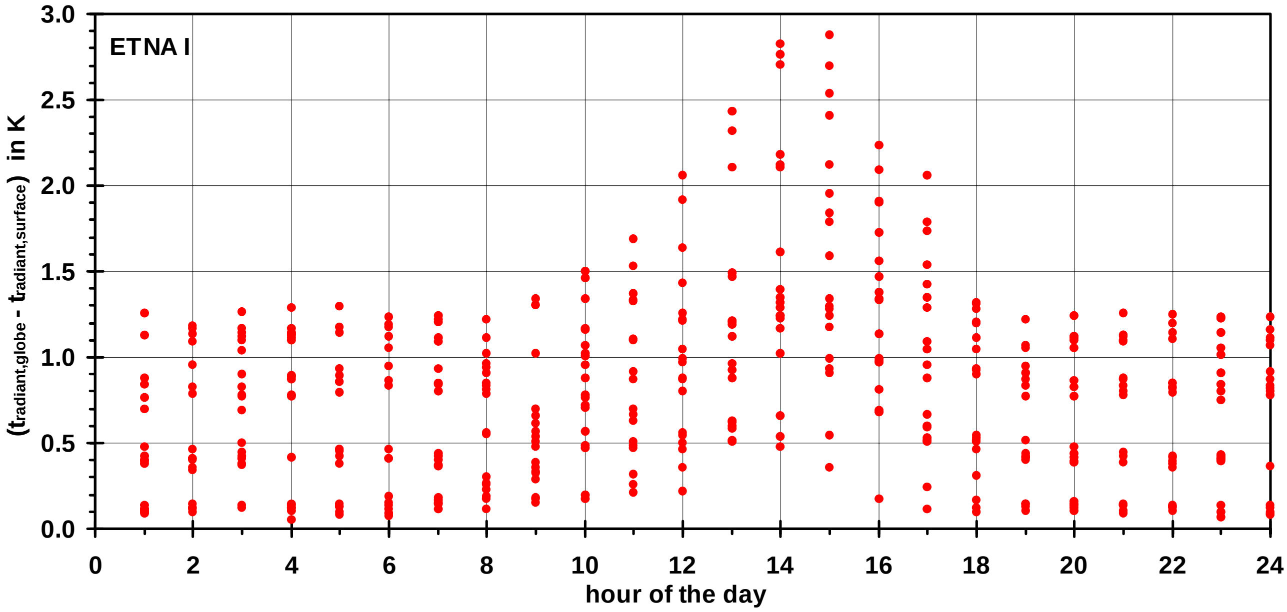


Figure 3 : Relation between the difference of the measured radiant temperatures and the hour of the day.

VIII.1.6.3.3. Comparison with radiant temperature determined from measured surface temperatures

PROMETHEUS calculates the radiant temperature from the surface temperatures according to the German standard DIN 1946, part 2 /2/. As the location for the calculation of the radiant temperature was not given for the blind-test, Equation 2 is suitable and sufficient. To validate the simulation results, the measured data should be derived from surface temperatures, too. Using data from a black-globe thermometer instead involves errors, e.g., due to direct solar impact or air velocities and thus, should be not be utilized in an empirical validation procedure.

Using the radiant temperature determined from the measured surface temperatures for the ETNA validation, shows that the simulation results with the optimized PROMETHEUS model match the measurements much better than with the original model. Especially, the room temperature calculated with the new model almost exactly matches the measured data. Figure 4 presents the room temperatures determined from different measurements and as a result of the two versions of PROMETHEUS. Table 3 summarizes the mean errors for the different temperatures. The improvement of the optimized model becomes clear. In recent applications of PROMETHEUS, the room temperature has often been the most important parameter for assessing the thermal conditions in a space. Thus, the achieved accuracy of the room temperature calculated is very satisfying.

Table 3 : Comparison of mean temperatures calculated and measured (day 60 through 78) (t : mean temperature; Δt : mean temperature difference)

variation	air temperature		radiant temperature		operative temperature	
	t [°C]	Δt [K]	t [°C]	Δt [K]	t [°C]	Δt [K]
$t_{radiant,globe}$	17.29	-	17.31	-	17.30	-
$t_{radiant,surface}$	17.29	-	16.51	0.80	16.90	0.40
blind-test PROMETHEUS	18.90	1.61	17.73	1.23*)	18.32	1.41*)
optimized PROMETHEUS model	17.53	0.24	16.36	-0.15*)	16.95	0.05*)

**) : difference between simulation result and $t_{radiant,surface}$*

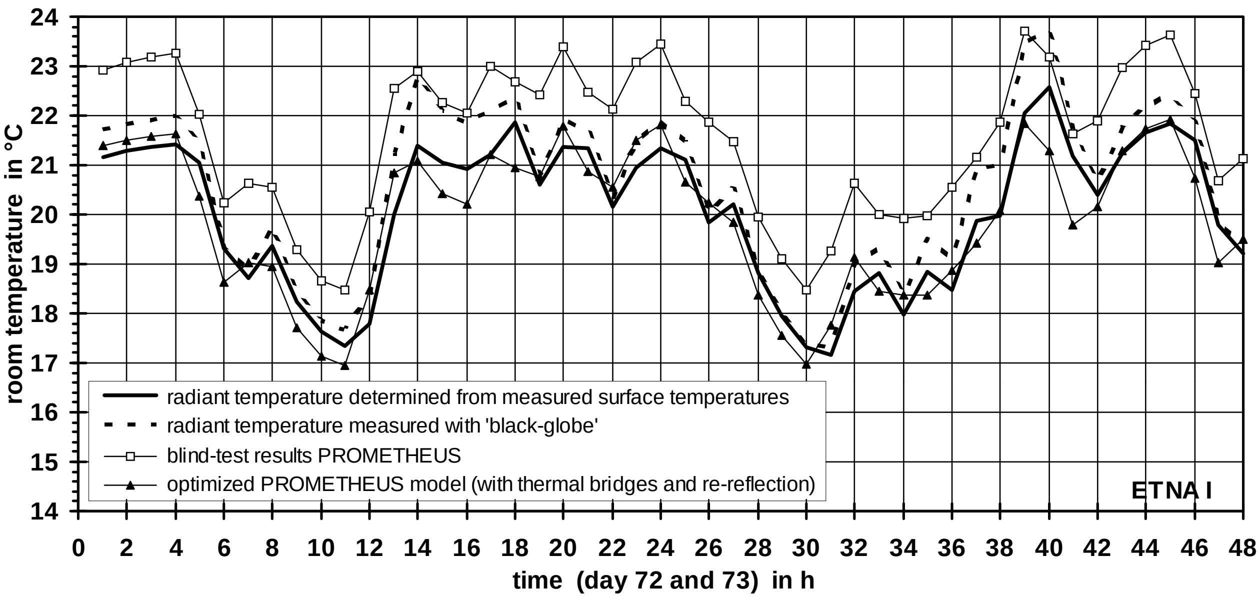


Figure 4 : Comparison of room temperature determined from measured surface temperatures and results of the optimized PROMETHEUS model (only 72th and 73th day)

VIII.1.7.Summary and Conclusion

For the ETNA blind-test, the original PROMETHEUS model and the other models participating calculated temperatures which were significantly higher than the measured ones. An analysis of the parameters involved in heat transfer showed that the heat losses were apparently underestimated and probably solar radiation was overrated. Thus, the possible additional heat losses were analyzed and eventually heat losses via thermal bridges and re-reflection of solar radiation to the exterior were investigated and added to the model. Thermal bridges were implemented by making use of coefficients and adjusting the heat transfer through all walls of the test-cells. An approach for re-reflection was accomplished by analyzing the diffuse radiation exchange and introducing an additional, fictional window layer. This kind of model extension is supposed to be applicable to any other analysis tool.

Implementing the effects of thermal bridges and re-reflection of solar radiation (optimized PROMETHEUS model), the simulation results were significantly closer to the measured data.

Evaluating the measured data used for the blind-test, it became obvious that the radiant temperatures directly measured with black-globe thermometers were biased by solar radiation and the air flow pattern in the space. The radiant temperature determined from measured data for the enclosure of the test-cells showed significant deviations from the measured data used for the blind-test. Based on the boundary conditions of the blind-test, a simulation tool can only calculate the radiant temperature using the surface temperatures and the respective areas. Therefore, to establish a sound empirical validation of the simulation results, the measured data should be determined in a similar way and reliably representing the real situation.

Using the radiant temperatures determined from measured surface temperatures, the results of the optimized PROMETHEUS model are very close to the measurements. The mean of the radiant temperature calculated deviates less than 0.2 K from the mean of the measured values and the mean of the room temperatures calculated almost exactly matches the measured data ($\Delta t_{R,mean}$ = 0.05 K).

Especially, the implementation of thermal bridges improved PROMETHEUS significantly. Although, considering re-reflection of solar radiation in this case has been fine-tuning rather than remarkable improvement, this effect should not be omitted in general as other rooms to be simulated might have higher heat gains due to solar radiation.

VIII.1.8.References

/1/ Hauser, G.,Stiegel. H.:
Wärmebrückenatlas für den Mauerwerksbau
Bauverlag GmbH, Berlin, Germany

/2/ DIN 1946, Teil 2 : *Raumlufttechnik, Gesundheitstechnische Anforderungen*
Beuth-Verlag, Berlin, Germany

VIII.2.VI.2 Program Proforma

Program name (please include version number)

PROMETHEUS

Your name and organisation

Martin Behne, KLIMASYSTEMTECHNIK

Program status

	Public domain
	Commercial
	Research
●	Other (please specify) The programm has been developed independently by the company

Solution method

	Explicit finite difference
	Implicit finite difference
●	Weighting factors
	Response factors
	Transfer functions
	Other (please specify)

Time step

●	Fixed within code (please specify time step) The time step is one hour
	User-specified (please specify time step)
	Other (please specify)

Timing convention for meteorological data : sampling interval

	Fixed within code (please specify interval)
●	User-specified

Timing convention for meteorological data : period covered by first record

	Fixed within code (please specify period or time which meteorological record covers)
●	User-specified

Meteorological data reconstitution scheme

●	Climate assumed stepwise constant over sampling interval
	Linear interpolation used over climate sampling interval
	Other (please specify)

Output timing conventions

	Produces spot predictions at the end of each time step
●	Produces spot output at end of each hour
	Produces average outputs for each hour (please specify period to which value relates)

Treatment of zone air

●	Single temperature (i.e. good mixing assumed)
	Stratified model
❍	Simplified distribution model
	Full CFD model
	Other (please specify)

Heater (dynamics)

	No dynamics assumed
●	Simple first order dynamics
	Detailed modelling of heat source dynamics

Heaters (output characteristics)

	Purely convective
	Radiative/Convective split fixed within code
●	Radiative/Convective split specified by user
	Detailed modelling of heat source output

Control temperature

	Air temperature
	Combination of air and radiant temperatures fixed within the code
●	User-specified combination of air and radiant temperatures
	User-specified construction surface temperatures
	User-specified temperatures within construction
	Other (please specify)

Control laws

●	Perfect control
	On/Off thermostatic control
❍	On/Off thermostatic control with deadband
	On/Off thermostatic control with accelerator heater
	Proportional control
	More comprehensive control laws (please specify)

Heat transfer within zones

	Radiation and convection combined
●	Radiation and convection treated separately

Convective heat transfer within zones

	Coefficients fixed within code
●	Coefficients specified by user
	Coefficients calculated by code as a function of surface orientation
	Coefficients calculated by code as a function of temperature difference
	Coefficients calculated by code as a function of surface finishes
	Other (please specify)

Longwave radiative heat transfer within zones

	Constant linearised coefficients
●	Linearised coefficients based on viewfactors
●	Linearised coefficients based on surface emissivities
	Non-linear treatment of radiation exchange
	Other (please specify)

Number of nodes placed within each layer of walls and slabs

	Not applicable for this solution method
	Fixed number of nodes per layer (please specify)
●	User-specified number of nodes per layer
	Other (please specify)

Airgaps within walls and slabs

	Resistance fixed within code
●	User-specified constant resistance
	Resistance calculated within code as a function of orientation
	Resistance calculated by code as a function of temperature difference
	Radiation and convection treated separately across airgaps
	Treated as additional zones
	Other (please specify)

Windows (heat loss)

	Fixed resitance used for window element
	Dynamic treatment of window heat loss using same scheme as opaque elements
●	Other (please specify) The hourly heat losses are calculated considering a operable shading device if applicable

Airgaps within windows

	Resistance fixed within code
●	User-specified constant resistance
	Resistance calculated within code as a function of orientation
	Resistance calculated by code as a function of temperature difference
	Radiation and convection treated separately across airgaps
	Treated as additional zones
	Other (please specify)

Windows (transmission of direct shortwave radiation)

	Fixed transmission used
	ASHRAE solar heat coefficients used
●	Calculated by code as a function of incidence angle
	Calculated by code from user-specified function of incidence angle
	Other (please specify)

Windows (transmission of diffuse radiation)

●	Diffuse radiation treated as direct from fixed altitude (please specify) The calculated diffuse radiation is based on the global solar radiation with a solar height of 60 °
	Other (please specify)

Distribution of solar radiation within zones

	Fixed within the code
●	Constant user-specified distribution
●	Calculated once by code and used throughout (please describe algorithm) New feature ! The reflection of solar radiation FROM the room to the ambient is calcutaed by analyzing the viewfactors and surface emissivities. The re-reflection is substracted from the solar radiation.
	Calculated as a function of solar position (please describe algorithm)

Heat transfer between external surfaces and surrounding environment

●	Radiation and convection combined
	Radiation and convection treated separately

External convection

	Coefficients fixed within code
●	User-specified constant coefficients
	Calculated within code as a function of orientation
	Calculated within code as a function of surface finish
	Calculated within code as a function of wind speed
	Calculated within code as a function of wind speed and direction
	Other (please specify)

External radiative heat transfer

●	Assumed to be to ambient temperature
	Assumed to be to sky temperature read from met file
	Based on calculated sky temperature (please specify algorithm and requirements)
	Includes view factor of surrounding obstruction

Diffuse sky model

●	Isotropic
	Other (please specify model used)

IX. M2M - GISE - FRANCE

IX.1. Modellers Report

IEA Task 22

Exercise no 1

Performed with M2mForAllan

Gilles LEFEBVRE

PROBLEMS ENCOUNTERED IN REPRESENTING THE TEST ROOMS WITHIN THE MODEL (KIND OF DIFFICULTIES EXPERIENCED IN DEVELOPING INPUT FILES FOR THE VALIDATION EXERCISES WITH THE PROGRAM).

The main problems were related with the fact that some modelling concepts which are introduced may be impossible to describe in the particular environment under test. Two consequences to this observation : the first one is that you then look for some trick in order to take into account the information which should be at the origin of some discrepancies between the experimental and the simulated results ; the second one is that, whether you develop the environment you are testing, you would like to improve it in order to take advantage of this information.

The other important problem is also very classical in a modelling process. A model includes many parameters which values must be given by the modeller. Some of them were indicated in the documentation, some others no. Among these last ones are the heat exchange coefficients which have a great influence on the simulation results ; it is then very frustrating, in the blind test, to know that the discrepancies between your simulation results and the experimental ones could be reduced only by modifying these values. I insist on the fact that it is a different problem from the one corresponding to the simplification assumptions which are made in a modelling tool because you know what you are neglecting ; in the case of the heat exchange coefficients, it is rather difficult to imagine what should be the “ good ” values to use.

PROBLEMS ENCOUNTERED WITH THE DOCUMENTATION PROVIDED.

The provided documentation was really very well organised for the kind of exercises we had to do. The tedious work consisting in extracting the geometrical measurements, establishing lists of materials, layers, etc. was prepared in order to restrict the modeller work to the essential. The main problem is not specific to this particular exercises. It is related to the formalism of the information. A part of the information is written under a non formalised way which does not allow to apply a systematic review of the document. The modeller must read carefully the document in order to be sure not to forget an essential information hidden in some sentence. We could dream by imagining some formalised grammar which could allow the modeller to express all the information required to describe a problem.

HOW USEFUL WAS THE HOTLINE WHEN NEEDED ?

Good.

WERE ANY BUGS FOUND IN THE MODEL AS A RESULT OF THIS EXERCISE ?

No, sorry.

ODD RESULTS OBTAINED

This kind of exercise shows that simulation tools may leads to rather large discrepancies between different simulations of a same technical object. The results of the simulations performed with our environment are not among the ones which best fit the experimental data. Nevertheless, the different results give indications on the way to follow for improving our tested environment, and then giving it more generality, but preserving its advantages which is its speediness.

IX.2. Program Proforma

Program name (please include version number)

M2mForAllan

Your name and organisation

Gilles LEFEBVRE - Ecole Nationale des Ponts et Chaussées

Program status

●	Public domain
	Commercial
	Research
	Other (please specify)

Solution method

	Explicit finite difference
	Implicit finite difference
	Weighting factors
	Response factors
	Transfer functions
●	Other (please specify) **Modal method (Eigen functions expansion)**

Time step

	Fixed within code (please specify time step)
	User-specified (please specify time step)
●	Other (please specify) **Fixed by the sampling of the input data**

Timing convention for meteorological data : sampling interval

	Fixed within code (please specify interval)
●	User-specified

Timing convention for meteorological data : period covered by first record

	Fixed within code (please specify period or time which meteorological record covers)
	User-specified

Meteorological data reconstitution scheme

	Climate assumed stepwise constant over sampling interval
●	Linear interpolation used over climate sampling interval
	Other (please specify)

Output timing conventions

●	Produces spot predictions at the end of each time step
	Produces spot output at end of each hour
	Produces average outputs for each hour (please specify period to which value relates)

Treatment of zone air

●	Single temperature (i.e. good mixing assumed)
	Stratified model
	Simplified distribution model
	Full CFD model
	Other (please specify)

Heater (dynamics)

●	No dynamics assumed
	Simple first order dynamics
	Detailed modelling of heat source dynamics

Heaters (output characteristics)

●	Purely convective
	Radiative/Convective split fixed within code
	Radiative/Convective split specified by user
	Detailed modelling of heat source output

Control temperature

	Air temperature
	Combination of air and radiant temperatures fixed within the code
	User-specified combination of air and radiant temperatures
	User-specified construction surface temperatures
	User-specified temperatures within construction
	Other (please specify)

Control laws

	Perfect control
	On/Off thermostatic control
	On/Off thermostatic control with deadband
	On/Off thermostatic control with accelerator heater
	Proportional control
	More comprehensive control laws (please specify)

Heat transfer within zones

	Radiation and convection combined
●	Radiation and convection treated separately

Convective heat transfer within zones

	Coefficients fixed within code
●	Coefficients specified by user
	Coefficients calculated by code as a function of surface orientation
	Coefficients calculated by code as a function of temperature difference
	Coefficients calculated by code as a function of surface finishes
	Other (please specify)

Longwave radiative heat transfer within zones

●	Constant linearised coefficients
●	Linearised coefficients based on viewfactors
●	Linearised coefficients based on surface emissivities
❍	Non-linear treatment of radiation exchange
	Other (please specify)

Number of nodes placed within each layer of walls and slabs

	Not applicable for this solution method
●	Fixed number of nodes per layer (please specify) **Default is an automatic meshing of the layers**
❍	User-specified number of nodes per layer
	Other (please specify)

Airgaps within walls and slabs

	Resistance fixed within code
●	User-specified constant resistance
	Resistance calculated within code as a function of orientation
	Resistance calculated by code as a function of temperature difference
	Radiation and convection treated separately across airgaps
	Treated as additional zones
	Other (please specify)

Windows (heat loss)

❍	Fixed resistance used for window element
●	Dynamic treatment of window heat loss using same scheme as opaque elements
	Other (please specify)

Airgaps within windows

	Resistance fixed within code
●	User-specified constant resistance
	Resistance calculated within code as a function of orientation
	Resistance calculated by code as a function of temperature difference
	Radiation and convection treated separately across airgaps
❍	Treated as additional zones
	Other (please specify)

Windows (transmission of direct shortwave radiation)

●	Fixed transmission used
	ASHRAE solar heat coefficients used
	Calculated by code as a function of incidence angle
	Calculated by code from user-specified function of incidence angle
	Other (please specify)

Windows (transmission of diffuse radiation)

	Diffuse radiation treated as direct from fixed altitude (please specify)
●	Other (please specify) **fixed direct and diffuse coefficient**

Distribution of solar radiation within zones

	Fixed within the code
	Constant user-specified distribution
●	Calculated once by code and used throughout (please describe algorithm) The user may specify which percentage of the incoming solar radiation is considered as convective ; the ramaining part is distributed around the connected surfaces proportionnaly to the surfaces and the emissivities.
	Calculated as a function of solar position (please describe algorithm)

Heat transfer between external surfaces and surrounding environment

	Radiation and convection combined
●	Radiation and convection treated separately

External convection

	Coefficients fixed within code
●	User-specified constant coefficients
	Calculated within code as a function of orientation
	Calculated within code as a function of surface finish
	Calculated within code as a function of wind speed
	Calculated within code as a function of wind speed and direction
	Other (please specify)

External radiative heat transfer

●	Assumed to be to ambient temperature
	Assumed to be to sky temperature read from met file
	Based on calculated sky temperature (please specify algorithm and requirements)
	Includes view factor of surrounding obstruction

Diffuse sky model

	Isotropic
	Other (please specify model used)

X. SERI-RES - NREL - UNITED STATES OF AMERICA

X.1. Modellers Report

IEA Task 22, Subtask A3, Empirical Validation Participant Report.

SERIRES/SUNCODE 6.0

National Renewable Energy Laboratory
United States

June 1998

1. Problems encountered in representing the test rooms within the model (kind of difficulties experienced in developing input files for the validation exercises with the program).

- NREL had to customize SERIRES/SUNCODE to get the hourly internal gains schedules (ETNA1) and thermostat setpoints (ETNA2) to be read directly from the external files. This was about a person-week of effort.

- Since SERIRES only allows six layers per wall type, for the internal wall its external air gap and polystyrene were characterized as a single steady-state R-value. Since these are low mass layers, such characterization is reasonable. All other materials were modeled dynamically (thermal mass included), except air gaps which were characterized using steady-state R-values. Also, scheduling window shutters required modeling the window sash as a steady-state opaque window rather than as a dynamic wall; the effect of such a modeling assumption for the window sash should be negligable.

- Since SERIRES must start a simulation with hour 1 (midnite to 1 AM), beginning and ending hours of the data sets provided by EDF were truncated when necessary. This does not affect results comparisons as EDF considered the first four days of ETNA1 data and simulations for initialization and did not consider this initial time period in the results comparisons; presumably, this is also the case for ETNA2.

- The window setback was modeled using overhangs and fins to achieve equivalent shading.

2. Problems encountered with the documentation provided.

The bullet items below summarize questions that came up during the course of developing input decks. The comments are presented in order of decreasing importance (more significant issues on top, minor details at the bottom).

- Since many of the material properties are taken from manufacturer literature, there is some uncertainty regarding the thermal behavior of materials as installed versus as simulated. NREL has developed methods for in-situ determination of whole building overall heat transmission coefficients which could be used to quantify this uncertainty.

- Ground reflectance was not provided.

- For the radiant heater in the MEASURE cell the percentages of internal gains by radiation and convection should be stated.

- For the convective heater in the REFERENCE cell, there should be more detail regarding how the more purely convective source was achieved.

- A brief discussion of the types and arrangement of temperature sensors and control sensors used should be included, especially regarding measurement of air and enclosure temperatures.

- After some discussion EDF suggested that interior solar absorptances should be 0.5 for the concrete floor and 0.2 for the walls and ceiling; this differs from the 0.3 listed in the building specification. This value matters most for the concrete floor.

- To evaluate window conductance we needed to know the types of spacers separating the panes at the window edges.

- Simulated surface heat fluxes and temperatures can vary depending on whether windows and doors related to a given surface are included in the calculations for that surface. The documentation was silent on whether or not to include related windows and doors in these calculations.

- "Total Solar Gain" was not defined.

- A definition of "Mean Radiant Temperature" should be provided.

- Although thermal bridging to attach the ceiling turned out to be insignificant, we did request a sketch to evaluate it.

- It should be clearer that Figure 5.2 represents the test cell floor which separates the basement from the test cell.

- It should be stated that the vent plugs may be modeled using the same materials as the rest or the wall.

- There should be a note with Figure 4.3 of the building specification that all dimensions relate to the inside of the test cell.

3. How useful was the hotline when needed ?

The hotline was very useful. Responses by EDF were prompt and complete. All of the above questions regarding the documentation were resolved via the hotline. Such a hotline is essential for this type of study.

4. Were any bugs found in the model as a result of this exercise ?

No bugs in SERIRES/SUNCODE were found. However, we did use the data to conduct a brief study regarding the effect of interior film coefficients as they relate to fast dynamic response. This is further discussed in Section 6.

5. Odd results obtained (for all programs)

One odd result indicated by EDF in an early draft report (Moinard, Guyon, and Ramdani, 1997) was that, in the ETNA1 experiment, for all the simulations mean air temperature difference is less for the MEASURE cell than for the REFERENCE cell; this is also noticeable to a lesser degree in the SERIRES/SUNCODE zone temperatures for ETNA2. However, we observe the heating load mean differences are less for the REFERENCE cell than for the MEASURE cell in the ETNA2 experiment. Therefore, the relatively large mean difference for ETNA1 air temperatures in the REFERENCE cell versus the MEASURE cell could be because the overall steady-state heat conduction (UAdT) of the test cells is likely higher as installed and measured, than as specified and simulated. Such a situation is consistent with SERIRES/SUNCODE predicting lower heating loads in both test cells. Which is to say that if steady-state response were matching between measured and simulated data in one of the cells (mean difference about zero) then it is possible that both the simulated heating loads and temperatures could show better agreement for that cell than for the other cell. That is, such matching should cause simulated heating load to increase relative to measurements (its currently lower), and simulated free float air temperature to drop relative to measurements (its currently higher). This could be demonstrated by a brief sensitivity study which we recommend for EDF to carry out using CLIM2000.

At the April 1998 experts meeting, other modelers presented similar conclusions that the overall test cell UA is likely higher as built than as specified in the drawings and material specifications.

Another interesting result from EDF's preliminary report on ETNA1 (Moinard, Guyon, and Ramdani, 1997, Tables 11 and 14) is that in general for all the various simulation models the mean difference and standard error for air temperatures relative to both test cells are significantly greater than for the radiant temperatures. A possible reason for this is that in the empirical data one value is more accurately measured/calculated/represented than the other, but its not clear which one. Similarly, it is possible that the definition of one of the measured quantities may more closely match the definition used by the simulations.

6. Results and conclusions from sensitivity studies.

6.1 Interior Film Coefficient Sensitivity Tests

The dynamic response of SERIRES/SUNCODE simulated heating loads and temperatures has good agreement with the empirically measured data in the ETNA test cells for both experiments when typical ASHRAE recommended interior film coefficients are used in the simulations. In comparing the agreement of other participant software with the measured data, adjustment of interior film coefficients resulted in SERIRES dynamic response going from one of the least agreeing programs (with misapplied film coefficients) to one of the most agreeing programs (when using typical ASHRAE recommended film coefficients).

In IEA BESTEST (Judkoff and Neymark, 1995) SERIRES/SUNCODE example results are presented using interior combined film coefficients that were modified to match the IEA BESTEST requirement that the thermostat sense only the air temperature. This modification was to reduce the heat transfer coefficient by an estimated portion attributable to infrared radiative exchange. A sensitivity study described below indicates that simulated dynamic response has much better agreement with the ETNA experimental data when the typical ASHRAE recommended interior film coefficients are applied than when radiative-exchange suppressed interior film coefficients are applied.

For these empirical validation studies we had initially presented data using similar reduced interior film coefficients (Moinard, Guyon, and Ramdani, 1997). However, in the ETNA2 experiment both test cells have thermostats that sense both the air temperature and radiative exchange to surrounding surfaces, so the suppression of the radiant portion of interior film coefficients was initially misapplied. In the ETNA1

MEASURE cell, the heater distributes heat both convectively and radiatively so that again typical ASHRAE film coefficients are more appropriate. However, for the ETNA1 REFERENCE cell it may have been more reasonable to expect the radiative-exchange supressed interior films to provide a better comparison with the empirically measured air temperature, because the heater is intended to be purely convective. However, the sensitivity tests indicate that use of ASHRAE film coefficients gives better agreement with dynamic response. One possible reason for this is that stirring of air in the REFERENCE test cell caused an increase in the convective portion of the interior film coefficient.

To follow up further, we tested the sensitivity of results to numerous variations of interior film coefficients. Such sensitivity tests also relate to the effect of assumptions regarding the thermostat in IEA BESTEST. Sensitivity tests based on ETNA data are summarized in Table 1 and Figures 1 through 3. Figures 1 through 3 show selected SERIRES/SUNCODE simulation results for the ETNA2 experiment REFERENCE cell and ETNA1 experiment REFERENCE cell, and compare them to the appropriate ETNA empirical data. Legend labels for SERIRES results in the figures correspond to case labels of Table 1; "IEA BESTEST" indicates radiant suppression of interior film coefficients per IEA BESTEST (Judkoff and Neymark, p. 2-51). In Table 1, the temperature comparisons are for SERIRES simulated "zone" temperatures versus empirically measured enclosure temperatures. The SERIRES "zone" temperature is the temperature at the thermostat based on an overall zonal energy balance including: convective and radiative exchange with interior surfaces, internal gains to interior air, solar gains to interior air and interior surfaces, etc (Kennedy *et al*). Temperatures shown in Figures 1 through 3 indicate the empirically measured air temperature is usually very close to the empirically measured enclosure temperature except when solar radiation is present (see center portion of Figure 2).

For the ETNA2 experiment, Table 1 indicates the least standard error (best dynamic response agreement) relative to the MEASURE cell heating load data is obtained when interior film coefficients are based on recommendations from the *ASHRAE Handbook of Fundamentals* (ASHRAE, 1997) with no other adjustment. For the REFERENCE cell (see also Figures 1 and 2) the least standard error for the ETNA2 experiment occurs when all the ASHRAE recommended interior film coefficients are increased by 7 or 8 W/m²C (approximately doubled); this could be caused by the stirring of heated air in the test cell, and would be interesting to check with boundary layer air velocity measurements in both test cells.

For the heating loads of ETNA2 the least mean difference (best steady-state agreement) between simulations and empirical data is when the interior film coefficient is increased to the maximum value allowed by SERIRES/SUNCODE ($\approx$ 99 W/m²C) in both the REFERENCE and MEASURE cells. Intuitively, increasing the interior film coefficient in this way implies an unreasonably large internal air flow is occuring inside both test cells which is not the case. It is more reasonable that differences in steady-state heat transfer between simulations and empirical data are due to disagreement regarding conduction through the walls than due to interior film coeficient assumptions. In such a case increasing the interior film coefficient to an extremely high level would cause an increase in mean difference for SERIRES/SUNCODE, which is intuitively more reasonable. A variation in the manufacturer description of material properties versus the behavior of the materials as installed is one possible reason for steady-state disagreement.

The observations regarding using ASHRAE recommended film coefficients for the ETNA1 experiment in Table 1 and Figure 3 are similar to those for the ETNA2 experiment. For the ETNA1 experiment, ASHRAE recommended film coefficients provide results near the least standard error in the both test cells. Additionally, for ETNA1 the empirical air and enclosure temperatures are very close; this seems reasonable because the test cell is well insulated.

It is also apparent for both experiments from Table 1 that use of radiant-exchange supressed interior film coefficients versus ASHRAE recommended interior film coefficients has a greater effect on standard error than on mean difference (when such differences occur) and therefore regarding IEA BESTEST would have a greater effect on dynamic response (peak hour and other hourly results) than on annual performance results. This is consistent with results given in IEA BESTEST (Judkoff and Neymark, p. 2-53.).

Table 1. Interior film coefficient sensitivity test summary
SERIRES/SUNCODE v ETNA Data

ETNA2 Reference Cell		Heating Load		SERIRES "zone" temperature v.		
(Q unknown)		Comparison		ETNA Enclosure Temperature		
Case	Interior Film	Mean	Stderr	Mean	Stderr	
ETN2-B	**iea bestest**	**-41.3**	**68.4**	**-0.07**	**0.73**	
ETN2-N	ashrae -4.5 W/m2C	-54.2	70.9			
ETN2-J	ashrae -4 W/m2C	-51.5	67.0	0.15	0.59	
ETN2-O	ashrae -3.5 W/m2C	-49.3	63.9			
ETN2-G	ashrae -3 W/m2C	-47.3	61.4	0.18	0.54	
ETN2-P	ashrae -2.5 W/m2C	-45.6	59.4			
ETN2-K	ashrae -2 W/m2C	-44.1	57.7	0.20	0.51	
ETN2-C	**ashrae**	**-39.6**	**53.5**	**0.22**	**0.47**	
ETN2-L	ashrae +3 W/m2C	-35.6	50.7	0.23	0.45	
ETN2-H	ashrae +5 W/m2C	-33.8	49.9	0.24	0.45	
ETN2-Q	ashrae +6 W/m2C	-33.0	49.7	0.24	0.45	
ETN2-M	**ashrae +7 W/m2C**	**-32.4**	**49.6**	**0.24**	**0.45**	
ETN2-R	ashrae +8 W/m2C	-31.8	49.6	0.24	0.45	
ETN2-D	ashrae +10 W/m2C	-30.8	49.7	0.24	0.45	
ETN2-I	ashrae +20 W/m2C	-27.8	50.7	0.25	0.47	
ETN2-E	ashrae +30 W/m2C	-26.3	51.7	0.25	0.49	
ETN2-F	**ashrae +90 W/m2C**	**-23.8**	**53.9**	**0.25**	**0.52**	
ETNA2 Measure Cell		Heating Load		SERIRES "zone" temperature v.		
(Q unknown)		Comparison		ETNA Enclosure Temperature		
Case	Interior Film	Mean	Stderr	Mean	Stderr	
ETN2M-B	iea bestest	-42.2	58.9	-0.09	0.89	
ETN2M-S	ashrae -6 W/m2C	-67.8	77.0	-0.22	1.01	
ETN2M-T	ashrae -5 W/m2C	-58.1	66.5			
ETN2M-J	ashrae -4 W/m2C	-52.2	62.0			
ETN2M-G	ashrae -3 W/m2C	-48.2	59.7	0.17	0.73	
ETN2M-K	ashrae -2 W/m2C	-45.1	58.4			
ETN2M-U	ashrae -1 W/m2C	-42.8	57.9			
ETN2M-C	ashrae	-40.9	57.7	0.22	0.67	
ETN2M-V	ashrae +1 W/m2C	-39.9	57.8			
ETN2M-L	ashrae +3 W/m2C	-37.0	58.3	0.23	0.65	
ETN2M-H	ashrae +5 W/m2C	-35.2	59.0	0.24	0.64	
ETN2M-M	ashrae +7 W/m2C	-33.8	59.7	0.24	0.64	
ETN2M-D	ashrae +10 W/m2C	-32.3	61.0	0.25	0.64	
ETN2M-E	ashrae +30 W/m2C	-27.9	65.8	0.26	0.65	
ETN2M-F	ashrae +90 W/m2C	-25.3	69.5	0.26	0.66	
ETNA1 (T unknown)		SRES "Zone" Temp v. ETNA Enclosure Temp				ETNA1
REF Cell		Reference Cell		Measure Cell		MEAS Cell
SRES Case	Interior Film	Mean	Stderr	Mean	Stderr	SRES Case
ETNA25	**iea bestest**	**1.78**	**1.26**	1.41	1.05	ETNM1
ETN1-G	ashrae -3 W/m2C	2.46	0.63	2.06	0.55	ETN1M-G
ETN1-K	ashrae -2 W/m2C	2.26	0.52	1.87	0.50	ETN1M-K
ETN1-U	ashrae -1 W/m2C	2.11	0.46	1.74	0.50	ETN1M-U
ETNA25NJ	**ashrae**	**2.00**	**0.43**	1.63	0.51	ETNM1NJ
ETN1-V	**ashrae +1 W/m2C**	**1.90**	**0.43**	1.54	0.53	ETN1M-V
ETN1-X	ashrae +2 W/m2C	1.83	0.43			ETN1M-X
ETN1-L	ashrae +3 W/m2C	1.76	0.44			ETN1M-L
ETN1-M	ashrae +7 W/m2C	1.58	0.50	1.23	0.64	ETN1M-M
ETN1-E	ashrae +30 W/m2C	1.24	0.64			ETN1M-E
ETN1-F	**ashrae +90 W/m2C**	**1.09**	**0.71**	0.78	0.84	ETN1M-F
Note: Cases hilighted in bold font are plotted on accompanying figures.						

table1, a1..h56; feb 26, 1998

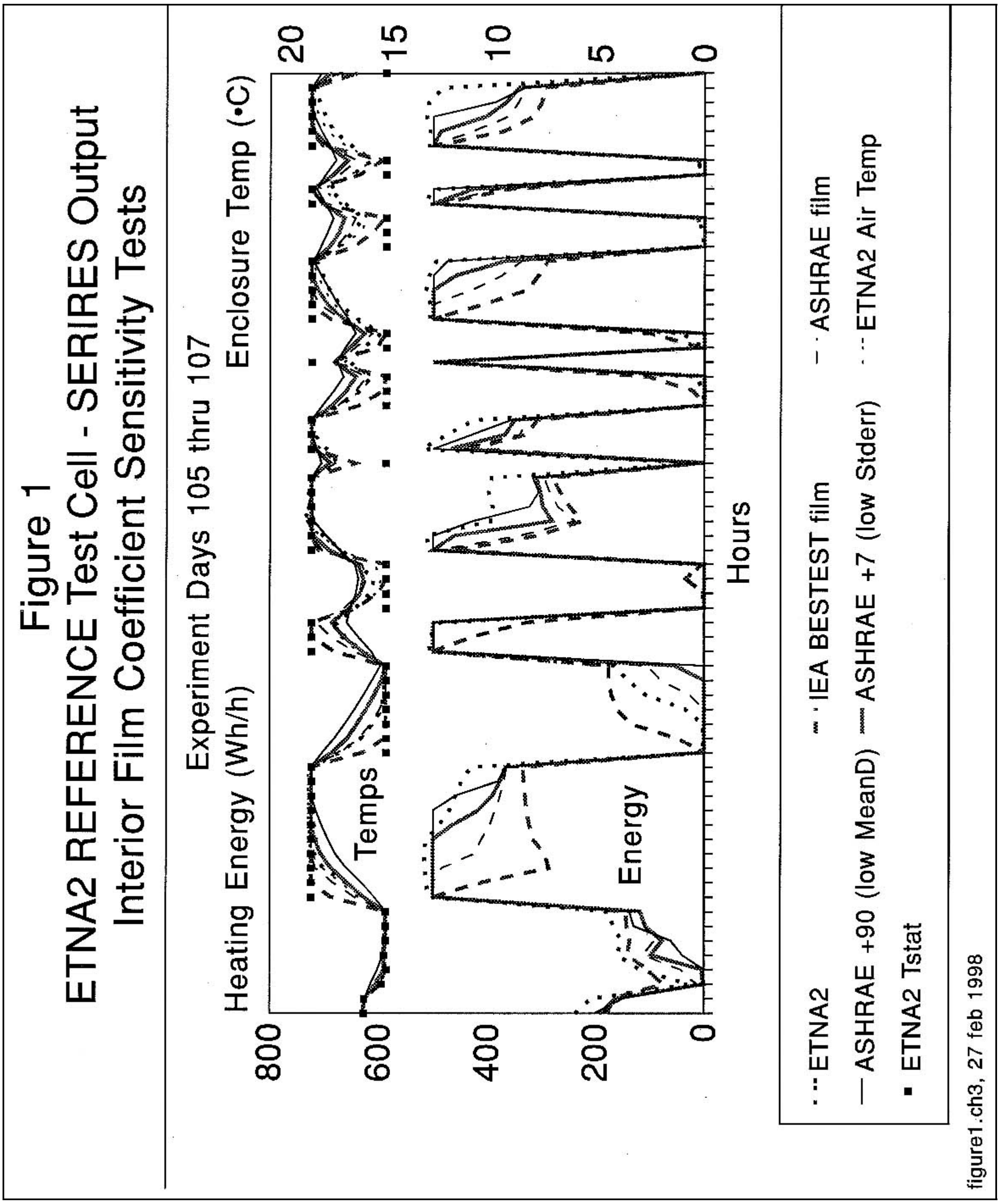


Figure 1
ETNA2 REFERENCE Test Cell - SERIRES Output
Interior Film Coefficient Sensitivity Tests
Experiment Days 105 thru 107
Heating Energy (Wh/h)
Enclosure Temp (•C)
800
600
400
200
0
20
15
10
5
0
Temps
Energy
Hours
ETNA2
IEA BESTEST film
ASHRAE film
ASHRAE +90 (low MeanD)
ASHRAE +7 (low Stderr)
ETNA2 Air Temp
ETNA2 Tstat
figure1.ch3, 27 feb 1998

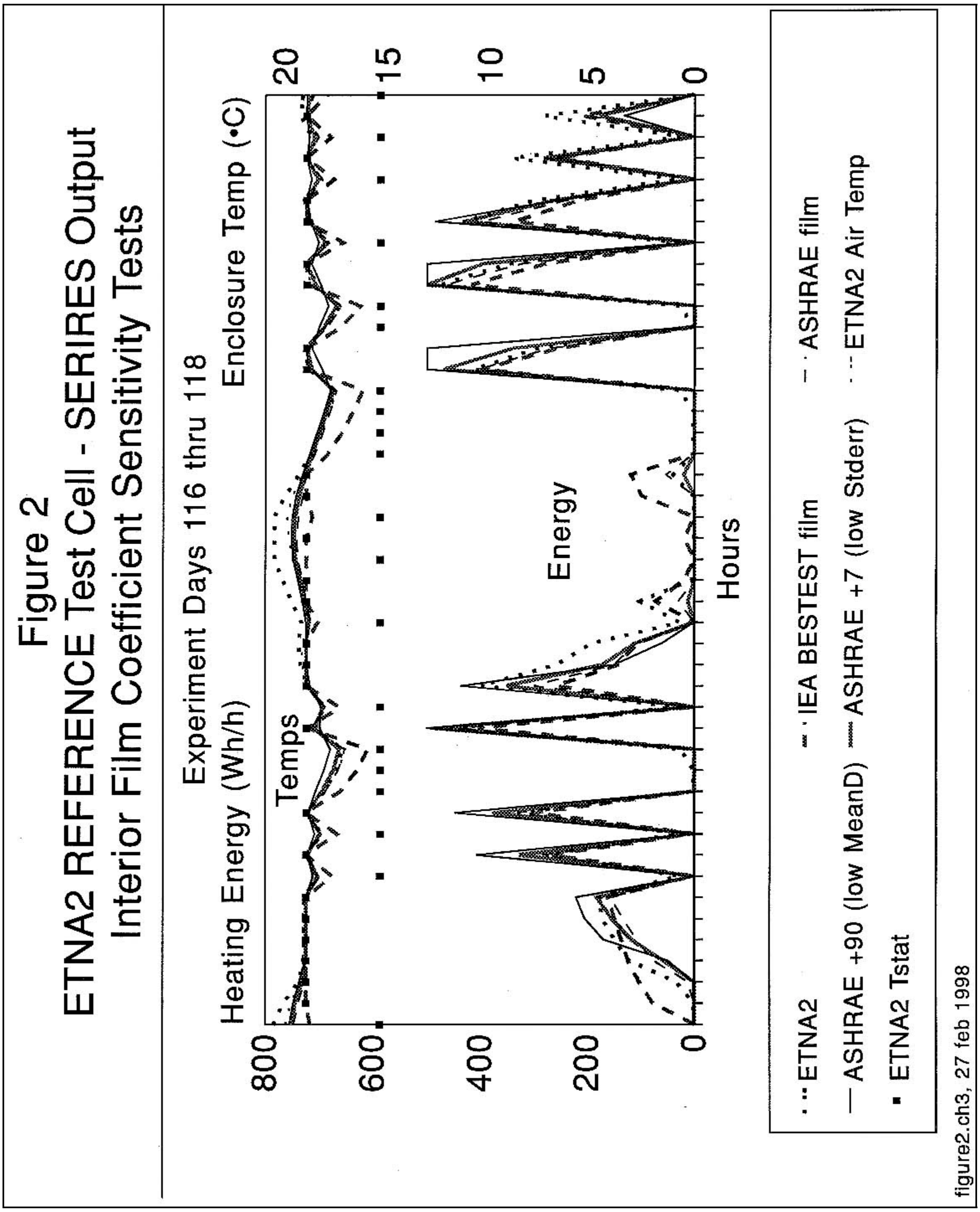


Figure 2
ETNA2 REFERENCE Test Cell - SERIRES Output
Interior Film Coefficient Sensitivity Tests
Experiment Days 116 thru 118
Heating Energy (Wh/h)
Enclosure Temp (•C)
Temps
Energy
Hours
800
600
400
200
0
20
15
10
5
0
ETNA2
IEA BESTEST film
ASHRAE film
ASHRAE +90 (low MeanD)
ASHRAE +7 (low Stderr)
ETNA2 Air Temp
ETNA2 Tstat
figure2.ch3, 27 feb 1998

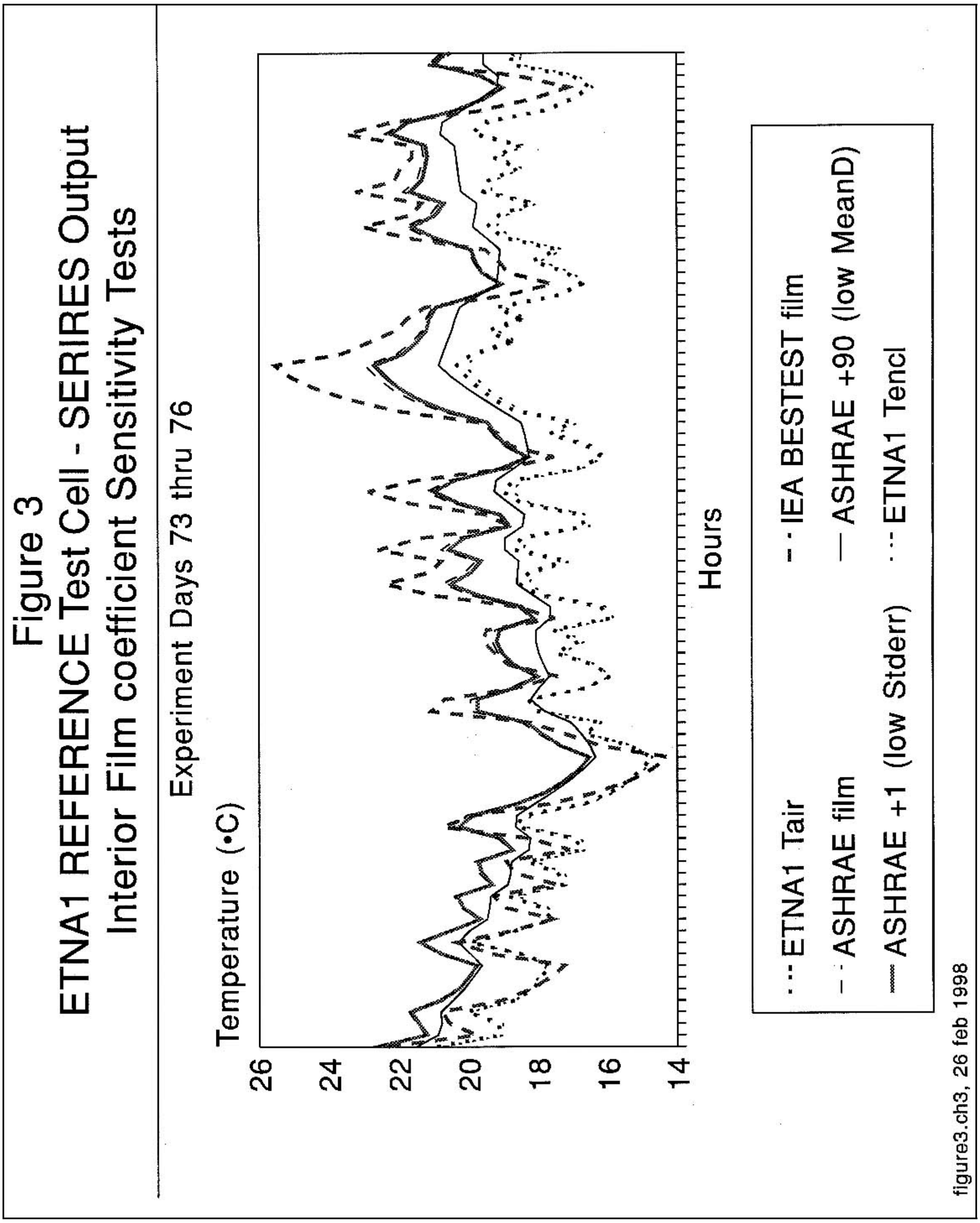


Figure 3
ETNA1 REFERENCE Test Cell - SERIRES Output
Interior Film coefficient Sensitivity Tests
Experiment Days 73 thru 76
Temperature (•C)
26
24
22
20
18
16
14
Hours
ETNA1 Tair
ASHRAE film
ASHRAE +1 (low Stderr)
IEA BESTEST film
ASHRAE +90 (low MeanD)
ETNA1 Tencl
figure3.ch3, 26 feb 1998

Finally, for ETNA1, the dynamic response agreement with measured data for SERIRES went from one of the least agreeing (when using the initially misapplied reduced interior film coefficients - "initial") to one of the most agreeing (when using typical ASHRAE recommended interior film coefficients - "ASHRAE"). This is illustrated in Table 2 below based on participant data presented by EDF in April of 1998 (Moynard, Guyon, and Ramdani, 1998). Additionally from Table 2, dynamic response agreement also improved relative to the other programs for the ETNA 2 experiment.

Table 2. SERIRES Dynamic Response Agreement with Measured Data using STDERR for ETNA 1 and ETNA 2 Versus Other Programs

	ETNA 1 Temperature STDERR		ETNA 2 Heating STDERR	
Software	REF	MES	REF	MES
APA	0.61	0.57	N/A	N/A
AXB	0.69	0.73	206.52	181.13
CLI	0.45	0.50	35.01	49.08
DOE2 (SP)	N/A	N/A	217.17	224.56
DOE2 (SW)	N/A	N/A	62.13	52.25
IDA	0.69	0.42	N/A	N/A
M2M	0.50	0.55	N/A	N/A
PRO	0.59	0.53	N/A	N/A
SER (initial)	**0.75**	**0.65**	**72.20**	**64.49**
SER (ASHRAE)	**0.43**	**0.51**	**53.88**	**57.63**

From these sensitivity tests we can then conclude:

- ASHRAE recommended interior film coefficients are more appropriate to be used for simulations of ETNA test cells than the modified interior film coefficients used for a pure air thermostat in IEA BESTEST. This is reasonable because: the ETNA2 thermostats respond to combined convective and radiative heat transfer, and the heater in the ETNA1 MEASURE cell distributes heat radiatively and convectively.

- Apparently, stirring heated air in the REFERENCE test cell could justify increasing interior film coefficients by roughly a factor of two in models of that test cell. However, more data are needed to verify differences between the appropriate boundary layer air velocities in both test cells, or to otherwise characterize local film coefficients.

- Adjustment of film coefficients and corresponding assumptions regarding thermostats in IEA BESTEST have a much greater effect on dynamic response than steady-state behaviour (see especially curves indicated by "IEA BESTEST film" and "ASHRAE film" in the figures and related statistics in Table 1). These results are consistent with those of IEA BESTEST.

- In comparing the agreement of other participant software with the measured data, adjustment of interior film coefficients resulted in SERIRES dynamic response going from one of the least agreeing programs (with misapplied film coefficients) to one of the most agreeing programs (when using typical ASHRAE recommended film coefficients).

- To be more realistic, future additional test cases for comparative validation procedures which include fast dynamic response tests (e.g. IEA BESTEST cases for thermostat setback/setup) should add the assumption of a more conventional thermostat which senses both radiant exchange and air temperature.

6.2 Preliminary Sensitivity Tests

In the course of setting up the initial ETNA1 REFERENCE cell input deck for SERIRES, a few sensitivity tests were run. These tests were done to determine the importance of inputs where values were assumed, and to compare window modeling techniques. These preliminary tests use the interior film coefficients with the radiant portion suppressed. Case descriptions are listed immediately below.

ETNA13: Base Case

ETNA14: like ETNA13 except opaque surface exterior solar absorptance = 0.9 (= 0.3 in ETNA 13)

ETNA15: like ETNA13 except ground reflectance = 0.9 (= 0.3 in ETNA13)

ETNA18: like ETNA13 except fraction of transmitted solar to floor as pure area weighted (= 0.63 in ETNA13)

ETNA19: like ETNA13 except fraction of transmitted solar to floor = 0.75 (= 0.63 in ETNA13)

ETNA21: like ETNA13 except fraction of transmitted solar to air = 0.05 (= 0.175 in ETNA13)

ETNA23: like ETNA21 except Index of Refraction (IR) and extinction coefficient (K) resulting from EDF's optical properties (ETNA13 uses IR and K resulting from WINDOW4.1 angle dependent optical properties)

ETNA24: like ETNA21 except use CSTB window air gap U-value values (ETNA13 uses WINDOW4.1 air gap U-value)

Table 3: Sensitivity Test Results

Case	Air Temp Mean (°C)	Air Temp Min (°C)	Air Temp Max (°C)	Air Temp Daily Range (°C)
ETNA13	18.80	10.3	27.2	8.5
ETNA14	19.04	10.5	27.7	8.6
ETNA15	19.44	10.7	28.7	8.7
ETNA18	18.82	9.7	29.2	9.5
ETNA19	18.83	10.5	26.7	8.3
ETNA21	18.77	10.3	26.9	8.4
ETNA23	18.71	10.2	26.8	8.4
ETNA24	18.57	10.1	26.6	8.4

In general, sensitivities are negligable (≤ 0.2°C) for:

• opaque surface exterior solar absorptance
• fraction of transmitted solar directly to air
• EDF versus WINDOW 4.1 angle dependent optical properties
• CSTB versus WINDOW 4.1 air gap

Sensitivities (≥ 0.2°C) occur for assumptions regarding:

• ground reflectance (ETNA15 v. ETNA13)
• fraction of transmitted solar absorbed by floor (ETNA18 v. ETNA13).

Of these, transmitted solar absorbed by floor can be well approximated in simulations by ray tracing or other algoritms (e.g. see IEA BESTEST p. F-1). However, variations in ground reflectance can only be approximated from weather data. Although it was clearly stated in response to a question that no snow was present during the test period, an "on/off" for snow could be included with future weather data.

7. References

ASHRAE Handbook of Fundamentals. (1997). Atlanta, Georgia, USA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers; chp. 24.

Judkoff R., and J. Neymark. (1995). *International Energy Agency Building Energy Simulation Test (BESTEST) and Diagnostic Method*. NREL/TP-472-6231. Golden, Colorado, USA: National Renewable Energy Laboratory.

Kennedy M., L. Palmiter, and T. Wheeling. (1992). *SUNCODE-PC Building Load Simulation Program.* Available from Ecotope, Inc., 2812 E. Madison, Seattle, WA, 98112, (206) 322-3753. This software is based on SERIRES 1.0 developed at National Renewable Energy Laboratory, Golden, Colorado. (See also Palmiter *et al.*)

Moinard S., G. Guyon, and N. Ramdani. (October 1997). *Comparison between EDF ETNA test-cell models developed with AxBU, APACHE, CA-SIS, CLIM2000, DOE-2 and SERI-RES; Empirical validation, 2nd RUN, First ETNA Sequence Feb-Mar 1995*. Cedex, France: Laboratoire d"Energetique et de Thermique Industrielle de l'Est Francilien - IUT de Cretéil.

Moinard S., G. Guyon, and N. Ramdani. (April 1998). *Comparison between EDF ETNA and GENEC test-cell models developed with AxBU, APACHE, CA-SIS, CLIM2000, DOE-2, SERI-RES, M2M, IDA and PROMETHEUS; Empirical validation, 3rd and last RUN*. Cedex, France: Laboratoire d"Energetique et de Thermique Industrielle de l'Est Francilien - IUT de Cretéil.

Palmiter L., T. Wheeling, R. Judkoff, B. O'Doherty, D. Simms, and D. Wortman. (1983). *Solar Energy Research Institute Residential Energy Simulator (Version 1.0).* Golden, CO: Solar Energy Research Institute (now National Renewable Energy Laboratory).

X.2. Program Proforma

Program name (please include version number)

SERIRES/SUNCODE 6.0

Your name and organisation

Joel Neymark, NREL

Program status

l	Public domain
l	Commercial
l	Research: *We customized SERIRES/SUNCODE 6.0 for this project to be able to read the detailed heater and thermostat schedules, and to reformat output for easier post-processing.*
l	Other (please specify): *The original SERIRES is public domain. The PC version (SUNCODE) used for this study is commercially available from Ecotope, Seattle, WA.*

Solution method

l	Explicit finite difference
	Implicit finite difference
	Weighting factors
	Response factors
	Transfer functions
	Other (please specify)

Time step

l	Fixed within code (please specify time step): *1 hour*
	User-specified (please specify time step)
	Other (please specify)

Timing convention for meteorological data : sampling interval

l	Fixed within code (please specify interval): *1 hour*
	User-specified

Timing convention for meteorological data : period covered by first record

l	Fixed within code (please specify period or time which meteorological record covers): *0:00-1:00*
	User-specified

Meteorological data reconstitution scheme

l	Climate assumed stepwise constant over sampling interval
	Linear interpolation used over climate sampling interval
	Other (please specify)

Output timing conventions

l	Produces spot predictions at the end of each time step
	Produces spot output at end of each hour
l	Produces average outputs for each hour (please specify period to which value relates): *for entire simulation period*

Treatment of zone air

l	Single temperature (i.e. good mixing assumed)
	Stratified model
	Simplified distribution model
	Full CFD model
	Other (please specify)

Heater (dynamics)

l	No dynamics assumed
	Simple first order dynamics
	Detailed modelling of heat source dynamics

Heaters (output characteristics)

l	Purely convective
	Radiative/Convective split fixed within code
	Radiative/Convective split specified by user
	Detailed modelling of heat source output

Control temperature

l	Air temperature
l	Combination of air and radiant temperatures fixed within the code
	User-specified combination of air and radiant temperatures
	User-specified construction surface temperatures
	User-specified temperatures within construction
	Other (please specify)

Control laws

l	Perfect control
	On/Off thermostatic control
l	On/Off thermostatic control with deadband
	On/Off thermostatic control with accelerator heater
	Proportional control
	More comprehensive control laws (please specify)

Heat transfer within zones

l	Radiation and convection combined
	Radiation and convection treated separately

Convective heat transfer within zones

l	Coefficients fixed within code
l	Coefficients specified by user
	Coefficients calculated by code as a function of surface orientation
	Coefficients calculated by code as a function of temperature difference
	Coefficients calculated by code as a function of surface finishes
	Other (please specify)

Longwave radiative heat transfer within zones

l	Constant linearised coefficients
	Linearised coefficients based on viewfactors
	Linearised coefficients based on surface emissivities
	Non-linear treatment of radiation exchange
l	Other (please specify): *Not treated separately, is part of combined film coefficient.*

Number of nodes placed within each layer of walls and slabs

	Not applicable for this solution method
	Fixed number of nodes per layer (please specify)
l	User-specified number of nodes per layer
	Other (please specify)

Airgaps within walls and slabs

l	Resistance fixed within code
l	User-specified constant resistance
	Resistance calculated within code as a function of orientation
	Resistance calculated by code as a function of temperature difference
	Radiation and convection treated separately across airgaps
	Treated as additional zones
	Other (please specify)

Windows (heat loss)

l	Fixed resitance used for window element
	Dynamic treatment of window heat loss using same scheme as opaque elements
	Other (please specify)

Airgaps within windows

l	Resistance fixed within code
l	User-specified constant resistance
	Resistance calculated within code as a function of orientation
	Resistance calculated by code as a function of temperature difference
	Radiation and convection treated separately across airgaps
	Treated as additional zones
l	Other (please specify): *Air gaps are not disaggregated from the general glzaing properties.*

Windows (transmission of direct shortwave radiation)

l	Fixed transmission used
	ASHRAE solar heat coefficients used
l	Calculated by code as a function of incidence angle
	Calculated by code from user-specified function of incidence angle
	Other (please specify)

Windows (transmission of diffuse radiation)

l	Diffuse radiation treated as direct from fixed altitude (please specify) diffuse treated as 60 degree angle of incidence
	Other (please specify)

Distribution of solar radiation within zones

l	Fixed within the code
l	Constant user-specified distribution
	Calculated once by code and used throughout (please describe algorithm)
	Calculated as a function of solar position (please describe algorithm)

Heat transfer between external surfaces and surrounding environment

l	Radiation and convection combined
	Radiation and convection treated separately

External convection

l	Coefficients fixed within code
l	User-specified constant coefficients
	Calculated within code as a function of orientation
	Calculated within code as a function of surface finish
	Calculated within code as a function of wind speed
	Calculated within code as a function of wind speed and direction
	Other (please specify)

External radiative heat transfer

l	Assumed to be to ambient temperature
	Assumed to be to sky temperature read from met file
	Based on calculated sky temperature (please specify algorithm and requirements)
l	Includes view factor of surrounding obstruction: *Calculation evaluates view to sky dome, does not include fins and overhangs or other surfaces defined by the building.*

Diffuse sky model

l	Isotropic
	Other (please specify model used)