# Empirical Validation of EDF ETNA and GENEC Test-Cell Models

A Report of Task 22
Building Energy Analysis Tools
May 1999

Project A.3 Empirical validation

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T.22.A.3

INTERNATIONAL ENERGY AGENCY
Solar Heating & Cooling Programme

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# PREFACE

# INTRODUCTION TO THE INTERNATIONAL ENERGY AGENCY

## BACKGROUND

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

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

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

## SOLAR HEATING AND COOLING PROGRAM

The Solar Heating and Cooling Program was one of the first IEA Implementing Agreements to be established. Since 1977, its 20 members have been collaborating to advance active solar, passive solar and photovoltaic technologies and their application in buildings.

The members are:

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

A total of 29 Tasks have been initiated, 19 of which have been completed. Each Task is managed by an Operating Agent from one of the participating countries. Overall control of the program rests with an Executive Committee comprised of one representative from each contracting party to the Implementing Agreement. In addition, a number of special ad hoc activities -- working groups, conferences and workshops -- have been organised.

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

**Completed Tasks:**

| | |
|---|---|
| Task 1 | Investigation of the Performance of Solar Heating and Cooling Systems |
| Task 2 | Coordination of Solar Heating and Cooling R&D |
| Task 3 | Performance Testing of Solar Collectors |
| Task 4 | Development of an Insolation Handbook and Instrument Package |
| Task 5 | Use of Existing Meteorological Information for Solar Energy Application |
| Task 6 | Performance of Solar Systems Using Evacuated Collectors |
| Task 7 | Central Solar Heating Plants with Seasonal Storage |
| Task 8 | Passive and Hybrid Solar Low Energy Buildings |
| Task 9 | Solar Radiation and Pyranometry Studies |
| Task 10 | Solar Materials R&D |
| Task 11 | Passive and Hybrid Solar Commercial Buildings |
| Task 12 | Building Energy Analysis and Design Tools for Solar Applications |
| Task 13 | Advance Solar Low Energy Buildings |
| Task 14 | Advance Active Solar Energy Systems |
| Task 16 | Photovoltaics in Buildings |
| Task 17 | Measuring and Modelling Spectral Radiation |
| Task 18 | Advanced Glazing Materials for Solar Applications |
| Task 19 | Solar Air Systems |
| Task 20 | Solar Energy in Building Renovation |

**Current Tasks and Working Groups:**

| | |
|---|---|
| Task 21 | Daylight in Buildings |
| Task 22 | Building Energy Analysis Tools |
| Task 23 | Optimisation of Solar Energy Use in Large Buildings |
| Task 24 | Active Solar Procurement |
| Task 25 | Solar Assisted Air Conditioning of Buildings |
| Task 26 | Solar Combisystems |
| Task 27 | Performance Assessment of Solar Building Components |
| Task 28 | Solar Sustainable Housing |
| Task 29 | Solar Drying in Agriculture |

# TASK 22 : BUILDING ENERGY ANALYSIS TOOLS

### Goal and objectives of the task

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

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

### Scope of the task

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

The audience for the results of the Task is building energy analysis tool developers. However, tool users, such as architects, engineers, energy consultants, product manufacturers, and building owners and managers, are the ultimate beneficiaries of the research, and will be informed through targeted reports and articles.

### Means

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

Subtasks A: Tool evaluation

Subtasks B: Model Documentation

### Participants

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

This report documents work carried out under Subtask A.3, Empirical Validation.

## AKNOWLDEGMENTS

The authors are grateful to all those who participated by running their thermal programs:

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- **Thomas Kretschmer**, **Jianxiong Guo** and **Martin Behne**, KLIMASYSTEMTECHIK (KST), Germany (program PROMETHEUS).
- **Gilles Lefebvre**, GISE, Ecole Nationale des Ponts et Chaussées, France (program M2M for ALLAN). **Elena Palomo** (GISE, ENPC France) for the application of parameter estimation technique to empirical validation exercise (ETNA1).
- **Joel Neymark** and **Ron Judkoff**, NREL, United States (program SERIRES/SUNCODE 6.0).

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# EXECUTIVE SUMMARY

This is a report on the ETNA/GENEC empirical validation project conducted by the International Energy Agency (IEA) Building Energy Analysis Tools Experts Group. The group was composed of experts from the Solar Heating and Cooling (SHC) Programme, Task 22, Subtask A. The objective of this subtask has been to develop practical implementation procedures and data for an overall IEA validation methodology which has been under development since the early 1980s. This report documents empirical validation testing for thermal models related to the architectural fabric of the building. Other projects (reported elsewhere) conducted by this group include work on comparative testing, analytical verification, and other empirical validation tests.

Empirical validation is about comparing the performance of building energy simulation software to real measured data. Therefore, it must be understood that this exercise is a test of the model, the modeler, the test specification and the experiment itself. Because of the expense of acquiring good measured data and the difficulty of matching experimental setups with typical simulation modeling assumptions, empirical validation experiments have been historically more difficult to do than comparative tests and analytical verification tests. Therefore where empirical validation has been successful, it has only covered a very limited number of test cases.

For this project the participating experts agreed that this exercise:

- facilitated improvements to and improved understanding of several of the models,
- pointed out aspects of the models and the experiment that make it difficult for modelers to develop accurate inputs (these points came up during the initial phases of the exercise when simulations were performed "blind", before viewing specific unknown measured data intended for the results comparisons),
- highlighted ways in which future experiments can be improved.

In this empirical validation study predictions from several building energy simulation programs were compared to measured results for three separate experiments. The simulation programs participating in the various studies are listed below, preceded by abbreviations used in this report and including the organization that performed the simulation (and its country).

| | |
|---|---|
| AxBU : | AxBU - Univ Dresden (Germany) ; |
| APA : | APACHE – BRE (UK) ; |
| K6 : | CA-SIS – EDF (France) ; |
| CLIM : | CLIM2000 – EDF (France) ; |
| SP : | DOE-2 - CIEMAT (Spain) ; |
| SW : | DOE-2 - ZTL (Switzerland) ; |
| ICE : | IDA Indoor Climate and Energy - KTH (Finland and Sweden) |
| M2M : | M2M - GISE (France) ; |
| KST : | PROMETHEUS – KlimaSystemTechnik (Germany) ; |
| SER : | SERI-RES - NREL (USA) ; |

The three different experiments are identified as ETNA1, ETNA2 and GENEC. All of the programs listed above participated in the ETNA1 experiment. For ETNA2 all but K6 and M2M participated, and for GENEC all but K6, SW, ICE and SER participated. The experiments are summarized as follows.

## ETNA1 AND ETNA2 EXERCISES

Both the ETNA1 and ETNA2 experiments were conducted at the Electricité de France (EDF) laboratory Essais Thermique en climat Natural ou Artificiel (ETNA test-cells). The configuration of the test facility for these experiments consisted of a building which contains two identically designed and oriented 16 m² test cells separated by and surrounded by three guard zones with an exposed (nominally "south") wall and window facing 30° West of South. In this experiment the test cells are separately identified as "REFERENCE" and "MEASURE" as described below.

For both the ETNA1 and ETNA2 experiments, the primary objective was to compare the influence of energy distribution on the air temperature in the centre of the rooms between :

- an "ideal" purely convective heat source, put in the centre of the "REFERENCE" cell with mechanical stirring of the air (when the source is “ on ”), *for which hypotheses are intended to be close to the model used in most software programs*,
- a realistic traditional electrical convector, located under the south window, without mechanical stirring of the internal air, *as commonly used in France and other European countries*.

The primary difference between the ETNA1 and ETNA2 experiments is that ETNA1 has an "open loop" system and ETNA2 has a "closed loop" system. In the open loop ETNA1 experiment, internal heat gains were varied and the zone temperatures were allowed to float in response. For the ETNA1 validation exercise the IEA participants were initially given relevant experimental data except for the resulting zone temperatures which they were to solve for their simulations. In the ETNA2 closed loop experiment, thermostat setpoints were varied and the heating system responded to meet the setpoints. For the ETNA2 validation exercise, the IEA participants were initially given relevant experimental data except for the resulting heating energy consumptions which they were to solve for in their simulations.

In both validation exercises several rounds of analysis were carried out from April 1997 through October 1998. Before the first round of simulations, the participants were provided with the same validation package (test cells physical descriptions, climate data and boundary conditions). A hot-line was available to answer questions regarding any modelling difficulties or uncertainties. All information were circulated to all participants.

In the first round of analysis participants submitted "blind" results in that they did not initially know the resulting ETNA1 zone temperatures, ETNA2 heating energy consumptions, or any other data measured within the test cells that were not required for developing simulation inputs. After running initial simulations, participants were then sent a full set of measured data including the ETNA1 zone temperatures and ETNA2 heating energy consumptions, and made adjustments to their modeling assumptions and/or fixed modeling algorithms as appropriate, or made no further changes.

Also, in the original experiments other phenomena were studied, such as solar gains (surface incident and transmitted through windows), zone temperature stratification, thermal losses behind the heater, and others. Predictions of such other phenomena by simulation software were compared to measured data where possible.

**ETNA1 Results**

For all the programs, the mean of the difference between simulated and measured temperatures is smaller for the MEASURE test-cell (realistic heat source) than for the REFERENCE test-cell (ideal convector). This indicates that the REFERENCE test cell (pure ideal heating source, with stirring of the indoor air) appears to be more difficult to simulate than expected. Several points could be stated :

- the better agreement for simulation results for the MEASURE test cell (in terms of air and radiant temperature) do not indicate that this test cell is better simulated. It is possible that some physical phenomena or interactions, not taken into account by the modellers, are compensating for the modelling disagreements with measured data ;
- less agreement among results for the REFERENCE cell simulations versus measured data indicates difficulties in describing the simplified indoor physical phenomena, or that the pure convective heater has created some other physical effect that was not created by the realistic heater (e.g. increased surface convection due to air mixing) ;
- the programs have difficulties in predicting the real difference between the South wall surface temperature of the MEASURE and REFERENCE cells.

There were four rounds of simulations in the ETNA1 empirical validation exercise beginning with an initial blind round where the measured results that were to be predicted by the simulations were not known by the participants. In the first round, it was possible to classify the simulation results into two groups : a group of programs giving “ good results ” in terms of air, radiant and operative temperature simulations, and a second group of programs with more disagreement among their results. The second group needed to be improved or checked for input errors.

In the last three rounds, the second group results improved. In the 4$^{th}$ round, they show no significant difference from those in the first group. It is difficult to state what simulation results are the “ best ”; the discrepancies become too small to allow a reliable diagnosis. The higher the number of **non-blind** runs, the better the agreement between the simulations and the measured data. Modelers were required to write modeling reports explaining the changes they made, and the physical reasons for those changes. Legitimate changes had to have a reasonable physical basis. Changes could not be made just to better match the measured data. Several experimental issues identified by modelers are described below.

There was some uncertainty regarding what film coefficients to use because the specification did not indicate the effect of mixing fan on surface heat transfer.Use of typical combined convective and radiative surface (film) coefficients - to account for the heat transfer interaction between zone air and interior surfaces - appears to sufficiently model actual non-ideal heat sources present in this single zone case. However, modeling a purely convective heat source may require some adjustment to typical values of film coefficients or use of a more detailed modeling algorithm depending on air flow rates from the convector. Sensitivity tests with varying interior film coefficients by the SERI-RES (NREL) modelers found that the value for interior film coefficients has an important effect on the modeling of fast dynamics. They found better fast-dynamics agreement between simulated results and measured data for both the MEASURE and REFERENCE cells when using values nearer to those typically recommended in the engineering literature. They found best static agreement when the convective portion of the interior film coefficient was set very high thereby indicating that the overall transmission coefficient may be higher than in the test specification.

It seems that there is a problem related to a difference in overall characteristics (UA-value) of the modelled test cell presented here. Different explanations are given by the participants (some of them disagreed on the potential source of disagreement in terms of overall characteristics). One explanation could be the thermal bridges (not considered in the technical specifications given to the modellers because the cells have been built with the intention of eliminating all thermal bridges). Another could be material properties not correctly defined (difference between given values and reality), and another could be surface coefficients not correctly chosen in relation to experimental conditions. Nevertheless, later studies (see modeller's reports) have indicated a significant impact of thermal bridges (assumption made that improvements could be made by considering thermal bridges). The input for two models have been compensated for this : SW (DOE-2-ZTL) and KST (PROMETHEUS-KlimasystemTechnik). The DOE-2 run from CIEMAT (SP) is uncompensated for this effect, providing some indication of the impact of thermal bridges. The global UA value of the cells should be checked experimentally.

As a final point, three programs have performed this exercise in real "blind" conditions (APACHE-BRE, CA-SIS-EDF and CLIM2000-EDF), without revising their results after their initial first round of blind simulations. Since these simulation results were not significantly different from the other simulation results, it may be concluded that the information provided in the original test procedure package was sufficient for carrying out the validation exercise. Additionally, reasonable agreement between these software and measured results, and indeed between the other software (after modeling assumptions were corrected or algorithms were changed), gives improved confidence in the calculation engines used by building energy simulation software to predict energy use in real buildings.

**ETNA2 Results**

For all the programs the energy consumptions are about 10-30% lower than the measurements in both test cells. This supports the indication of a problem characterizing overall UA-value of the test cells previously noted. For all programs, except for AxBU and SP, the simulated temperatures have close agreement, but are often lower than the measurements during the daytime. For AxBU and SP the temperature results in the day-light period are closer to empirical data, but the free float period (at the end of the experiment) shows these programs are more sensitive to solar radiation than the measured data and the other simulations.

In general, for most of the data, the measurements are more sensitive to solar radiation than the simulation predictions. The similarity in the modelled results for a large group of programs together with differences from measured results suggests that there could be some difference in the experimental sequence or in its regulation which has not been taken into account for the corresponding simulations.

**Consistency between the results of ETNA2 and ETNA1**

**AxBU :** In terms of temperatures, AxBU results for ETNA1 show temperatures higher than empirical data. This is not the case in the ETNA2 sequence during the free float evolution at the end of the sequence. Also for ETNA1 the AxBU temperatures are generally lower than for the other simulations. However for ETNA2, the energy consumption is also lower for AxBU than for the other programs, but the air temperatures are higher than for the other simulations. For AxBU results to be consistent with the other simulations and have consistency between ETNA1 and ETNA2 results (considering the disagreement regarding overall test cell UA identified previously), we should have observed a higher energy consumption for AxBU in ETNA2.

**CLIM :** The results of CLIM2000 for the two sequences are consistent. In ETNA1, the predicted temperatures are higher than the empirical data, and the energy consumption in ETNA2 is lower than empirical data.

**ICE :** For the REFERENCE cell, ICE shows a probable problem of set-point or control (too low set-point).

**SER :** The results of SERI-RES runs are consistent in terms of energy consumption. A lower energy consumption in ETNA2 is consistent with the fact that operative temperatures in ETNA1 are higher than empirical data. In addition, SER consumptions are lower than CLI consumption for ETNA2. This is consistent with the fact that operative temperatures in ETNA1 for SER are higher than CLI operative temperatures in ETNA1.

**APA, KST, SW and SP :** The lower consumption predicted by these simulations in ETNA2 are consistent regarding the higher temperature reached in ETNA1 sequence.

## GENEC EXERCISE

The GENEC test facility located in France (Commissariat à l'Energie Atomique) consists of 7 test cells in outdoor conditions. Three cells were made using sandwich prefabricated walls (Concrete, insulation, concrete) and are called FAI test cells. They were used for testing "solar" building envelope components like windows, solar shading devices or solar walls, or for more fundamental studies (effect of night ventilation, effects of architectural shading devices, radiative floor...). These three test-cells were used simultaneously for comparison tests on different products. The tests presented here were in test-cell 2 (FAI2).
An experiment was carried out in the GENEC test-cell 2 (FAI2) to validate the calculation of solar gains through glazed surfaces. During this experiment, the south wall of the cell and its glazed surfaces were exposed to the natural climate and in **free float** (only solar heating). The ceiling, floor, and all other walls were guarded by maintaining specific temperatures in the neighboring guard-zone spaces (respectively the attic, crawl space and the spaces adjacent to non-exposed walls). For FAI2, there was no air infiltration and the air inside the test-cell was not stirred.

For the GENEC results, one simulation run was performed by the participants, except BRE which performed a second run with APACHE. The different simulation results show less agreement with measured data than for the ETNA1 and ETNA2 experiments, but the simulation results are roughly equivalent with each other. M2M simulation results indicate that the M2M model does not provide enough thermal inertia compared to the measured results and the other simulations.

## FINAL CONCLUSION ABOUT THESE EXERCISES

In the context of making final conclusions, it must again be understood that any empirical validation exercise is a test of the model, the modeler, the test specification, and the experiment itself. As a result of this empirical validation exercise conducted by the IEA SHC Task 22 Participants, the participating experts agreed that the following conclusions can be made:

- ETNA and GENEC test cells and the collected data represent an excellent source for empirical validation of building energy analysis tools. However, some of the participants felt the ETNA data were of higher quality.
- Good initial agreement of ETNA1 blind results with measured data indicates the test specification for the project was well written and the required input data for the simulation programs were well organized.
- With the high level of control of the test-cell variables, it is possible (and desirable) to generate additional measured data for building energy simulation program diagnosis.
- At the end of the exercise, the building energy analysis tools evaluated had good agreement with the measured test-cells' data. Most of the calculation engines studied here can accurately model the interaction of a room exposed to natural climate with a typical French electric heater, and we may have confidence in simulation results that employ such engines. Isolated disagreements for three of the programs, requiring further investigation by their modelers, are noted previously.
- After withheld measured results were released (participants unblinded), many of the participants used the previously unknown measured data to improve their models and modelling assumptions from one round of analysis to the next.
- Algorithmic problems were found and fixed in several simulation models through comparison of the predicted to the measured data, thus leading to improved energy analysis tools.
- The use of multiple simulation models is helpful in evaluating the validity and accuracy of the measured data. Model results and parameter estimation analysis techniques isolated a potential problem with the overall building heat loss coefficient (overall U-value) of the test cells; the resulting U-value determined from the test specification material properties may be too low.
- On the potential problem with the overall U-value of the cells, there are several possible explanations (different explanations are given by the participants, some of them disagreed on the potential source of disagreement in terms of overall characteristics) : material properties given in the test specification may be different from the as-installed properties, there could be undocumented thermal bridges, internal surface heat transfer may be higher due to operation of fans.

As a result of the experiences of the Task 22 Participants in conducting this empirical validation, the following recommendations are made:

- ETNA and GENEC specifications require a more precise definition of measured temperatures and thermostat controls.
- For more detailed models, a need exists to better understand the test-cell electric heaters heat distribution patterns (convection versus radiation). For example, what influence on the interior wall convective surface coefficients does the blower in the heater have ?
- More preliminary experiments to empirically characterize fundamental heat transfer properties of the test cells should be done.
- Further empirical test cell experiments are needed to expand the range of variables (parameters) that can be evaluated versus measured data, and to isolate the validity of specific algorithms applied in the simulation models.

For more information on obtaining the validation test packages, contact :

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# I. FIRST EXPERIMENT : ETNA1

## I.1. Context of the empirical validation

An experiment has been carried out in ETNA test-cells to measure the difference between :

- a purely convective heat source, put in the centre of the room, with stirring of air (when the source is “ on ”), and
- a realistic convector, located under the window, without stirring of the internal air.

The experiment was conducted in natural climate, i.e. the South wall was exposed to solar radiation, and the other surfaces were connected to guard zones.

- In the **“ REFERENCE ”** cell, there was an “ ideal reference heat source ” (ideal source, purely convective), *for which hypotheses are close to the model used in most software programs,*
- In the **“ MEASURE ”** cell, a “ classical electrical convector ” is located under the South window.

The aim of this experiment was to compare the influence of energy distribution on the air temperature in the centre of the rooms, for the realistic convector (no stirring) and the ideal heat source with stirring. Different phenomena were studied such as the losses behind the heater, the stratification, and others.

In this experiment, internal heat gains were varied and the zone temperatures were allowed to float in response. For the empirical validation exercise, the IEA participants were initially given relevant experimental data except for the resulting zone temperatures which they were to solve for in their simulations.

## I.2. Review of the first three rounds on ETNA1

The first three rounds of empirical analyses were carried out in April 97, October 97 and March 98.

In the first round, we analysed the results of ETNA test-cells models developed with the seven following simulation programs : AxBU, APACHE, CA-SIS, CLIM2000, DOE-2, PROMETHEUS and SERI-RES. The results indicated that the AxBU models were very weak, in particular in the modelling of static heat loss (U-value). DOE-2 and SERI-RES underestimated the static heat loss U-values, but this underestimation was smaller than for AxBU. The fast dynamics of the test-cells were poorly predicted by SERI-RES. This was related to an input error regarding the interior surface coefficients ; the fast dynamics problem was later corrected by using the standard ASHRAE-recommended surface coefficients. DOE-2 did not accurately simulate slow dynamics, but more accurately described fast dynamics.

In this 1$^{st}$ analysis, we concluded that the slow dynamics were well predicted for all other programs. CLIM2000 and CA-SIS were judged to have the closest agreement with the experimental data.

For all the programs, the mean deviations between simulations and empirical data were smaller for the MEASURE test-cell (realistic heat source) than for REFERENCE test-cell (ideal convector). It was concluded that the models more accurately simulated the MEASURE test-cell ; this was an unexpected result. None of the programs predicted the heterogeneous surface temperature for the South wall for MEASURE and REFERENCE cell.

In the 2$^{nd}$ round of analysis, 7 program results were analysed (AxBU, APACHE, CA-SIS, CLIM2000, DOE-2-ZTL, PROMETHEUS and SERI-RES).

For the 3$^{rd}$ round of analysis, we analysed the results of 10 simulation programs : AxBU, APACHE, CA-SIS, CLIM2000, SERI-RES, DOE-2 for CIEMAT and ZTL, M2M, PROMETHEUS and ICE. For this comparison, the programs gave more homogeneous results, and in general better results compared to the 1$^{st}$ round. This is due to adjustments or correction of errors after the first analysis (some participants explain these correction in their modellers reports), or some participants providing results using different assumptions, giving results more agreeing with the measurements.

## I.3. Participants of the 4$^{th}$ round of ETNA1

This 4$^{th}$ round was then to compare test-cells models developed with the 9 following programs (used by 10 teams) with the measured data. Table 1 presents the list of the participants of all the rounds of simulation, with the files analysed and presented in the corresponding reports.

In this report, we include only the latest results, which were provided before 10/98. For the teams that provided more than one set of results, discussions are provided in modeller's reports.

| Notation | Program / Contributors | Intermediate report of 04/97 | Intermediate report of 10/97 | Intermediate report of 03/98 | Final report |
|---|---|---|---|---|---|
| AXBU | AxBU<br>Univ. Dresden, Germany | etna_mea.ssx<br>etna_ref.ssx<br>(files of 03/97) | etna_mea.axb<br>etna_ref.axb<br>(files of 09/97) | etna_mea.axb<br>etna_ref.axb<br>(files of 02/98) | Idem |
| APA | APACHE<br>BRE, Great Britain | etna_mea.apa<br>etna_ref.apa<br>(files of 09/95) | Idem | Idem | Idem |
| CA6 | CA-SIS<br>EDF, France | etna_mes.k6<br>etna_ref.k6<br>(files of 03/97) | Idem | Idem | Idem |
| CLIM | CLIM2000<br>EDF, France | etna_mes.clm<br>etna_ref.clm<br>(files of 03/97) | Idem | Idem | Idem |
| SP | DOE-2<br>CIEMAT, Spain | | etna1_me.doe<br>etna1_re.doe<br>(files of 09/97) | etna1_me.doe<br>etna1_re.doe<br>(files of 12/97) | Idem |
| SW | DOE-2<br>ZTL, Switzerland | | gilles_m.prn<br>gilles_r.prn<br>(files of 03/97) | gilles_m.prn<br>gilles_r.prn<br>(files of 12/97) | test1_meas.prn<br>test1_ref.prn<br>(files of 10/98)<br>test1-htg-pwr.prn<br>(file of 03/99) |
| ICE | ICE<br>KTH, Sweden and Finland | | | etna_mea.ice<br>etna_ref.ice<br>(files of 02/98) | etna_mea.ice<br>etna_ref.ice<br>(files of 06/98) |
| M2M | M2M<br>GISE, Marne la Vallée, France | | | measure.m2m.txt<br>reference.m2m.txt<br>(files of 02/98) | Idem |
| KST | PROMETHEUS<br>KlimaSystem-Technik, Germany | *by mistake, the KST blind-test results were not presented although sent on time* | etna_mea.kst<br>etna_ref.kst<br>(files of 03/97) | etna_mea.kst*<br>etna_ref.kst*<br>etna_mea_op.kst**<br>(* files of 03/97)<br>(** file of 03/98) | etna_mea.kst<br>etna_ref.kst<br>(files of 03/97) |
| SER | SERI-RES<br>NREL, USA | etnam1.blg (mea)<br>etna25.blg (ref)<br>(files of 03/97) | et1_mesa.ser<br>et1_refa.ser<br>(files of 09/97) | et1_mesc.ser<br>et1_refc.ser<br>(files of 02/98) | et1_mesd.ser<br>et1_refd.ser<br>(files of 06/98) |

*Table 1 : List of the participants and data sets analysed over the 4 rounds.*

## I.4. The ETNA test-rooms

The E.T.N.A. test cells are a facility of the Research Centre of Electricité de France at Les Renardières site. This is a real size building, including two identical symmetrical cells, surrounded by temperature-conditioned space guards. By use of removable outdoor partitions, the cells can be exposed to a partially or totally artificial climate. A comprehensive description of the test-cells is given in EDF report[1].

[1] P.GIRAULT, Description of ETNA Cells : Physical and geometrical configuration, Internal report EDF HE-14/94/054, Accessibility : Restricted, © EDF-DER 1994.

## I.5. Description of the first stage : open loop system (ETNA 1)

The data used for validation have a duration of 23 days at a 1 hour time step. The experiment started on 25/02/95 (day 56) and ended on 19/03/95 (day 78). No preconditioning period has been offered to modellers.

During this experiment, the cells configuration was as follows :

- guard temperatures controlled at approximately 10°C (actual data were given in separate files) ;
- no air infiltration ;
- pseudo-random heating at a nominal value of 500W ;
- for “ REFERENCE ” cell, the air inside the test-cell was **stirred** (when heating is on) using a fan to guarantee temperature homogenisation and the heating system was assumed to be a pure convective heater ;
- for “ MEASURE ” cell, the air inside the test-cell was **not stirred** and the heating system was a "classical" electrical convector, commonly used in France ;
- no additional thermal mass for the two test-cells.

All data were measured at a 5 minute time step, except global horizontal solar radiation which was measured at 1 minute time step. The data were then averaged over appropriate 1 hour time interval.

The following variables have been measured :

- horizontal global solar radiation ;
- horizontal diffuse solar radiation ;
- global solar radiation on a vertical wall parallel to the glazing (oriented at 30°West from South) ;
- wind speed and direction ;
- relative humidity ;
- ambient air temperature.

The following variables have also been measured in each room :

- heating power ;
- several shielded dry bulb temperature sensors and three black globe temperatures ;
- indoor air temperature was taken as a spatial average of several shielded dry-bulb temperature sensors. Mean radiant temperature was taken using an average of 3 black globe temperature sensors. The operative temperature was taken as the average of the average dry-bulb and the mean radiant temperature.
- two surface temperatures per wall and a surface heat flux per wall. Surface temperatures were taken as the average of the two sensors.

**Note** : When a sensor was judged too sensitive to solar radiation, it was removed.

## I.6. Program results format for ETNA1

Participating teams were asked to supply, for each cell, hourly data regarded as the average over the past hourly period. For this exercise the model output format is given in Table 2.

| | Description | Units |
|---|---|---|
| 1 | Day number | |
| 2 | Hour Number | |
| 3 | External "south" facing vertical radiation flux | W/m² |
| 4 | Global radiation flux behind glazing inside test cell | W/m² |
| 5 | Test cell energy consumption | W |
| 6 | Test cell air temperature | °C |
| 7 | Test cell mean radiant temperature | °C |
| 8 | Test cell operative temperature | °C |
| 9 | Test cell south wall surface temperature | °C |
| 10 | Test cell south wall surface heat flux | W/m² |
| 11 | Test cell west wall surface temperature | °C |
| 12 | Test cell west wall surface heat flux | W/m² |
| 13 | Test cell north wall surface temperature | °C |
| 14 | Test cell north wall surface heat flux | W/m² |
| 15 | Test cell east wall surface temperature | °C |
| 16 | Test cell east wall surface heat flux | W/m² |
| 17 | Test cell ceiling surface temperature | °C |
| 18 | Test cell ceiling surface heat flux | W/m² |
| 19 | Test cell floor surface temperature | °C |
| 20 | Test cell floor surface heat flux | W/m² |

*Table 2 : Output files format.*

***Notes :***

1. Times are assumed to be GMT.
2. The day numbers are given assuming 01/01/95 to be day 1.
3. "South" means 30° West of South.
4. Operative temperature is defined as 0.5 x test-cell air temperature + 0.5 x test-cell mean radiant temperature (see note for SERI-RES results).
5. Heat fluxes should be signed positive outwards.
6. Wall surface data relate to indoor surfaces.
7. All data should represent the data averaged over the preceding hour time step. If a program predicts data in a different manner, the manner must be indicated. If a program is able to predict both data (averaged and instantaneous), both data must be given in two separate files. This detail is particularly important for solar radiation.
8. Where a model cannot predict a temperature (air, radiant or operative), an alternate one can be given in place. Modellers should indicate what is actually supplied. For surfaces data, a zero should be entered in place of the prediction if the data are not supplied.

# I.7. ETNA1 : Preliminary steps

## I.7.1. Choosing the variables to compare

To eliminate the influence of the model preconditioning period, which is often model dependent, but also to compare fully convergent predictions, we assume **96 hours** are necessary to obtain convergence for all models. **Consequently model-data comparison only starts at day 60**.

In the following presentation of results, we refer only to the simulation programs used to analyse the data. The abbreviations used are as follows :

- AxBU : for AxBU - Univ. DRESDEN (Germany) ;
- APA : for APACHE – BRE (UK) ;
- K6 : for CA-SIS – EDF (France) ;
- CLIM : for CLIM2000 – EDF (France) ;
- SP : for DOE-2 - CIEMAT (Spain) ;
- SW : for DOE-2 - ZTL (Switzerland) ;
- ICE : for Indoor Climate & Energy - KTH (Finland and Sweden) ;
- M2M : for M2M - GISE (France) ;
- KST : for PROMETHEUS – KlimaSystemTechnik (Germany) ;
- SER : for SERI-RES - NREL (USA).

The corresponding data and files presented in this report are summarised in Table 1.

## I.7.2. 4th round analysis

### *I.7.2.1 Available data*

**Notation :**

N/A : non available ;

ENERGY : data given is Energy (hourly integrated Power).

**ETNA1 - MEA : 4th AVAILABLE DATA**

| | Global solar flux | Flux inside cell | Heating power | Air temperature | Radiant temperature | Enclosure temperature |
|---|---|---|---|---|---|---|
| APA | | | | | | |
| AxBu | | | | | | |
| Clim | | | | N/A | N/A | |
| K6 | | | | | N/A | N/A |
| ICE | | | | | | |
| M2M | | | N/A | | | |
| KST | | | | | | |
| SP | | | | | N/A | N/A |
| SW | | | | | N/A | N/A |
| SER | | | | N/A | | |
| MEASUREMENTS | | N/A | | | | |

| | South wall temperature | South wall flux | West wall temperature | West wall flux | North wall temperature | North wall flux |
|---|---|---|---|---|---|---|
| APA | | | | | | |
| AxBu | | | | | | |
| Clim | | | | | | |
| K6 | | | | | | |
| ICE | | | | | | |
| M2M | N/A | | | | | |
| KST | N/A | N/A | N/A | N/A | N/A | N/A |
| SP | N/A | N/A | N/A | N/A | N/A | N/A |
| SW | N/A | N/A | N/A | N/A | N/A | N/A |
| SER | | | | | | |
| MEASUREMENTS | | | | | | |

| | East wall temperature | East wall flux | Ceiling temperature | Ceiling flux | Floor temperatrue | Floor flux |
|---|---|---|---|---|---|---|
| APA | | | | | | |
| AxBu | | | | | | |
| Clim | | | | | | |
| K6 | | | | | | |
| ICE | | | | | | |
| M2M | | | | | | |
| KST | N/A | N/A | N/A | N/A | N/A | N/A |
| SP | N/A | N/A | N/A | N/A | N/A | N/A |
| SW | N/A | N/A | N/A | N/A | N/A | N/A |
| SER | | | | | | |
| MEASUREMENTS | | | | | | N/A |

*Table 3 : Output files data checking for the MEASURE test cell.*

**ETNA1 - REF : 4th RUN AVAILABLE DATA**

| | Global solar flux | Flux inside cell | Heating power | Air temperature | Radiant temperature | Enclosure temperature |
|---|---|---|---|---|---|---|
| APA | | | | | | |
| AxBu | | | | | | |
| Clim | | | | N/A | N/A | |
| K6 | | | | | N/A | N/A |
| ICE | | | | | | |
| M2M | | | N/A | | | |
| KST | | | | | | |
| SP | | | | | N/A | N/A |
| SW | | | | | N/A | N/A |
| SER | | | | N/A | | |
| MEASUREMENTS | | N/A | | | | |

| | South wall temperature | South wall flux | West wall temperature | West wall flux | North wall temperature | North wall flux |
|---|---|---|---|---|---|---|
| APA | | | | | | |
| AxBu | | | | | | |
| Clim | | | | | | |
| K6 | | | | | | |
| ICE | | | | | | |
| M2M | | | | | | |
| KST | N/A | N/A | N/A | N/A | N/A | N/A |
| SP | N/A | N/A | N/A | N/A | N/A | N/A |
| SW | N/A | N/A | N/A | N/A | N/A | N/A |
| SER | | | | | | |
| MEASUREMENTS | | | | | | |

| | East wall temperature | East wall flux | Ceiling temperature | Ceiling flux | Floor temperatrue | Floor flux |
|---|---|---|---|---|---|---|
| APA | | | | | | |
| AxBu | | | | | | |
| Clim | | | | | | |
| K6 | | | | | | |
| ICE | | | | | | |
| M2M | | | | | | |
| KST | N/A | N/A | N/A | N/A | N/A | N/A |
| SP | N/A | N/A | N/A | N/A | N/A | N/A |
| SW | N/A | N/A | N/A | N/A | N/A | N/A |
| SER | | | | | | |
| MEASUREMENTS | | | | | | N/A |

*Table 4 : Output files data checking for the REFERENCE test cell.*

#### *I.7.2.2 Validity of the data*

All results are valid, and were included in this exercise of comparison. When energy is given (instead of Power), only integrated values are compared with each other.

### I.7.3. Hourly results

The definitions of these statistics are presented in Table 5 below.

| | | |
|---|---|---|
| **Minimum** | MIN | $X_{MIN} = Min(X_t)$ |
| **Maximum** | MAX | $X_{MAX} = Max(X_t)$ |
| **Mean** | MEAN | $\overline{X} = \sum_{t=1}^{N} X_t / N$ |
| **Difference** | DT | $\mathrm{D_t = X_t - M_t}$<br>$D_t = REF_t - MEA_t$ |
| **Smallest Difference** | DTMIN | $D_{MIN} = Min(D_t)$ |
| **Largest Difference** | DTMAX | $D_{MAX} = Max(D_t)$ |
| **Mean Difference** | MEANDT | $\overline{D} = \sum_{t=1}^{N} D_t / N$ |
| **Absolute Mean Difference** | ABMEANDT | $\left\|\overline{D}\right\| = \sum_{t=1}^{N} \left\|D_t / N\right\|$ |
| **Root Mean Square Difference** | RSQMEANDT | $\sqrt{D^2} = \sqrt{\sum_{t=1}^{N} D_t^2 / N}$ |
| **Standard Error** | STDERR | $\sigma = \sqrt{\frac{1}{N}\sum_{t=1}^{N} (D_t - \overline{D})^2}$ |

*Table 5 : Definition of the calculated statistics.*

where $\mathrm{X_t}$ : predicted value at hour t (for MEASURE or REFERENCE data) ;

$\mathrm{M_t}$ : measurement value at hour t ;

$\mathrm{REF_t}$ : REFERENCE test-cell value at hour t ;

$\mathrm{MEA_t}$ : MEASURE test-cell value at hour t ;

N : total hours in period comparison.

The first six statistics are spot values, and the last four statistics provide measures of the overall agreement between the measurements and the predicted values.

**MEANDT** is the mean deviation between simulation and reference data. It is meaningful while studying static or permanent behaviour.

**STDERR** (Standard deviation) gives a measure of the dispersion of the time series (actually the deviation between simulation and reference data). It discards mean value and remains meaningful only for dynamic behaviour.

**RSQMEANDT** (Root mean square) is the mean of square deviations. It encompasses the measure of dispersion and of mean deviation. It aggregates MEANDT and STDERR in a unique statistic. Its square value can also be regarded as a measure of time series power.

**ABMEANDT** is the mean absolute deviation. It gives similar information to the previous statistic, but with equivalent weighting to all values whereas RSQMEANDT emphasises large values.

***Note for statistical calculations :*** We considered that the dynamic effect due to a difference in the initial conditions of the models was insignificant from day 60 onward (03/01/95). All the presented statistics were calculated from this day.

## I.8. ETNA1 : Data analysis and comparisons for MEASURE and REFERENCE cells

### I.8.1. Solar radiation flux (south facing and vertical)

***Graphical comparison***

The response of the simulations for the solar radiation flux are presented in Figure 1 and Figure 2. The results are exactly the same for REFERENCE and MEASURE test cells.

The ICE calculation showed problems in the previous round (over-predictions). This problem has been checked and solved.

A similar problem for DOE-2 (Spain) has been verified and corrected in the 3rd round, giving more accurate results than for the previous round (Sept. 97).

All programs present simulations in good agreement with measurements.

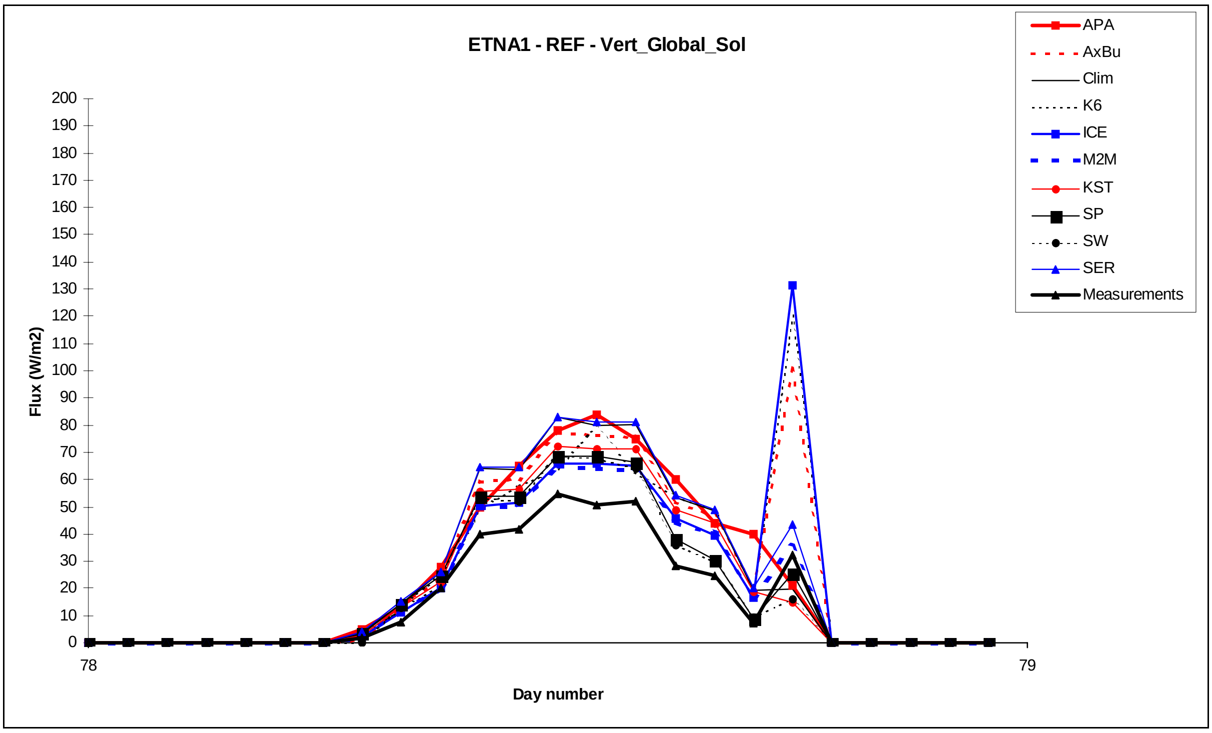


*Figure 1 : Vertical radiation flux for days 78 and 79.*

Note that some programs give larger values at the end of the day, when the sun height is low. These problems are less important than for the two first rounds, but in this case, K6, ICE and AxBU have probably abnormal sensitivity to such low values of the solar altitude. This should be checked and corrected.

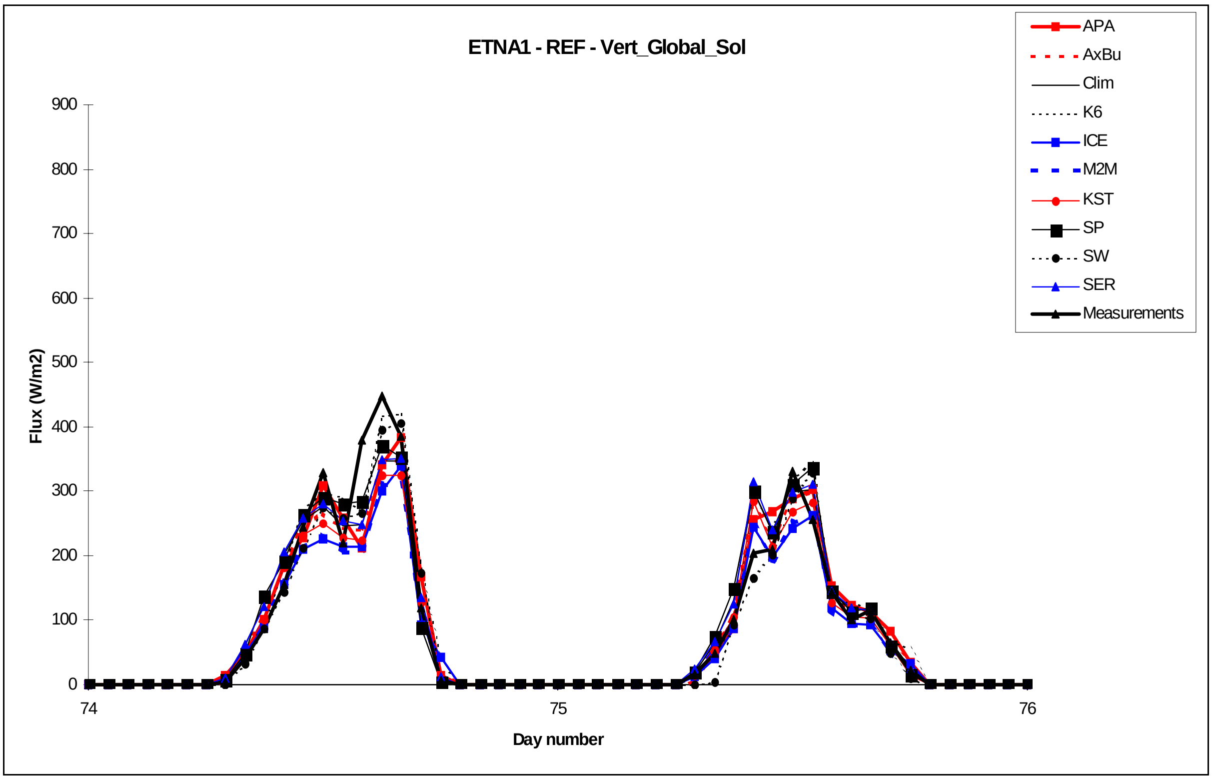


*Figure 2 : Vertical radiation flux for days 74 and 76.*

## *Statistical comparison of the models*

| Global solar flux - MEA | APA | AxBu | Clim | K6 | ICE | M2M | KST | SP | SW | SER | MEAS. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DTMIN | -192.66 | -140.80 | -131.91 | -111.08 | -170.44 | -172.74 | -156.04 | -248.18 | -142.99 | -130.94 | |
| DTMAX | 245.28 | 134.67 | 130.45 | 190.58 | 128.55 | 95.86 | 108.25 | 133.18 | 208.64 | 138.78 | |
| MEANDT | 4.17 | 4.57 | 2.91 | 10.91 | -5.46 | -8.13 | -2.50 | -1.65 | -6.28 | 6.45 | |
| MIN | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -69.85 | 0.00 | 0.00 |
| MAX | 862.00 | 920.61 | 880.75 | 942.80 | 823.03 | 825.69 | 856.29 | 828.56 | 859.95 | 908.90 | 895.88 |
| MEAN | 100.80 | 101.19 | 99.53 | 107.54 | 91.17 | 88.50 | 94.13 | 94.98 | 90.35 | 103.08 | 96.63 |
| AB MEAN DT | 17.60 | 14.97 | 15.65 | 14.96 | 15.95 | 15.00 | 14.27 | 18.26 | 13.42 | 15.77 | |
| SQ MEAN DT | 37.58 | 30.51 | 31.76 | 32.02 | 35.12 | 35.80 | 31.43 | 43.38 | 30.23 | 31.77 | |
| STDERR | 37.39 | 30.20 | 31.66 | 30.13 | 34.73 | 34.91 | 31.36 | 43.40 | 29.60 | 31.14 | |

| Energies in Wh/m2 | APA | AxBu | Clim | K6 | ICE | M2M | KST | SP | SW | SER | MEAS. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Global solar flux | 45965 | 46144.55 | 45387.61 | 49039.44 | 41235.76 | 40354.46 | 42922.78 | 43311.58 | 41200.63 | 47002.5611 | 44062.88 |
| (meas.-sim.)/meas. | -4% | -5% | -3% | -11% | 6% | 8% | 3% | 2% | 6% | -7% | |

*Table 6 : Statistical comparison for the vertical radiation flux calculation (in Wh.m$^{-2}$).*

These results are for the MEASURE test-cell. It is expected that the results for the REFERENCE test-cell are the same. In fact, ICE results for Vert_glob_sol in REFERENCE test-cell show a little difference between MEASURE and REFRENCE cells (total energy is 41235.76 Wh.m$^{-2}$ for REFERENCE, and is 41573.69 Wh.m$^{-2}$ for MEASURE test-cell).

Table 6 confirms the graphical results about the improvement in ICE calculation : the energy (hourly integrated values) is close to the other results.

For M2M calculation, results are lowest (difference of 8% with measurements), and highest for K6 (-11%).

In terms of total energy received by solar radiation, the predictions giving best agreement are given by SP (-2%).

### I.8.2. Solar Flux inside test cell

| Flux inside cell (W/m2) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBu | Clim | K6 | ICE | M2M | KST | SP | SW | SER | MEAS. |
| MIN | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -34.60 | 0.00 | |
| MAX | 610.00 | 562.17 | 577.67 | 513.10 | 538.71 | 825.69 | 530.83 | 518.24 | 564.30 | 626.11 | |
| MEAN | 60.06 | 54.58 | 62.35 | 56.37 | 48.03 | 88.50 | 41.31 | 57.59 | 52.07 | 61.93 | |
| Energies in W.h/m2 | | | | | | | | | | | |
| | APA | AxBu | Clim | K6 | ICE | M2M | KST | SP | SW | SER | Mean of Sim |
| Energy | 27388.00 | 24886.21 | 28433.72 | 25703.53 | 21900.29 | 40354.46 | 18835.89 | 26262.51 | 23745.50 | 28239.88 | 26575.00 |
| Relative difference to the mean of simulation data in % | | | | | | | | | | | |
| | APA | AxBu | Clim | K6 | ICE | M2M | KST | SP | SW | SER | Mean of Sim |
| (Sim.-Mean)/Mear | 3% | -6% | 7% | -3% | -18% | 52% | -29% | -1% | -11% | 6% | 0.00 |

*Table 7 : Statistical comparison for the vertical radiation flux calculation.*

The energies presented in Table 7 show large differences between the different simulations.

For M2M, we can state that the value given as Flux_inside_cell is in fact Vert_glob_sol. This is explained in the modellers report. The " Global radiation flux behind glazing inside test cell " is not available among the outputs of the model. The indicated value is the " External "south" facing vertical radiation flux ".

The mean value for the 10 available simulations is 26575 W.h.m$^{-2}$. As there is no measurement for solar flux inside the test-cell, we compare simulation results to the mean of all results. We define the deviation by $Deviation\% = 100 \cdot \frac{Sim - Mean}{Mean}$. The lowest deviation are given by APA and SP (3% and –1% respectively) and the higher deviation are for KST (-29%).

For KST, this difference for the estimated fluxes inside cells is explained in the modeller's report.

For some programs like K6, the predictions of the vertical global solar radiation are too high for low values of the solar angles (end of the day), and seem to be a little lower elsewhere. This is an interesting example of how compensating errors can achieve an apparently good result.

### I.8.3. Heating power

| Heating power - MEA | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBu | Clim | K6 | ICE | M2M | KST | SP | SW | SER | MEAS. |
| DTMIN | -4.90 | 0.00 | -0.58 | 0.00 | -115.85 | | 0.00 | -0.50 | -0.10 | -0.01 | |
| DTMAX | 5.00 | 0.00 | -0.17 | 0.00 | 15.34 | | 0.00 | 0.50 | 0.10 | 0.01 | |
| MEANDT | -0.88 | 0.00 | -0.39 | 0.00 | 0.23 | | 0.00 | -0.02 | -0.01 | 0.00 | |
| MIN | 0.00 | 2.10 | 1.75 | 2.10 | 2.00 | | 2.10 | 2.00 | 2.20 | 2.11 | 2.10 |
| MAX | 520.00 | 520.60 | 520.25 | 520.60 | 520.92 | | 520.60 | 521.00 | 520.60 | 520.61 | 520.60 |
| MEAN | 239.45 | 240.33 | 239.94 | 240.33 | 240.56 | | 240.33 | 240.31 | 240.33 | 240.33 | 240.33 |
| AB MEAN DT | 2.65 | 0.00 | 0.39 | 0.00 | 2.78 | | 0.00 | 0.27 | 0.02 | 0.01 | |
| SQ MEAN DT | 2.90 | 0.00 | 0.40 | 0.00 | 6.86 | | 0.00 | 0.30 | 0.04 | 0.01 | |
| STDERR | 2.77 | 0.00 | 0.06 | 0.00 | 6.86 | | 0.00 | 0.30 | 0.04 | 0.01 | |
| Energies in Wh/m2 | | | | | | | | | | | |
| Heating power | 109190 | 109592 | 109413 | 109592 | 109696 | | 109592 | 109581 | 109589 | 109592 | 109592 |

*Table 8 : Statistical comparison for the heating power in MEASURE test cell.*

All simulation programs reproduce this entry with a very good accuracy. This is to be expected, because the heating power is an input of the simulations.

## I.8.4. Air temperatures

### *I.8.4.1 MEASURE Cell*

| Air temperature - MEA | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBu | Clim | K6 | ICE | M2M | KST | SP | SW | SER | MEAS. |
| DTMIN | 0.47 | -1.88 | | -1.41 | -0.52 | 0.29 | -0.15 | -0.18 | -2.35 | | |
| DTMAX | 4.17 | 1.59 | | 1.46 | 2.26 | 5.34 | 3.12 | 4.59 | 2.23 | | |
| MEANDT | 1.93 | 0.08 | | 0.17 | 0.98 | 2.55 | 1.61 | 1.64 | 0.40 | | |
| MIN | 13.80 | 12.13 | | 12.67 | 13.38 | 14.58 | 13.50 | 14.00 | 13.40 | | 12.53 |
| MAX | 26.00 | 23.33 | | 22.85 | 23.55 | 27.17 | 24.93 | 25.90 | 22.60 | | 23.53 |
| MEAN | 19.22 | 17.37 | | 17.46 | 18.28 | 19.84 | 18.90 | 18.94 | 17.70 | | 17.30 |
| AB MEAN DT | 1.93 | 0.52 | | 0.48 | 1.00 | 2.55 | 1.61 | 1.64 | 0.69 | | |
| SQ MEAN DT | 2.08 | 0.64 | | 0.61 | 1.10 | 2.63 | 1.79 | 1.85 | 0.85 | | |
| STDERR | 0.78 | 0.64 | | 0.58 | 0.50 | 0.66 | 0.79 | 0.85 | 0.75 | | |

*Table 9 : Statistical comparison of air temperature to measurements for MEASURE test cell.*

Apart from the transient period of 4 days, the established results in Table 9 demonstrate :

- in most cases, all simulations over-estimate the air temperature ;
- two groups are detected :
  - ◊ “ large ” MEANDT for APA, M2M, KST and SP simulations (probably a bad reproduction of static heat losses, due to a low U-Value for the modelled test-cell) ;
  - ◊ “ smaller ” MEANDT for other programs. Note here that the results of SW are better for this round than for the previous.
- a very accurate prediction for static and dynamic response for air temperature for AxBu, K6 and SW.

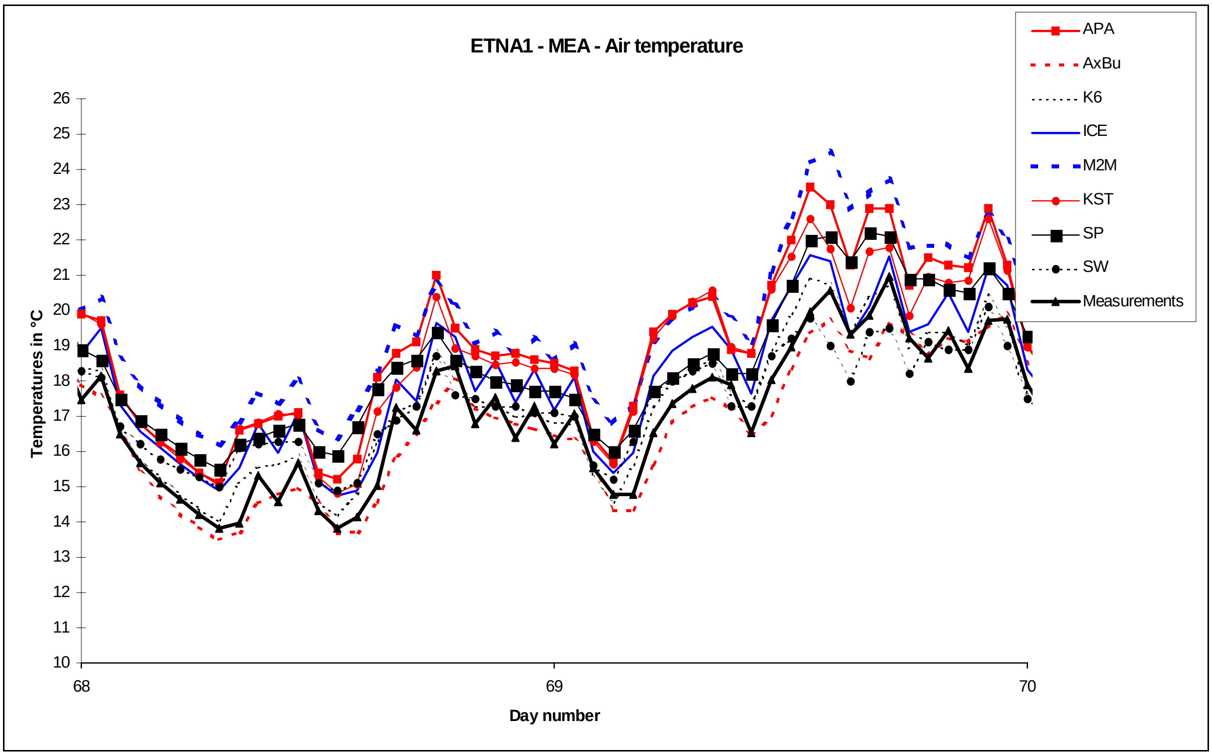


*Figure 3 : Air temperature for MEASURE test cell. ETNA1.*

Note that Figure 3 shows that the very fast dynamics are smoothed by SP and KST simulations. Nevertheless, their STDERR are similar to the other ones.

### *I.8.4.2 REFERENCE Cell*

| Air temperature - REF | APA | AxBu | Clim | K6 | ICE | M2M | KST | SP | SW | SER | MEAS. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DTMIN | 0.62 | -1.58 | | -0.97 | -0.54 | -3.97 | 0.02 | -0.26 | -1.54 | | |
| DTMAX | 5.00 | 1.88 | | 2.12 | 3.68 | 3.27 | 4.17 | 4.51 | 1.88 | | |
| MEANDT | 2.27 | 0.28 | | 0.54 | 1.60 | 1.36 | 2.12 | 1.79 | 0.51 | | |
| MIN | 14.10 | 12.48 | | 13.15 | 13.75 | 14.41 | 13.95 | 15.50 | 13.70 | | 13.08 |
| MAX | 27.50 | 24.40 | | 24.26 | 25.68 | 25.54 | 26.81 | 25.00 | 23.70 | | 23.53 |
| MEAN | 20.13 | 18.13 | | 18.40 | 19.46 | 19.22 | 19.97 | 19.65 | 18.37 | | 17.86 |
| AB MEAN DT | 2.27 | 0.64 | | 0.66 | 1.62 | 1.38 | 2.12 | 1.79 | 0.67 | | |
| SQ MEAN DT | 2.45 | 0.79 | | 0.83 | 1.87 | 1.47 | 2.34 | 2.09 | 0.81 | | |
| STDERR | 0.94 | 0.74 | | 0.63 | 0.97 | 0.55 | 1.01 | 1.09 | 0.63 | | |

*Table 10 : Statistical comparison of air temperature to measurements for REFERENCE test cell.*

The statistics presented in Table 10 show :

- for ICE, the results are less accurate for the REFERENCE cell than for MEASURE cell (see MEANDT and STDERR in tables) ;
- for the other programs, the same conclusion can be stated for REFERENCE cell as for MEASURE cell.

In addition, we conclude that the calculation for all programs are less accurate except M2M. The response for air temperature is more accurate in the case of the MEASURE cell (real heat source) than for REFERENCE cell (including an ideal heat source). The best predictions are given by AxBU and SW (in terms of mean difference).

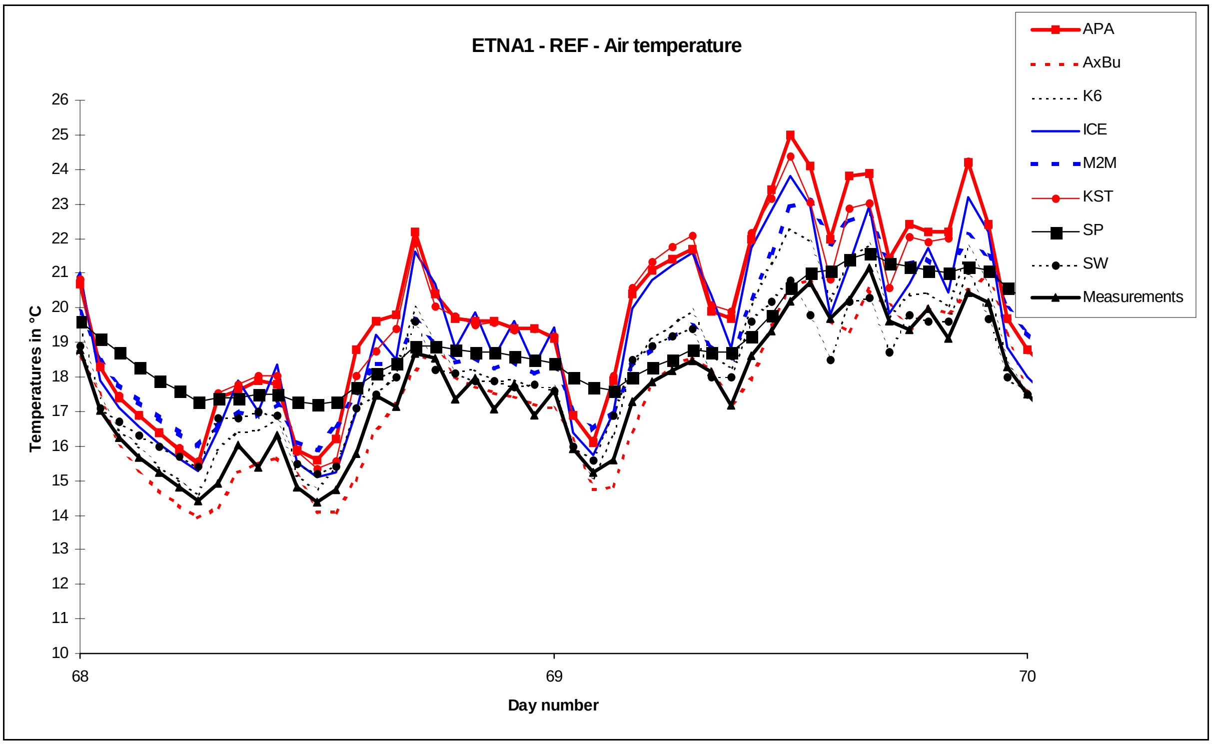


*Figure 4 : Air temperature for REFERENCE test cell. ETNA1.*

## I.8.5. Mean radiant temperatures

### *I.8.5.1 MEASURE Cell*

| Radiant temperature - MEA | APA | AxBu | Clim | K6 | ICE | M2M | KST | SP | SW | SER | MEAS. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DTMIN | -0.93 | -3.66 | | | -2.32 | -0.15 | -1.71 | | | -0.95 | |
| DTMAX | 2.19 | 1.41 | | | 1.34 | 3.08 | 1.50 | | | 2.49 | |
| MEANDT | 1.00 | -0.75 | | | 0.02 | 1.78 | 0.42 | | | 1.23 | |
| MIN | 13.70 | 12.28 | | | 13.38 | 14.56 | 13.49 | | | 14.25 | 12.59 |
| MAX | 23.80 | 21.77 | | | 22.00 | 25.10 | 22.59 | | | 23.42 | 23.87 |
| MEAN | 18.32 | 16.57 | | | 17.33 | 19.10 | 17.73 | | | 18.54 | 17.32 |
| AB MEAN DT | 1.02 | 0.95 | | | 0.49 | 1.78 | 0.59 | | | 1.26 | |
| SQ MEAN DT | 1.13 | 1.19 | | | 0.62 | 1.89 | 0.73 | | | 1.40 | |
| STDERR | 0.52 | 0.92 | | | 0.62 | 0.64 | 0.60 | | | 0.66 | |

*Table 11 : Statistical comparison of mean radiant temperature to measurements for MEASURE test cell.*

The results presented in Table 11 show :

- similar results of mean radiant temperature for all comparable simulations (air temperatures are compared in Table 9 and Table 10) ;
- same results for SER for this 4th round as for the 3rd : less agreement for results in terms of MEANDT, but dynamic behaviour is more accurate (lower value of STDERR) for this round.

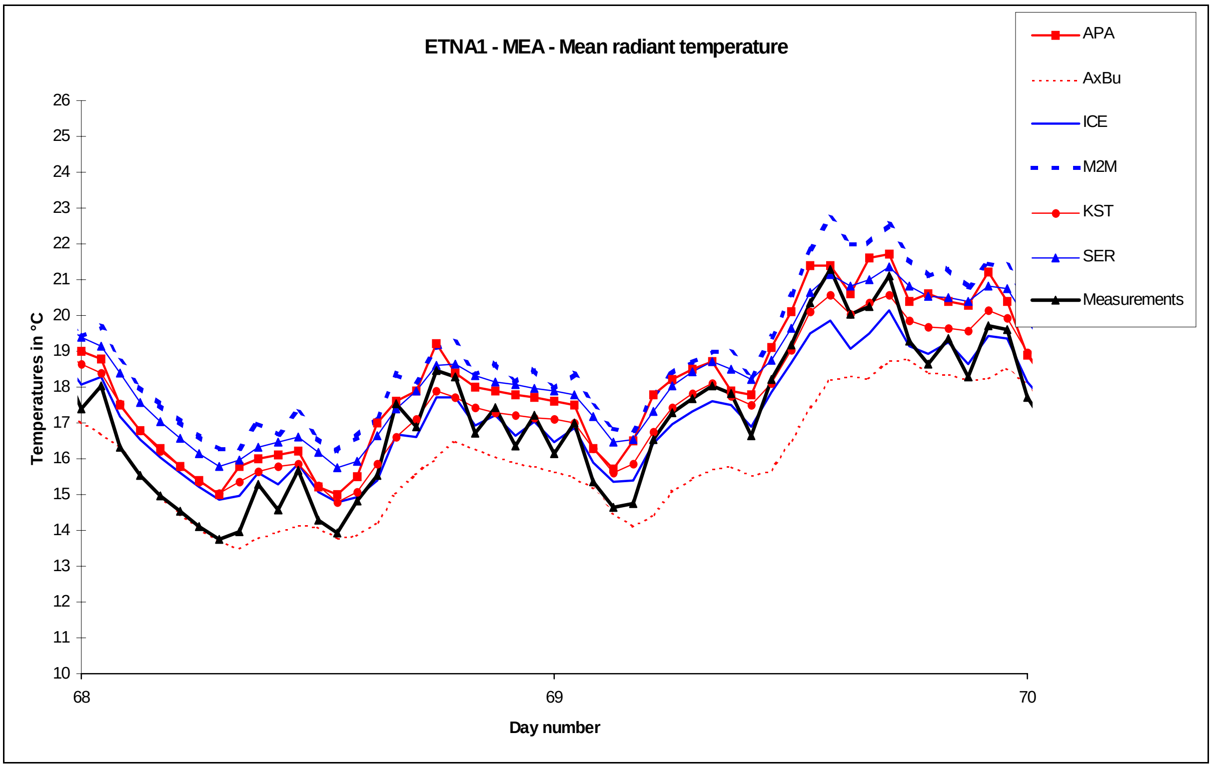


*Figure 5 : Mean radiant temperature for MEASURE test cell. ETNA1.*

### *I.8.5.2 REFERENCE Cell*

| Radiant temperature - REF | APA | AxBu | Clim | K6 | ICE | M2M | KST | SP | SW | SER | MEAS. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DTMIN | 0.10 | -3.11 | | | -1.35 | -3.74 | -0.75 | | | -0.18 | |
| DTMAX | 2.23 | 1.44 | | | 1.18 | 2.26 | 1.78 | | | 2.91 | |
| MEANDT | 1.27 | -0.52 | | | 0.20 | 1.16 | 0.88 | | | 1.71 | |
| MIN | 14.10 | 12.65 | | | 13.71 | 14.38 | 13.94 | | | 14.77 | 13.08 |
| MAX | 24.50 | 22.38 | | | 22.63 | 24.12 | 23.57 | | | 24.40 | 23.71 |
| MEAN | 18.87 | 17.07 | | | 17.80 | 18.75 | 18.47 | | | 19.30 | 17.59 |
| AB MEAN DT | 1.27 | 0.76 | | | 0.41 | 1.18 | 0.90 | | | 1.71 | |
| SQ MEAN DT | 1.34 | 0.95 | | | 0.51 | 1.27 | 0.98 | | | 1.78 | |
| STDERR | 0.41 | 0.80 | | | 0.47 | 0.53 | 0.44 | | | 0.51 | |

*Table 12 : Statistical comparison of mean radiant temperature to measurements for REFERENCE test cell.*

The results presented in Table 12 for REFERENCE show similar results to those for the MEASURE cell, i.e.

– similar results of mean radiant temperature for all comparable simulations
– less good agreement results for SER (see modeller's report).

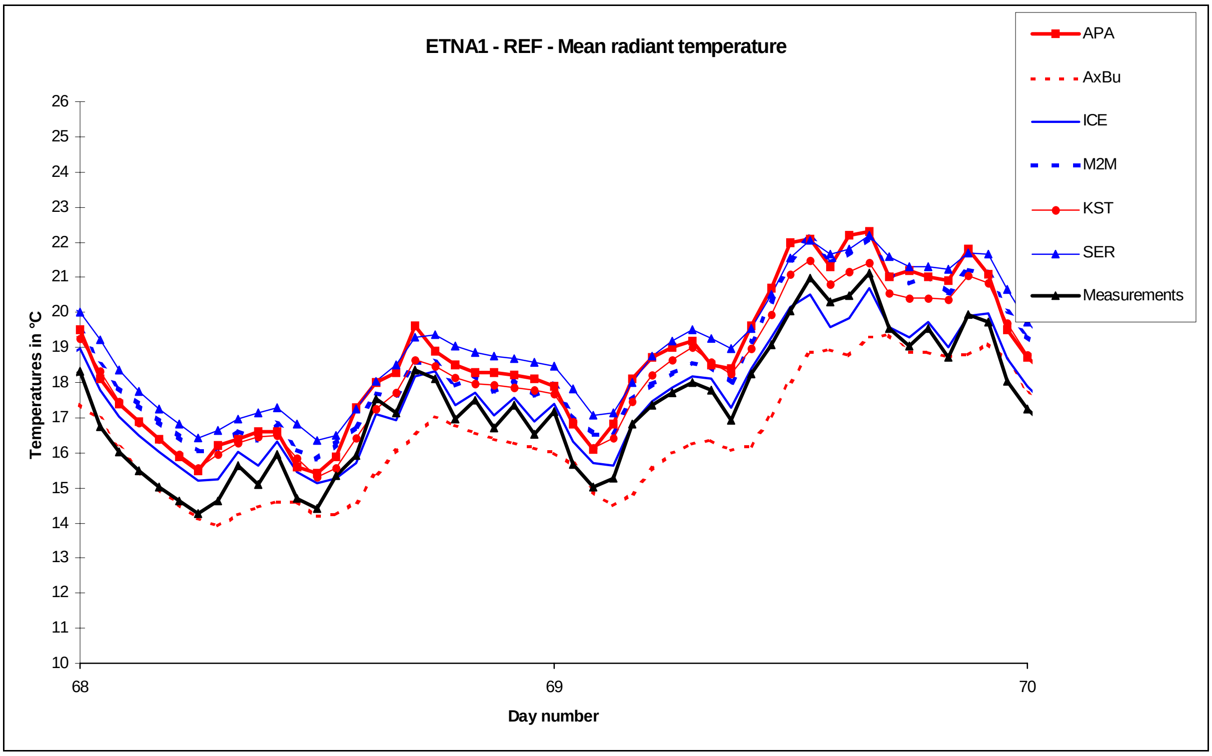


*Figure 6 : Mean radiant temperature for REFERENCE test cell. ETNA1.*

## I.8.6. Operative temperatures

### *I.8.6.1 MEASURE Cell*

| Enclosure temperature - MEA | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBu | Clim | K6 | ICE | M2M | KST | SP | SW | SER | MEAS. |
| DTMIN | 0.11 | -2.77 | -1.53 | | -1.21 | 0.07 | -0.89 | | | -0.20 | |
| DTMAX | 2.78 | 1.41 | 1.43 | | 1.54 | 4.13 | 2.17 | | | 2.85 | |
| MEANDT | 1.47 | -0.34 | 0.56 | | 0.50 | 2.16 | 1.01 | | | 1.63 | |
| MIN | 13.75 | 12.20 | 13.03 | | 13.38 | 14.57 | 13.50 | | | 14.20 | 12.56 |
| MAX | 24.90 | 22.55 | 23.42 | | 22.77 | 26.02 | 23.70 | | | 24.08 | 23.70 |
| MEAN | 18.77 | 16.97 | 17.86 | | 17.81 | 19.47 | 18.32 | | | 18.93 | 17.31 |
| AB MEAN DT | 1.47 | 0.62 | 0.67 | | 0.58 | 2.16 | 1.03 | | | 1.63 | |
| SQ MEAN DT | 1.57 | 0.80 | 0.75 | | 0.67 | 2.23 | 1.14 | | | 1.71 | |
| STDERR | 0.57 | 0.73 | 0.50 | | 0.44 | 0.55 | 0.53 | | | 0.51 | |

*Table 13 : Statistical comparison of operative temperature to measurements for MEASURE test cell.*

The statistics shown in Table 13 show :

– a good estimation for dynamic responses for all simulation programs (STDERR for all the programs are close together ) ;
– two groups are detected :
  ◊ " large " MEANDT for APA, M2M, and SER simulations (probably a bad reproduction of static heat losses, due to a too low U-Value of the modelled test cell, or a higher U-value in the test cell than listed thermal properties would indicate) ;
  ◊ " smaller " MEANDT for other programs.
– a very good agreement for AxBU and ICE, in terms of MEANDT.

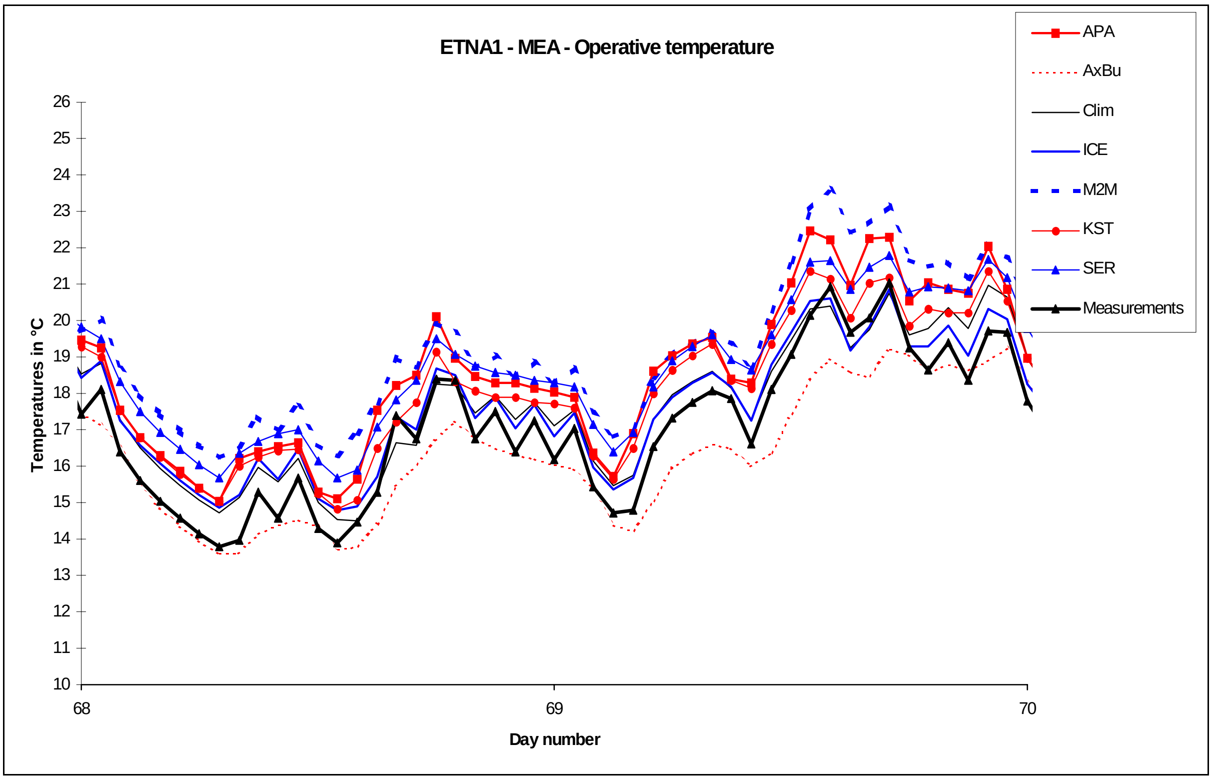


*Figure 7 : Operative temperature for MEASURE test cell. ETNA1.*

### *I.8.6.2 REFERENCE Cell*

| Enclosure temperature - REF | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBu | Clim | K6 | ICE | M2M | KST | SP | SW | SER | MEAS. |
| DTMIN | 0.60 | -2.35 | -1.32 | | -0.82 | -3.86 | -0.24 | | | 0.55 | |
| DTMAX | 3.48 | 1.60 | 1.82 | | 2.12 | 2.71 | 2.68 | | | 3.03 | |
| MEANDT | 1.77 | -0.12 | 0.91 | | 0.90 | 1.26 | 1.50 | | | 2.00 | |
| MIN | 14.10 | 12.56 | 13.55 | | 13.74 | 14.39 | 13.95 | | | 14.72 | 13.08 |
| MAX | 26.00 | 23.39 | 24.59 | | 23.93 | 24.82 | 25.19 | | | 25.30 | 23.62 |
| MEAN | 19.50 | 17.60 | 18.64 | | 18.63 | 18.99 | 19.22 | | | 19.72 | 17.73 |
| AB MEAN DT | 1.77 | 0.57 | 0.94 | | 0.93 | 1.28 | 1.50 | | | 2.00 | |
| SQ MEAN DT | 1.87 | 0.70 | 1.01 | | 1.04 | 1.36 | 1.61 | | | 2.04 | |
| STDERR | 0.61 | 0.69 | 0.45 | | 0.53 | 0.50 | 0.59 | | | 0.43 | |

*Table 14 : Statistical comparison of operative temperature to measurements for REFERENCE test cell.*

The same results are shown in Table 14 for the REFERENCE test cell, and we can add that the statistics show, in general, less accurate results for this cell than for the MEASURE cell, for all programs.

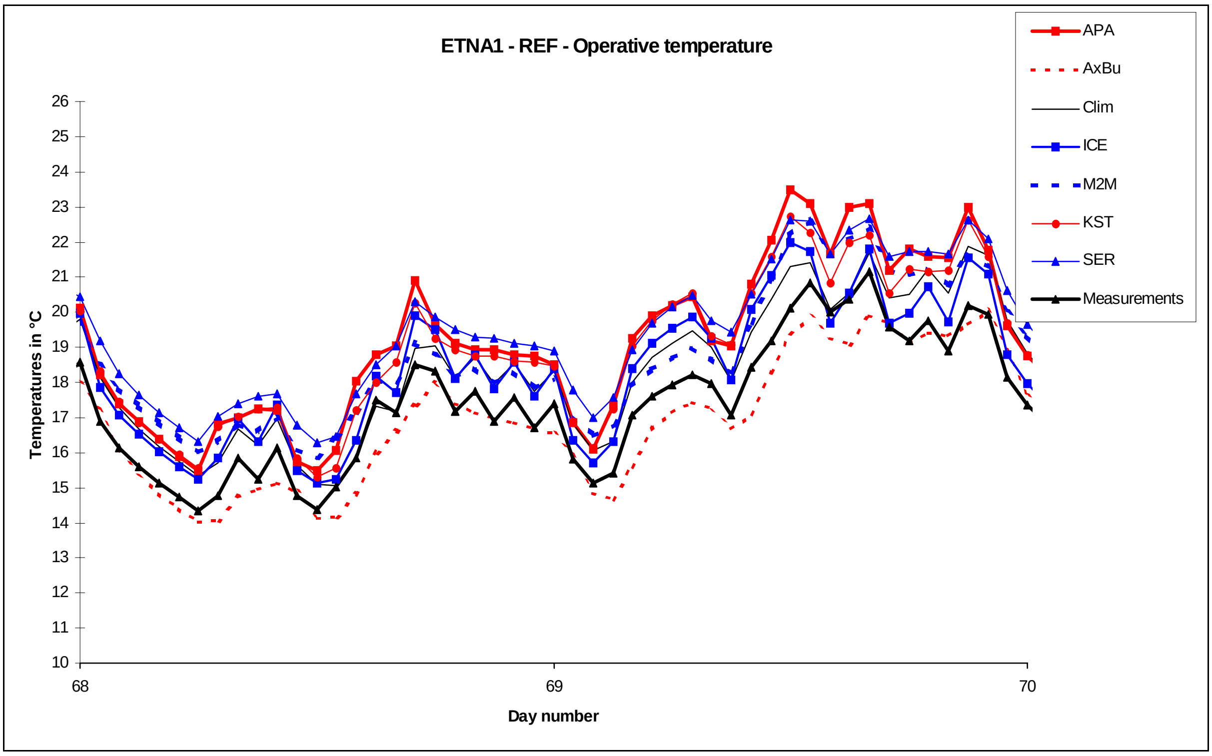


*Figure 8 : Operative temperature for REFERENCE test cell. ETNA1.*

## I.8.7. Surface temperatures

### *I.8.7.1 MEASURE test cell*

| South wall temperature - MEA | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBu | Clim | K6 | ICE | M2M | KST | SP | SW | SER | MEAS. |
| DTMIN | -1.39 | -3.03 | -1.83 | -3.24 | -2.41 | | | | | -0.70 | |
| DTMAX | 4.35 | 1.67 | 1.50 | 1.82 | 1.74 | | | | | 2.61 | |
| MEANDT | 0.87 | -0.91 | -0.06 | -0.68 | -0.23 | | | | | 1.01 | |
| MIN | 13.32 | 11.94 | 12.52 | 12.39 | 12.94 | | | | | 13.74 | 11.42 |
| MAX | 24.85 | 21.55 | 22.86 | 21.65 | 22.25 | | | | | 23.41 | 23.81 |
| MEAN | 18.23 | 16.45 | 17.31 | 16.68 | 17.14 | | | | | 18.37 | 17.36 |
| AB MEAN DT | 1.09 | 1.20 | 0.70 | 1.03 | 0.87 | | | | | 1.11 | |
| SQ MEAN DT | 1.35 | 1.50 | 0.80 | 1.27 | 1.01 | | | | | 1.38 | |
| STDERR | 1.04 | 1.20 | 0.80 | 1.08 | 0.99 | | | | | 0.95 | |

*Table 15 : South wall.*

| West wall temperature - MEA | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBu | Clim | K6 | ICE | M2M | KST | SP | SW | SER | MEAS. |
| DTMIN | 0.76 | -0.87 | -0.02 | -0.60 | 0.51 | 1.27 | | | | 1.80 | |
| DTMAX | 5.24 | 1.85 | 2.28 | 1.97 | 2.05 | 5.49 | | | | 3.51 | |
| MEANDT | 2.28 | 0.55 | 1.45 | 0.62 | 1.31 | 3.10 | | | | 2.63 | |
| MIN | 13.67 | 12.21 | 12.94 | 12.59 | 13.33 | 14.46 | | | | 14.23 | 11.91 |
| MAX | 24.88 | 21.77 | 22.81 | 21.58 | 22.35 | 25.53 | | | | 23.71 | 21.30 |
| MEAN | 18.36 | 16.63 | 17.53 | 16.70 | 17.39 | 19.18 | | | | 18.71 | 16.08 |
| AB MEAN DT | 2.28 | 0.64 | 1.45 | 0.66 | 1.31 | 3.10 | | | | 2.63 | |
| SQ MEAN DT | 2.40 | 0.77 | 1.49 | 0.78 | 1.34 | 3.15 | | | | 2.66 | |
| STDERR | 0.76 | 0.54 | 0.37 | 0.49 | 0.30 | 0.59 | | | | 0.36 | |

*Table 16 : West wall.*

| North wall temperature - MEA | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBu | Clim | K6 | ICE | M2M | KST | SP | SW | SER | MEAS. |
| DTMIN | 0.19 | -1.12 | -0.28 | -0.94 | 0.18 | 1.04 | | | | 1.19 | |
| DTMAX | 5.23 | 1.43 | 1.84 | 1.52 | 1.60 | 4.95 | | | | 2.83 | |
| MEANDT | 1.88 | 0.15 | 1.04 | 0.23 | 0.93 | 2.69 | | | | 2.05 | |
| MIN | 13.64 | 12.32 | 13.03 | 12.64 | 13.45 | 14.51 | | | | 14.13 | 12.52 |
| MAX | 24.87 | 21.46 | 22.65 | 21.38 | 22.06 | 25.34 | | | | 23.30 | 21.39 |
| MEAN | 18.34 | 16.60 | 17.49 | 16.68 | 17.38 | 19.14 | | | | 18.51 | 16.45 |
| AB MEAN DT | 1.88 | 0.44 | 1.04 | 0.43 | 0.93 | 2.69 | | | | 2.05 | |
| SQ MEAN DT | 2.07 | 0.54 | 1.10 | 0.54 | 0.97 | 2.75 | | | | 2.08 | |
| STDERR | 0.86 | 0.52 | 0.38 | 0.49 | 0.30 | 0.59 | | | | 0.33 | |

*Table 17 : North wall.*

| East wall temperature - MEA | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBu | Clim | K6 | ICE | M2M | KST | SP | SW | SER | MEAS. |
| DTMIN | 0.31 | -1.26 | -0.43 | -1.37 | -0.64 | 1.02 | | | | 0.81 | |
| DTMAX | 4.88 | 1.51 | 2.07 | 1.80 | 2.16 | 5.06 | | | | 2.82 | |
| MEANDT | 2.04 | 0.20 | 1.14 | 0.46 | 0.99 | 2.78 | | | | 2.04 | |
| MIN | 13.83 | 12.30 | 13.06 | 12.77 | 13.42 | 14.57 | | | | 14.07 | 12.27 |
| MAX | 25.09 | 21.83 | 22.97 | 21.96 | 22.47 | 25.67 | | | | 23.51 | 21.96 |
| MEAN | 18.54 | 16.71 | 17.65 | 16.97 | 17.50 | 19.29 | | | | 18.55 | 16.51 |
| AB MEAN DT | 2.04 | 0.46 | 1.15 | 0.56 | 0.99 | 2.78 | | | | 2.04 | |
| SQ MEAN DT | 2.17 | 0.57 | 1.22 | 0.68 | 1.07 | 2.84 | | | | 2.07 | |
| STDERR | 0.76 | 0.53 | 0.43 | 0.50 | 0.42 | 0.56 | | | | 0.35 | |

*Table 18 : East wall.*

| Ceiling temperature - MEA | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBu | Clim | K6 | ICE | M2M | KST | SP | SW | SER | MEAS. |
| DTMIN | 0.20 | -1.69 | -0.65 | -1.22 | -0.20 | 0.59 | | | | 0.98 | |
| DTMAX | 4.38 | 1.37 | 1.43 | 1.41 | 1.40 | 4.66 | | | | 2.67 | |
| MEANDT | 1.62 | -0.13 | 0.77 | 0.05 | 0.60 | 2.47 | | | | 1.83 | |
| MIN | 13.75 | 12.24 | 13.02 | 12.71 | 13.47 | 14.55 | | | | 14.19 | 12.38 |
| MAX | 25.28 | 22.17 | 23.15 | 22.04 | 22.51 | 25.97 | | | | 23.86 | 22.51 |
| MEAN | 18.58 | 16.82 | 17.73 | 17.00 | 17.55 | 19.42 | | | | 18.78 | 16.95 |
| AB MEAN DT | 1.62 | 0.49 | 0.79 | 0.39 | 0.61 | 2.47 | | | | 1.83 | |
| SQ MEAN DT | 1.77 | 0.61 | 0.85 | 0.48 | 0.69 | 2.53 | | | | 1.86 | |
| STDERR | 0.71 | 0.60 | 0.34 | 0.48 | 0.33 | 0.56 | | | | 0.33 | |

*Table 19 : Ceiling.*

| Floor temperature - MEA | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBu | Clim | K6 | ICE | M2M | KST | SP | SW | SER | MEAS. |
| DTMIN | 1.85 | 0.07 | 1.03 | -0.45 | 0.63 | 1.63 | | | | 2.29 | |
| DTMAX | 3.59 | 2.93 | 3.86 | 1.18 | 2.14 | 4.07 | | | | 4.11 | |
| MEANDT | 2.63 | 1.05 | 2.08 | 0.45 | 1.50 | 3.08 | | | | 3.03 | |
| MIN | 14.57 | 13.13 | 14.15 | 13.14 | 14.03 | 15.14 | | | | 15.25 | 12.49 |
| MAX | 23.02 | 22.55 | 23.38 | 19.79 | 21.48 | 23.75 | | | | 23.80 | 20.02 |
| MEAN | 18.57 | 16.98 | 18.01 | 16.38 | 17.43 | 19.01 | | | | 18.97 | 15.93 |
| AB MEAN DT | 2.63 | 1.05 | 2.08 | 0.49 | 1.50 | 3.08 | | | | 3.03 | |
| SQ MEAN DT | 2.65 | 1.19 | 2.13 | 0.57 | 1.53 | 3.12 | | | | 3.05 | |
| STDERR | 0.34 | 0.55 | 0.48 | 0.35 | 0.29 | 0.50 | | | | 0.35 | |

*Table 20 : Floor.*

Tables 15 to Table 20 show that, in general, surface temperatures are over-predicted, except for the south wall (only APA and SER over estimate this temperature). In this test cell, the convector is located on the south wall.

These differences on surface temperature predictions are consistent with the hypothesis of thermal bridges in the test cell.

Note that the surface temperature “ measured ” is the mean of two temperatures taken behind the heater and away from the heater. The measurements from the different sensors (not presented here) show that on the south wall, the differences between the sensors reach 8°C.

So, it would be very difficult to state on a “ real surface temperature ”, and to compare it to the surface temperature given by simulation, because one can not simply compare them to a relevant measurement.

If the surface temperatures are higher than reality (measurements), this should result in a radiant temperature often higher than measurements. However, this is not the case for AxBU.

### *I.8.7.2 REFERENCE test cell*

| South wall temperature - REF | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBu | Clim | K6 | ICE | M2M | KST | SP | SW | SER | MEAS. |
| DTMIN | 0.70 | -0.86 | 0.30 | -0.84 | -0.13 | -2.54 | | | | 1.51 | |
| DTMAX | 5.55 | 1.91 | 2.72 | 2.75 | 2.85 | 4.23 | | | | 3.72 | |
| MEANDT | 2.46 | 0.56 | 1.63 | 1.00 | 1.47 | 2.33 | | | | 2.71 | |
| MIN | 13.67 | 12.30 | 13.02 | 12.86 | 13.28 | 14.12 | | | | 14.23 | 11.95 |
| MAX | 25.78 | 22.22 | 23.97 | 22.60 | 23.25 | 24.52 | | | | 24.53 | 21.81 |
| MEAN | 18.87 | 16.97 | 18.04 | 17.41 | 17.89 | 18.74 | | | | 19.12 | 16.41 |
| AB MEAN DT | 2.46 | 0.62 | 1.63 | 1.02 | 1.48 | 2.35 | | | | 2.71 | |
| SQ MEAN DT | 2.60 | 0.76 | 1.69 | 1.16 | 1.56 | 2.39 | | | | 2.74 | |
| STDERR | 0.83 | 0.52 | 0.45 | 0.59 | 0.51 | 0.51 | | | | 0.42 | |

*Table 21 : South wall.*

| West wall temperature - REF | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBu | Clim | K6 | ICE | M2M | KST | SP | SW | SER | MEAS. |
| DTMIN | 0.67 | -1.33 | -0.32 | -0.42 | 0.01 | -2.70 | | | | 1.60 | |
| DTMAX | 5.15 | 1.75 | 2.96 | 2.42 | 2.77 | 3.84 | | | | 4.06 | |
| MEANDT | 2.32 | 0.45 | 1.60 | 0.75 | 1.32 | 2.15 | | | | 2.79 | |
| MIN | 14.02 | 12.57 | 13.46 | 13.08 | 13.63 | 14.32 | | | | 14.73 | 12.74 |
| MAX | 25.81 | 22.39 | 23.94 | 22.53 | 23.29 | 24.55 | | | | 24.75 | 22.01 |
| MEAN | 19.00 | 17.13 | 18.28 | 17.43 | 18.01 | 18.83 | | | | 19.48 | 16.69 |
| AB MEAN DT | 2.32 | 0.58 | 1.60 | 0.78 | 1.32 | 2.16 | | | | 2.79 | |
| SQ MEAN DT | 2.47 | 0.72 | 1.70 | 0.93 | 1.44 | 2.21 | | | | 2.84 | |
| STDERR | 0.86 | 0.57 | 0.60 | 0.55 | 0.56 | 0.51 | | | | 0.50 | |

*Table 22 : West wall.*

| North wall temperature - REF | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBu | Clim | K6 | ICE | M2M | KST | SP | SW | SER | MEAS. |
| DTMIN | 0.33 | -1.22 | -0.26 | -0.69 | 0.24 | -3.01 | | | | 1.26 | |
| DTMAX | 5.48 | 1.50 | 2.34 | 1.89 | 2.15 | 3.78 | | | | 3.36 | |
| MEANDT | 2.03 | 0.17 | 1.28 | 0.45 | 1.10 | 1.85 | | | | 2.31 | |
| MIN | 14.00 | 12.66 | 13.54 | 13.11 | 13.75 | 14.34 | | | | 14.64 | 13.03 |
| MAX | 25.80 | 22.18 | 23.73 | 22.30 | 22.99 | 24.31 | | | | 24.37 | 21.85 |
| MEAN | 18.98 | 17.12 | 18.23 | 17.40 | 18.05 | 18.80 | | | | 19.26 | 16.95 |
| AB MEAN DT | 2.03 | 0.48 | 1.28 | 0.54 | 1.10 | 1.86 | | | | 2.31 | |
| SQ MEAN DT | 2.22 | 0.59 | 1.36 | 0.68 | 1.17 | 1.92 | | | | 2.35 | |
| STDERR | 0.92 | 0.57 | 0.45 | 0.51 | 0.40 | 0.53 | | | | 0.41 | |

*Table 23 : North wall.*

| East wall temperature - REF | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBu | Clim | K6 | ICE | M2M | KST | SP | SW | SER | MEAS. |
| DTMIN | 1.16 | -1.85 | -0.96 | -0.75 | -0.35 | -2.69 | | | | 0.43 | |
| DTMAX | 5.59 | 2.08 | 2.86 | 2.58 | 3.10 | 4.15 | | | | 3.69 | |
| MEANDT | 2.58 | 0.63 | 1.78 | 1.09 | 1.58 | 2.29 | | | | 2.70 | |
| MIN | 14.19 | 12.66 | 13.57 | 13.24 | 13.77 | 14.39 | | | | 14.59 | 12.48 |
| MAX | 26.04 | 22.50 | 24.09 | 22.93 | 23.40 | 24.65 | | | | 24.56 | 21.86 |
| MEAN | 19.20 | 17.24 | 18.40 | 17.71 | 18.20 | 18.91 | | | | 19.32 | 16.62 |
| AB MEAN DT | 2.58 | 0.71 | 1.78 | 1.10 | 1.59 | 2.30 | | | | 2.70 | |
| SQ MEAN DT | 2.70 | 0.87 | 1.85 | 1.21 | 1.66 | 2.35 | | | | 2.73 | |
| STDERR | 0.80 | 0.60 | 0.49 | 0.51 | 0.49 | 0.53 | | | | 0.42 | |

*Table 24 : East wall.*

| Ceiling temperature - REF | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBu | Clim | K6 | ICE | M2M | KST | SP | SW | SER | MEAS. |
| DTMIN | 0.69 | -1.26 | -0.25 | -0.34 | 0.20 | -2.95 | | | | 1.52 | |
| DTMAX | 5.29 | 1.77 | 2.71 | 2.32 | 2.43 | 3.80 | | | | 3.73 | |
| MEANDT | 2.25 | 0.39 | 1.50 | 0.79 | 1.26 | 2.00 | | | | 2.57 | |
| MIN | 14.11 | 12.60 | 13.54 | 13.19 | 13.77 | 14.38 | | | | 14.70 | 12.79 |
| MAX | 26.24 | 22.89 | 24.29 | 23.06 | 23.46 | 24.80 | | | | 24.93 | 22.35 |
| MEAN | 19.24 | 17.38 | 18.49 | 17.77 | 18.25 | 18.99 | | | | 19.56 | 16.99 |
| AB MEAN DT | 2.25 | 0.56 | 1.50 | 0.81 | 1.26 | 2.01 | | | | 2.57 | |
| SQ MEAN DT | 2.40 | 0.71 | 1.59 | 0.95 | 1.33 | 2.06 | | | | 2.60 | |
| STDERR | 0.84 | 0.60 | 0.52 | 0.54 | 0.42 | 0.50 | | | | 0.43 | |

*Table 25 : Ceiling.*

| Floor temperature - REF | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBu | Clim | K6 | ICE | M2M | KST | SP | SW | SER | MEAS. |
| DTMIN | 1.42 | -0.20 | 1.02 | -0.92 | 0.03 | -2.46 | | | | 2.20 | |
| DTMAX | 3.51 | 2.06 | 3.43 | 1.02 | 1.59 | 2.85 | | | | 3.67 | |
| MEANDT | 2.40 | 0.65 | 1.94 | 0.26 | 0.95 | 1.97 | | | | 2.92 | |
| MIN | 15.00 | 13.52 | 14.74 | 13.67 | 14.31 | 14.51 | | | | 15.84 | 13.27 |
| MAX | 23.87 | 23.07 | 24.19 | 20.70 | 21.75 | 23.45 | | | | 24.66 | 21.31 |
| MEAN | 19.22 | 17.47 | 18.76 | 17.08 | 17.77 | 18.79 | | | | 19.74 | 16.82 |
| AB MEAN DT | 2.40 | 0.66 | 1.94 | 0.40 | 0.95 | 1.98 | | | | 2.92 | |
| SQ MEAN DT | 2.44 | 0.81 | 1.98 | 0.48 | 1.00 | 2.01 | | | | 2.94 | |
| STDERR | 0.41 | 0.47 | 0.42 | 0.40 | 0.31 | 0.41 | | | | 0.33 | |

*Table 26 : Floor.*

Tables 21 to Table 26 show that all surface temperatures are over-estimated, with no exception. In this test cell, the “ ideal source ” (a purely convective heat source) is located in the centre of the room, and the air is stirred.

For the REFERENCE cell, as for the MEASURE test cell, the mean radiant temperatures are not systematically over estimated.

### I.8.8. Surface fluxes

#### *I.8.8.1 MEASURE Test cell*

| Energies in Wh/m2 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBu | Clim | K6 | ICE | M2M | KST | SP | SW | SER | MEAS. |
| South wall flux | -2111.50 | 1939.80 | 2307.49 | -2225.87 | 2010.59 | 7269.63 | | | | -2279.48 | 1692.23 |
| West wall flux | -1614.30 | 982.56 | 1388.47 | -1429.67 | 1353.22 | 16398.93 | | | | -965.97 | 1213.67 |
| North wall flux | -1696.40 | 1113.85 | 1541.80 | -1986.47 | 1505.16 | 12489.90 | | | | -1741.87 | 1034.93 |
| East wall flux | -883.70 | 522.29 | 877.93 | -637.48 | 847.94 | 12361.93 | | | | -1584.79 | 897.74 |
| Ceiling flux | -762.02 | 384.72 | 688.83 | -624.31 | 677.05 | 11594.39 | | | | -778.68 | 519.32 |
| Floor flux | -793.96 | -914.36 | 1308.39 | -365.13 | 1255.59 | 16009.32 | | | | -968.48 | |

*Table 27 : Surface fluxes for MEASURE cell.*

#### *I.8.8.2 REFERENCE Test cell*

| Energies in Wh/m2 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBu | Clim | K6 | ICE | M2M | KST | SP | SW | SER | MEAS. |
| South wall flux | -2239.60 | 1939.80 | 2453.60 | -2370.06 | 2156.70 | -9303.89 | | | | -2432.03 | 1670.61 |
| West wall flux | -1738.50 | 982.56 | 1471.29 | -1520.88 | 1541.43 | -15761.89 | | | | -1073.61 | 760.06 |
| North wall flux | -1826.60 | 1113.85 | 1687.34 | -2190.02 | 1630.38 | -12436.57 | | | | -1889.75 | 1081.42 |
| East wall flux | -961.80 | 522.29 | 982.17 | -727.40 | 859.12 | -12195.98 | | | | -1670.65 | 1196.21 |
| Ceiling flux | -820.56 | 384.72 | 756.83 | -692.72 | 736.57 | -11112.36 | | | | -847.61 | 500.07 |
| Floor flux | -868.30 | -914.36 | 1371.76 | -385.28 | 1234.93 | -15639.06 | | | | -1020.08 | |

*Table 28 : Surface fluxes for REFERENCE cell.*

Table 27 and Table 28 show a very large difference for M2M compared to other programs (in absolute value).

As for the measurement of the temperatures, the measurement of heat fluxes on large surfaces is very difficult, and it would be difficult to draw conclusions on these results.

## I.9. Conclusions for ETNA1 Rounds

***Validity of the data***

For this last round, no problems were detected for the data provided, which were all included in this comparison exercise.

For the calculation of the vertical solar radiation, a problem has been detected for ICE simulations (predictions are too high).

***Discussion about the accuracy of the simulations of MEASURE and REFERENCE cells temperature***

For all the programs, the mean of the difference between simulations and measurements is smaller for the MEASURE test-cell (realistic heat source) than for REFERENCE test-cell (ideal convector).

This indicates that the REFERENCE test cell (pure ideal heating source, with stirring of the indoor air) appears to be more difficult to simulate than expected.

Several points could be stated :

- the better agreement for simulation results for the MEASURE test cell (in terms of air and radiant temperature) do not indicate that this test cell is better simulated. It is possible that some physical phenomena or interactions, not taken into account by the modellers, are compensating for the modelling disagreements with measured data ;

- less agreement among results for the REFERENCE cell simulations versus measured data indicates difficulties in describing the simplified indoor physical phenomena, or that the pure convective heater has created some other physical effect that was not created by the realistic heater (e.g. increased surface convection due to air mixing) ;
- the programs have difficulties in predicting the real difference between the South wall surface temperature of the MEASURE and REFERENCE cells.

***Final conclusions for ETNA1***

For all the programs, the mean of the difference between simulated and measured temperatures is smaller for the MEASURE test-cell (realistic heat source) than for the REFERENCE test-cell (ideal convector). This indicates that the REFERENCE test cell (pure ideal heating source, with stirring of the indoor air) appears to be more difficult to simulate than expected. Several points could be stated :

- the better agreement for simulation results for the MEASURE test cell (in terms of air and radiant temperature) do not indicate that this test cell is better simulated. It is possible that some physical phenomena or interactions, not taken into account by the modellers, are compensating for the modelling disagreements with measured data ;
- less agreement among results for the REFERENCE cell simulations versus measured data indicates difficulties in describing the simplified indoor physical phenomena, or that the pure convective heater has created some other physical effect that was not created by the realistic heater (e.g. increased surface convection due to air mixing) ;
- the programs have difficulties in predicting the real difference between the South wall surface temperature of the MEASURE and REFERENCE cells.

There were four rounds of simulations in the ETNA1 empirical validation exercise beginning with an initial blind round where the measured results that were to be predicted by the simulations were not known by the participants. In the first round, it was possible to classify the simulation results into two groups : a group of programs giving “ good results ” in terms of air, radiant and operative temperature simulations, and a second group of programs with more disagreement among their results. The second group needed to be improved or checked for input errors.

In the last three rounds, the second group results improved. In the $4^{th}$ round, they show no significant difference from those in the first group. It is difficult to state what simulation results are the “ best ”; the discrepancies become too small to allow a reliable diagnosis. The higher the number of **non-blind** runs, the better the agreement between the simulations and the measured data. Modelers were required to write modeling reports explaining the changes they made, and the physical reasons for those changes. Legitimate changes had to have a reasonable physical basis. Changes could not be made just to better match the measured data. Several experimental issues identified by modelers are described below.

There was some uncertainty regarding what film coefficients to use because the specification did not indicate the effect of mixing fan on surface heat transfer.Use of typical combined convective and radiative surface (film) coefficients - to account for the heat transfer interaction between zone air and interior surfaces - appears to sufficiently model actual non-ideal heat sources present in this single zone case. However, modeling a purely convective heat source may require some adjustment to typical values of film coefficients or use of a more detailed modeling algorithm depending on air flow rates from the convector. Sensitivity tests with varying interior film coefficients by the SERI-RES (NREL) modelers found that the value for interior film coefficients has an important effect on the modeling of fast dynamics. They found better fast-dynamics agreement between simulated results and measured data for both the MEASURE and REFERENCE cells when using values nearer to those typically recommended in the engineering literature. They found best static agreement when the convective portion of the interior film coefficient was set very high thereby indicating that the overall transmission coefficient may be higher than in the test specification.

It seems that there is a problem related to a difference in overall characteristics (UA-value) of the modelled test cell presented here. Different explanations are given by the participants (some of them disagreed on the potential source of disagreement in terms of overall characteristics). One explanation could be the thermal bridges (not considered in the technical specifications given to the modellers because the cells have been built with the intention of eliminating all thermal bridges). Another could be material properties not correctly defined (difference between given values and reality), and another could be surface coefficients not correctly chosen in relation to experimental conditions. Nevertheless, later studies (see modeller’s reports) have indicated a significant impact of thermal bridges (assumption made that improvements could be made by considering thermal bridges). The input for two models have been compensated for this : SW (DOE-2, ZTL) and KST (PROMETHEUS - KlimasystemTechnik). The DOE-2 run from CIEMAT (SP) is uncompensated for this effect, providing some indication of the impact of thermal bridges. The global UA value of the cells should be checked experimentally.

As a final point, three programs have performed this exercise in real "blind" conditions (Apache-BRE, CA-SIS-EDF and CLIM2000-EDF), without revising their results after their initial first round of blind simulations. Since these simulation results were not significantly different from the other simulation results, it may be concluded that the information provided in the original test procedure package was sufficient for carrying out the the validation exercise. Additionally, reasonable agreement between these software and measured results, and indeed between the other software (after modeling assumptions were corrected or algorithms were changed), gives improved confidence in the calculation engines used by building energy simulation software to predict energy use in real buildings.

# II. SECOND EXPERIMENT : ETNA2

## II.1. Context of the empirical validation

An experiment has been carried out in ETNA test-cells to measure the difference between :

- a purely convective heat source, put in the centre of the room, with stirring of air (when the source is “ on ”), and
- a realistic convector, located under the window, without stirring of the internal air.

The experiment was conducted in natural climate, i.e. the South wall was exposed to solar radiation, and the other surfaces were connected to guard zones.

- In the **“ REFERENCE ”** cell, there was an “ ideal reference heat source ” (purely convective), *for which hypotheses are close to the model used in most software programs,*
- In the **“ MEASURE ”** cell, a “ classical electrical convector ” is located under the South window.

The aim of this experiment is to compare the influence of energy distribution on the air temperature in the centre of the rooms for the realistic convector (no stirring) and the ideal heat source with stirring. Different phenomena were studied such as the losses behind the heater, the stratification, and others.

In this experiment, the thermostat setpoint was varied and the heating system respond to meet the setpoints. For the empirical validation exercise, the IEA participants were initially given relevant experimental data except for heating energy consumptions which they were to solve for in their simulations.

## II.2. ETNA2 participants

This exercise was undertaken to compare test-cells models developed with the 7 following programs (used by 8 teams) with the measured data. Table 29 presents the list of the participants of all three rounds of simulation, with the files analysed and presented in the corresponding reports.

In this report, we include only the latest results, which were provided before 10/98. For the teams that provided more than one set of results, please refer to previous reports to find discussions about it.

| **Notation** | **Program / Contributors** | **Intermediate report of 03/98** | **Final report** |
|---|---|---|---|
| AXBU | AxBU<br>Univ. Dresden, Germany | etna2mea.axb<br>etna2ref.axb<br>(files of 01/98) | etna2mea.axb<br>etna2ref.axb<br>(files of 03/98) |
| APA | APACHE<br>BRE, Great Britain | | etna2_mea.apa<br>etna2_ref.apa<br>(files of 08/98) |
| CLIM | CLIM2000<br>EDF, France | etna2mea.c2k<br>etna2mea.c2k<br>(files of 12/97) | Id. |
| SP | DOE-2<br>CIEMAT, Spain | etna2mea.doe<br>etna2ref.doe<br>(files of 12/97) | Id. |
| SW | DOE-2<br>ZTL, Switzerland | etna2_mea.prn<br>etna2_ref.prn<br>(files of 12/97) | test2_mea.prn<br>test2_ref.prn<br>(files of 10/98) |
| ICE | ICE<br>KTH, Sweden and Finland | etna2_mea1.ic<br>e<br>etna2_ref1.ice<br>(files of 02/98) | etna2_mea2.ice<br>etna2_ref2.ice<br>(files of 06/98) |
| KST | PROMETHEUS<br>KlimaSystemTechnik, Germany | etna2mea.kst<br>etna2ref.kst<br>(files of 01/98) | etna2mea.kst<br>etna2ref.kst<br>(files of 01/98) |
| SER | SERI-RES<br>NREL, USA | et2_mes.ser<br>et2_ref.ser<br>(files of 03/97)<br>et2_mesa.ser<br>et2_refa.ser<br>(files of 09/97)<br>et2_mesc.ser<br>et2_refc.ser<br>(files of 02/98) | et2_mesd.ser<br>et2_refd.ser<br>(files of 06/98) |

*Table 29 : List of the participants and corresponding data files.*

## II.3. Description of the second stage : closed loop system (ETNA 2)

The data used for validation have a duration of 41 days at 1 hour time step. The experiment started on day 97 (1$^{st}$ April) and ended on day 137 (17$^{th}$ May). No preconditioning period has been offered to modellers.

During this experiment the cells configurations were as follows :

– guard temperatures controlled at approximately 10°C (actual data were given in separate files) ;
– no air infiltration ;
– pseudo-random sequence on the set-point ;

- for “ REFERENCE ” cell, the air inside the test-cell was **stirred** (when heating is on) using a fan to guarantee temperature homogenisation and the heating system was assumed to be a pure convective heater ;
- for “ MEASURE ” cell, the air inside the test-cell was **not stirred** and the heating system was a "classical" electrical convector, commonly used in France.

All data were measured at a 5 minutes time step, except global horizontal solar radiation which was measured at 1 minute time steps. The data were then averaged over the appropriate 1 hour time intervals.

The following variables have been measured :

- horizontal global solar radiation ;
- horizontal diffuse solar radiation ;
- global solar radiation over a vertical wall parallel to the glazing (oriented at 30°West from South) ;
- wind speed and direction ;
- relative humidity ;
- ambient air temperature.

The following variables have also been measured in each room :

- heating power ;
- several shielded dry bulb temperature sensors and three black globe temperatures ;
- indoor air temperature was taken as a spatial average of several shielded dry-bulb temperature sensors. Mean radiant temperature was taken using an average of 3 black globe temperature sensors. The operative temperature was taken as the average of the average dry-bulb and the mean radiant temperature ;
- two surface temperatures per wall and a surface heat flux per wall. Surface temperatures were taken as the average of the two sensors.

***Note :*** When a sensor was judged too sensitive to solar radiation, it was removed.

Each heater had its own control system. The setpoints followed a PRBS (pseudo-random binary sequence), after a step near 19°C.

***Setpoint (see*** Figure 9**)**

For the two cells, there was a period of adjustments on the setpoints (from day 97 to 109). Afterwards, there was a PRBS (pseudo-random binary sequence) of 21 days on the setpoint temperature : this varied randomly between the high setpoint and the low setpoint (from day 109 to 130). For the end of the sequence, the two cells were in free float mode (the setpoint is put to zero).

***Control***

In the “ MEASURE ” cell, the convector is equipped with its own controller, which is a proportional controller :

- Proportional band : 1°C ;

– Sample time : 30 s.

In the “ REFERENCE ” cell, a PID controller was installed for the experiment. Its characteristics are as follows :

– Integral time : 60 s ;
– Derivative time : 0 s ;
– Proportional band : 1°C ;
– Sample time : 30 s.

For the “ MEASURE ” cell, the controller sensor is on the convector, whereas it is in the centre of the room in the “ REFERENCE ” cell.

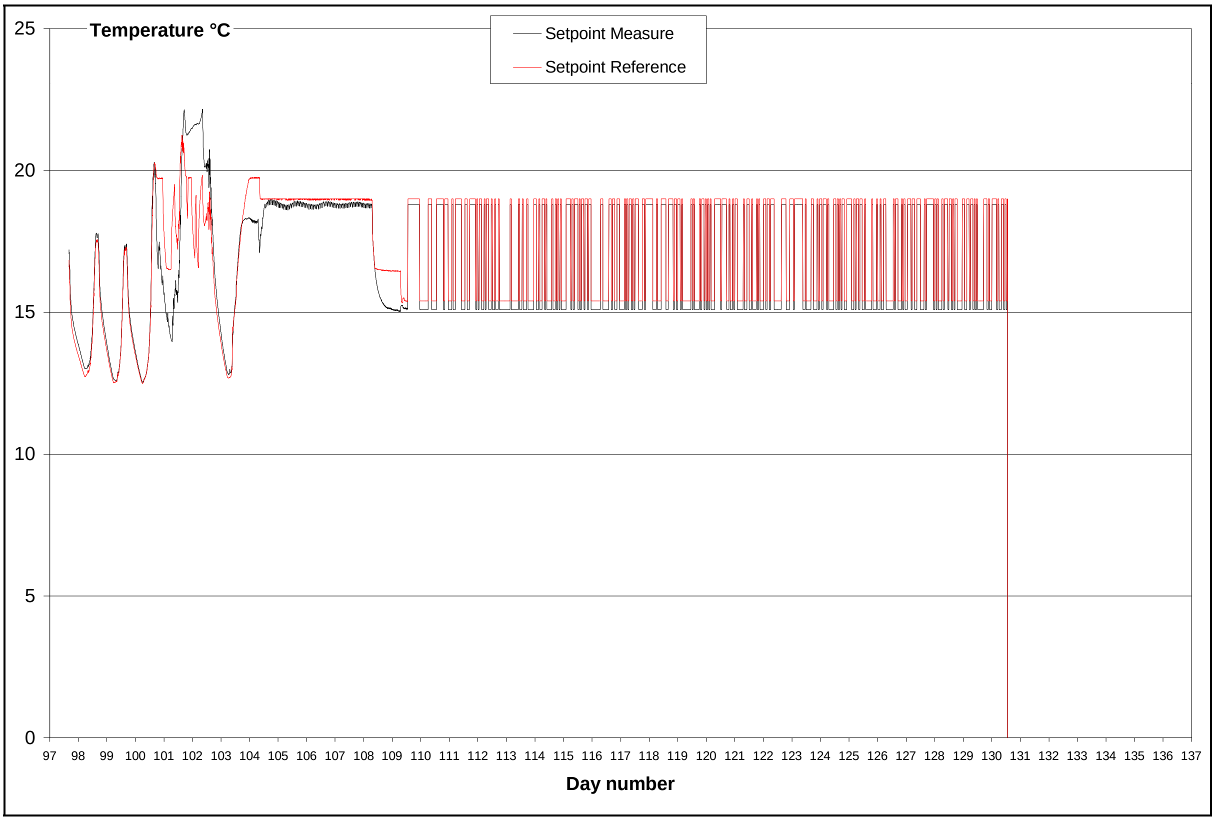


*Figure 9 : Setpoints evolution for the two test-cells.*

***IMPORTANT NOTE ABOUT THE SEQUENCE***

A problem occurred during the experiments on ETNA2 : the shutters were closed from day 103 (April 13 1995 at 12h) to day 109 (April 19 1995 at 10h) to adjust precisely the set-point by turning off the sun effect. This has normally been taken into account by the modellers, or if not, this was notified (case of Apache-BRE).

## II.4. Programs results format for ETNA2

Participants were asked to supply simulation results for each cell as hourly data regarded as the average over the past hourly period. For this exercise, the model output format is given in Table 30.

| Entry | Description | Units |
|---|---|---|
| 1 | Day number | |
| 2 | Hour Number | |
| 3 | External "south" facing vertical radiation flux | $W/m^2$ |
| 4 | Global radiation flux behind glazing inside test cell | $W/m^2$ |
| 5 | Test cell energy consumption | W |
| 6 | Test cell air temperature | °C |
| 7 | Test cell mean radiant temperature | °C |
| 8 | Test cell operative temperature | °C |
| 9 | Test cell south wall surface temperature | °C |
| 10 | Test cell south wall surface heat flux | $W/m^2$ |
| 11 | Test cell west wall surface temperature | °C |
| 12 | Test cell west wall surface heat flux | $W/m^2$ |
| 13 | Test cell north wall surface temperature | °C |
| 14 | Test cell north wall surface heat flux | $W/m^2$ |
| 15 | Test cell east wall surface temperature | °C |
| 16 | Test cell east wall surface heat flux | $W/m^2$ |
| 17 | Test cell ceiling surface temperature | °C |
| 18 | Test cell ceiling surface heat flux | $W/m^2$ |
| 19 | Test cell floor surface temperature | °C |
| 20 | Test cell floor surface heat flux | $W/m^2$ |

*Table 30 : Output files format.*

***Notes :***

1. Times are assumed to be GMT.
2. The day number are given assuming 01/01/95 to be day 1.
3. "South" means 30° West of South.
4. Operative temperature is defined as 0.5 x test-cell air temperature + 0.5 x test-cell mean radiant temperature (see note for SERI-RES results).
5. Heat fluxes should be signed positive outwards.
6. Wall surface data relate to indoor surfaces.
7. All data should represent the data averaged over the preceding hour time step. If a program predicts data in a different manner, the manner must be indicated. If a program is able to predict both data (averaged and instantaneous), both data must be given in two separate files. This detail is particularly important for solar radiation.
8. Where a model cannot predict a temperature (air, radiant or operative), an alternate one can be given in place. Modellers should indicate what is actually supplied. For surfaces data, a zero should be entered in place of the prediction if the data are not supplied.

# II.5. ETNA2 : Preliminary steps

## II.5.1. Choosing the variables to compare

To eliminate the influence of the model preconditioning period, often model dependent, but also to compare fully convergent predictions, we assume that **96 hours** are necessary to obtain convergence for all models. **Consequently model-data comparison only starts at day 101**.

## II.5.2. List of the analysed data files

In the following, we often refer only to the simulation programs used to analyse the data. The abbreviations used are as follows :

- AxBU : for AxBU - Univ. DRESDEN (Germany) ;
- APA : for APACHE – BRE (UK) ;
- CLIM : for CLIM2000 – EDF (France) ;
- SP : for DOE-2 - CIEMAT (Spain) ;
- SW : for DOE-2 - ZTL (Switzerland) ;
- ICE : for Indoor Climate & Energy – KTH (Finland and Sweden) ;
- KST : for PROMETHEUS – KlimaSystemTechnik (Germany) ;
- SER : for SERI-RES - NREL (USA).

The corresponding data and files presented in this report are summarised in Table 29 above.

## II.5.3. Preliminary analysis

### *II.5.3.1 Available data*

**Notation :**

N/A : non available ;

ENERGY : data given is Energy (hourly integrated Power).

Puis_mes : values that have needed some changes because not given in right units.

**ETNA2 - MEA - 3rd run AVAILABLE DATA**

| | Global solar flux | Flux inside cell | Heating power | Air temperature | Radiant temperature | Enclosure temperature |
|---|---|---|---|---|---|---|
| APA | | | Puis_mes/1000 | | | |
| AxBU | | | | | | |
| CLIM | | | | N/A | N/A | |
| ICE | | | ENERGY | | | |
| KST | | | ENERGY | | | |
| SP | | | | | N/A | N/A |
| SW | | | - Puis_mes | | N/A | N/A |
| SER | | | Puis_mes/1000 | N/A | | |
| MEASUREMENTS | N/A | N/A | | | N/A | |

| | South wall temperature | South flux | West wall temperature | West flux | North wall temeprature | North flux |
|---|---|---|---|---|---|---|
| APA | | | | | | |
| AxBU | | | | | | |
| CLIM | | | | | | |
| ICE | | | | | | |
| KST | N/A | N/A | N/A | N/A | N/A | N/A |
| SP | N/A | N/A | N/A | N/A | N/A | N/A |
| SW | N/A | N/A | N/A | N/A | N/A | N/A |
| SER | | | | | | |
| MEASUREMENTS | | N/A | | N/A | | N/A |

| | East wall temperature | East flux | Ceiling temperature | Ceiling flux | Floor temperature | Floor flux |
|---|---|---|---|---|---|---|
| APA | | | | | | |
| AxBU | | | | | | |
| CLIM | | | | | | |
| ICE | | | | | | |
| KST | N/A | N/A | N/A | N/A | N/A | N/A |
| SP | N/A | N/A | N/A | N/A | N/A | N/A |
| SW | N/A | N/A | N/A | N/A | N/A | N/A |
| SER | | | | | | |
| MEASUREMENTS | | N/A | | N/A | | N/A |

*Table 31 : Output files data checking for the MEASURE test cell.*

**ETNA2 - REF - 3rd run AVAILABLE DATA**

| | Global solar flux | Flux inside cell | Heating power | Air temperature | Radiant temperature | Enclosure temperature |
|---|---|---|---|---|---|---|
| APA | | | Puis_mes/1000 | | | |
| AxBU | | | | | | |
| CLIM | | | | N/A | N/A | |
| ICE | | | ENERGY | | | |
| KST | | | ENERGY | | | |
| SP | | | | | N/A | N/A |
| SW | | | - Puis_mes | | N/A | N/A |
| SER | | | Puis_mes/1000 | N/A | | |
| MEASUREMENTS | N/A | N/A | | | N/A | |

| | South wall temperature | South flux | West wall temperature | West flux | North wall temeprature | North flux |
|---|---|---|---|---|---|---|
| APA | | | | | | |
| AxBU | | | | | | |
| CLIM | | | | | | |
| ICE | | | | | | |
| KST | N/A | N/A | N/A | N/A | N/A | N/A |
| SP | N/A | N/A | N/A | N/A | N/A | N/A |
| SW | N/A | N/A | N/A | N/A | N/A | N/A |
| SER | | | | | | |
| MEASUREMENTS | | N/A | | N/A | | N/A |

| | East wall temperature | East flux | Ceiling temperature | Ceiling flux | Floor temperature | Floor flux |
|---|---|---|---|---|---|---|
| APA | | | | | | |
| AxBU | | | | | | |
| CLIM | | | | | | |
| ICE | | | | | | |
| KST | N/A | N/A | N/A | N/A | N/A | N/A |
| SP | N/A | N/A | N/A | N/A | N/A | N/A |
| SW | N/A | N/A | N/A | N/A | N/A | N/A |
| SER | | | | | | |
| MEASUREMENTS | | N/A | | N/A | | N/A |

*Table 32 : Output files data checking for the REFERENCE test-cell.*

#### *II.5.3.2 Validity of the data*

All results are valid, and were included in this exercise of comparison. When energy is given (instead of Power), only integrated values are compared with each other.

### II.5.4. Hourly results

Simple statistical measures were used to quantify the differences between the measurements and the predictions. The definitions of these statistical measures are presented in Table 33 below.

| | | |
|---|---|---|
| **Minimum** | MIN | $X_{MIN} = Min(X_t)$ |
| **Maximum** | MAX | $X_{MAX} = Max(X_t)$ |
| **Mean** | MEAN | $\overline{X} = \sum_{t=1}^{N} X_t / N$ |
| **Difference** | DT | $\mathrm{D_t = X_t - M_t}$<br>$D_t = REF_t - MEA_t$ |
| **Smallest Difference** | DTMIN | $D_{MIN} = Min(D_t)$ |
| **Largest Difference** | DTMAX | $D_{MAX} = Max(D_t)$ |
| **Mean Difference** | MEANDT | $\overline{D} = \sum_{t=1}^{N} D_t / N$ |
| **Absolute Mean Difference** | ABMEANDT | $\left\|\overline{D}\right\| = \sum_{t=1}^{N} \left\|D_t / N\right\|$ |
| **Root Mean Square Difference** | RSQMEANDT | $\sqrt{D^2} = \sqrt{\sum_{t=1}^{N} D_t^2 / N}$ |
| **Standard Error** | STDERR | $\sigma = \sqrt{\frac{1}{N}\sum_{t=1}^{N}(D_t - \overline{D})^2}$ |

*Table 33 : Definition of the calculated statistics.*

where $X_t$ : predicted value at hour t (for MEASURE or REFERENCE data) ;

$M_t$ : measurement value at hour t ;

$REF_t$ : REFERENCE test-cell value at hour t ;

$MEA_t$ : MEASURE test-cell value at hour t ;

N : total hours in period comparison.

The first six statistics are spot values, and the last four statistics provide measures of the overall agreement between the measurements and the predicted values.

**MEANDT** is the mean deviation between simulation and reference data. It is meaningful while studying static or permanent behaviour.

**STDERR** (Standard deviation) gives a measure of the dispersion of the time series (actually the deviation between simulation and reference data). It discards mean value and remains meaningful only for dynamic behaviour.

**RSQMEANDT** (Root mean square) is the mean of square deviations. It encompasses the measure of dispersion and of mean deviation. It aggregates MEANDT and STDERR in a unique statistic. Its square value can also be regarded as a measure of time series power.

**ABMEANDT** is the mean absolute deviation. It gives similar information to the previous statistic, but with equivalent weighting to all values whereas RSQMEANDT emphasises large values.

### *NOTE FOR STATISTICAL CALCULATIONS*

We considered that the dynamic effect due to a difference in the initial conditions of the models was insignificant from day 101 at 17h00 (inclusive) to the day 136 (inclusive). All the presented statistics were calculated from this day.

# II.6. ETNA2 : Data analysis and comparisons for MEASURE and REFERENCE cells

## II.6.1. Energy consumption

### *II.6.1.1 MEASURE Cell*

| Energies in Wh/m2 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | ICE | KST | SP | SW | SER | MEAS. |
| Global solar flux | 82329.00 | 88378.99 | 90146.75 | 72092.37 | 79973.72 | 84981.78 | 87524.22 | 88818.26 | |
| Flux inside cell | 37233.00 | 45133.08 | 51000.86 | 36262.82 | 21880.13 | 44256.77 | 34930.10 | 43970.95 | |
| Heating power (Wh) | 123986.00 | 103947.41 | 136804.17 | 122000.00 | 120892.00 | 109630.00 | 135114.00 | 117456.16 | 154029.83 |
| (Sim-Meas.)/Meas. | -20% | -33% | -11% | -21% | -22% | -29% | -12% | -24% | |
| **Heating power - MEA** | | | | | | | | | |
| | APA | AxBU | Clim | ICE | KST | SP | SW | SER | MEAS. |
| DTMIN | -355.90 | -473.54 | -409.34 | | | -501.90 | -501.90 | -501.90 | |
| DTMAX | 163.90 | 418.63 | 145.37 | | | 506.60 | 167.10 | 97.95 | |
| MEANDT | -35.43 | -59.06 | -20.31 | | | -56.74 | -22.31 | -43.13 | |
| MIN | 0.00 | 0.00 | 0.00 | | | 0.00 | 0.00 | 0.00 | 0.10 |
| MAX | 493.00 | 508.21 | 500.04 | | | 507.00 | 520.00 | 500.00 | 506.80 |
| MEAN | 146.21 | 122.58 | 161.33 | | | 129.28 | 159.33 | 138.51 | 181.64 |
| AB MEAN DT | 39.01 | 128.78 | 31.80 | | | 161.84 | 32.29 | 48.63 | |
| SQ MEAN DT | 59.54 | 190.42 | 53.09 | | | 231.38 | 52.19 | 73.33 | |
| STDERR | 47.87 | 181.13 | 49.08 | | | 224.56 | 47.21 | 59.34 | |

*Table 34 : Statistical comparison of energy consumption for MEASURE test cell.*

The results in Table 34 show that for all programs, predicted energy consumption is lower than the actual data. Table 34 gives the relative difference of energy consumption to the measurement :

- CLI and SW give the closest predictions ;
- APA, ICE, KST and SER give predictions with almost -20% deviation ;
- AXBU and SP give predictions with about -30% deviation.

Regarding ABMEANDT, we derive a similar classification but with enhanced discrepancies for AXBU and SP predictions. This is due to large standard-error for the latter prediction errors.

### *II.6.1.2 REFERENCE Cell*

| Energies in Wh/m2 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | ICE | KST | SP | SW | SER | MEAS. |
| Global solar flux | 82329.00 | 88378.99 | 90146.75 | 72118.88 | 79973.72 | 84981.78 | 87524.22 | 88818.26 | |
| Flux inside cell | 37233.00 | 45133.08 | 50327.80 | 36334.51 | 21880.13 | 44256.77 | 34930.10 | 43970.95 | |
| Heating power (Wh) | 125073.00 | 103434.68 | 138805.62 | 116040.00 | 129480.00 | 109463.00 | 136648.00 | 118365.31 | 153695.88 |
| (Sim-Meas.)/Meas. | -19% | -33% | -10% | -25% | -16% | -29% | -11% | -23% | |
| **Heating power - REF** | | | | | | | | | |
| | APA | AxBU | Clim | ICE | KST | SP | SW | SER | MEAS. |
| DTMIN | -329.10 | -501.80 | -318.42 | | | -509.90 | -447.10 | -460.13 | |
| DTMAX | 150.40 | 560.93 | 112.17 | | | 382.90 | 117.80 | 81.97 | |
| MEANDT | -33.75 | -59.27 | -17.56 | | | -58.87 | -20.10 | -41.66 | |
| MIN | 0.00 | 0.00 | 0.00 | | | 0.00 | 0.00 | 0.00 | 0.10 |
| MAX | 494.00 | 581.00 | 500.04 | | | 454.00 | 555.00 | 500.00 | 554.30 |
| MEAN | 147.49 | 121.97 | 163.69 | | | 129.08 | 161.14 | 139.58 | 181.25 |
| AB MEAN DT | 42.04 | 141.07 | 22.61 | | | 161.33 | 33.83 | 44.17 | |
| SQ MEAN DT | 66.27 | 214.74 | 39.15 | | | 224.78 | 56.69 | 69.64 | |
| STDERR | 57.06 | 206.52 | 35.01 | | | 217.17 | 53.04 | 55.83 | |

*Table 35 : Statistical comparison of energy consumption for REFERENCE test cell.*

The results in Table 35 show that the conclusions for the MEASURE cell remains true.

## II.6.2. Air temperature

### *II.6.2.1 MEASURE Cell*

| Air temperature - MEA | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | ICE | KST | SP | SW | SER | MEAS. |
| DTMIN | -1.34 | -1.86 | | -1.68 | -2.32 | -2.96 | -1.96 | | |
| DTMAX | 1.95 | 2.59 | | 1.94 | 1.78 | 6.45 | 3.21 | | |
| MEANDT | 0.10 | 0.40 | | -0.20 | -0.37 | 0.10 | -0.25 | | |
| MIN | 10.60 | 11.15 | | 10.65 | 10.40 | 11.30 | 10.60 | | 10.86 |
| MAX | 22.40 | 21.61 | | 21.73 | 21.93 | 21.90 | 21.60 | | 22.18 |
| MEAN | 17.13 | 17.42 | | 16.81 | 16.66 | 17.29 | 16.77 | | 17.02 |
| AB MEAN DT | 0.51 | 0.78 | | 0.45 | 0.75 | 0.99 | 0.56 | | |
| SQ MEAN DT | 0.67 | 1.00 | | 0.59 | 0.90 | 1.35 | 0.75 | | |
| STDERR | 0.67 | 0.92 | | 0.55 | 0.82 | 1.35 | 0.71 | | |

*Table 36 : Statistical comparison of air temperature to measurements for MEASURE test cell.*

The analysis of the results (Table 36) shows no significant discrepancy exists between program predictions and actual data. This result is expected because air temperatures were provided as setpoints, except in free float mode.

Figure 10 and Figure 11 show that :

- SP exhibits one time step advance in addition to an excessive response to solar radiation ;
- For SP and AxBU, the simulations in free float mode at the end of the sequence show for temperatures higher than empirical data, pointing to an under-estimated U-value ;
- For the other programs, the magnitude of the predicted variations are close together, but temperatures are lower than measurements when the heating is on and for periods with high solar radiation ;
- SP shows an inaccurate response for dynamic events (large STDERR) ;

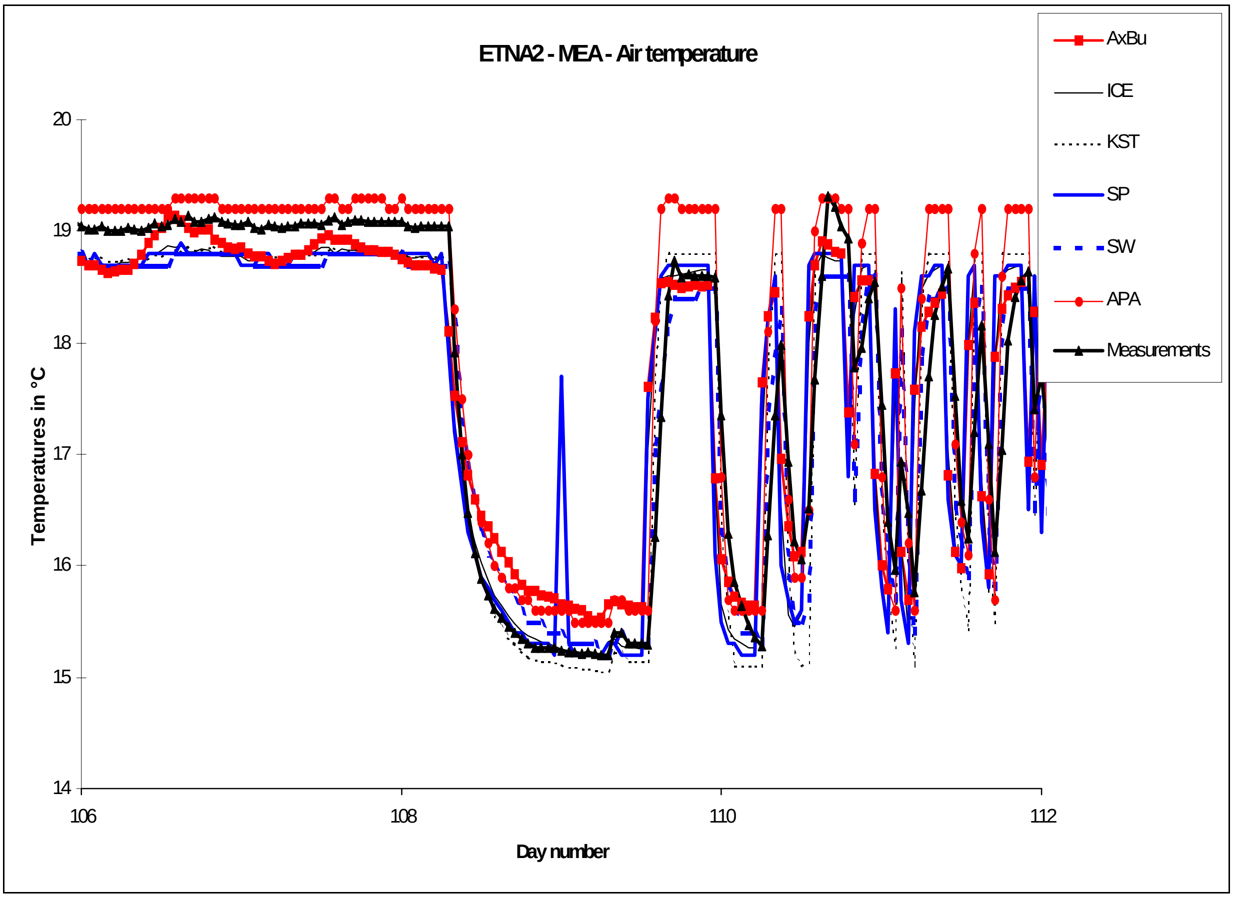


*Figure 10 : Air temperature for MEASURE test cell. ETNA2.*

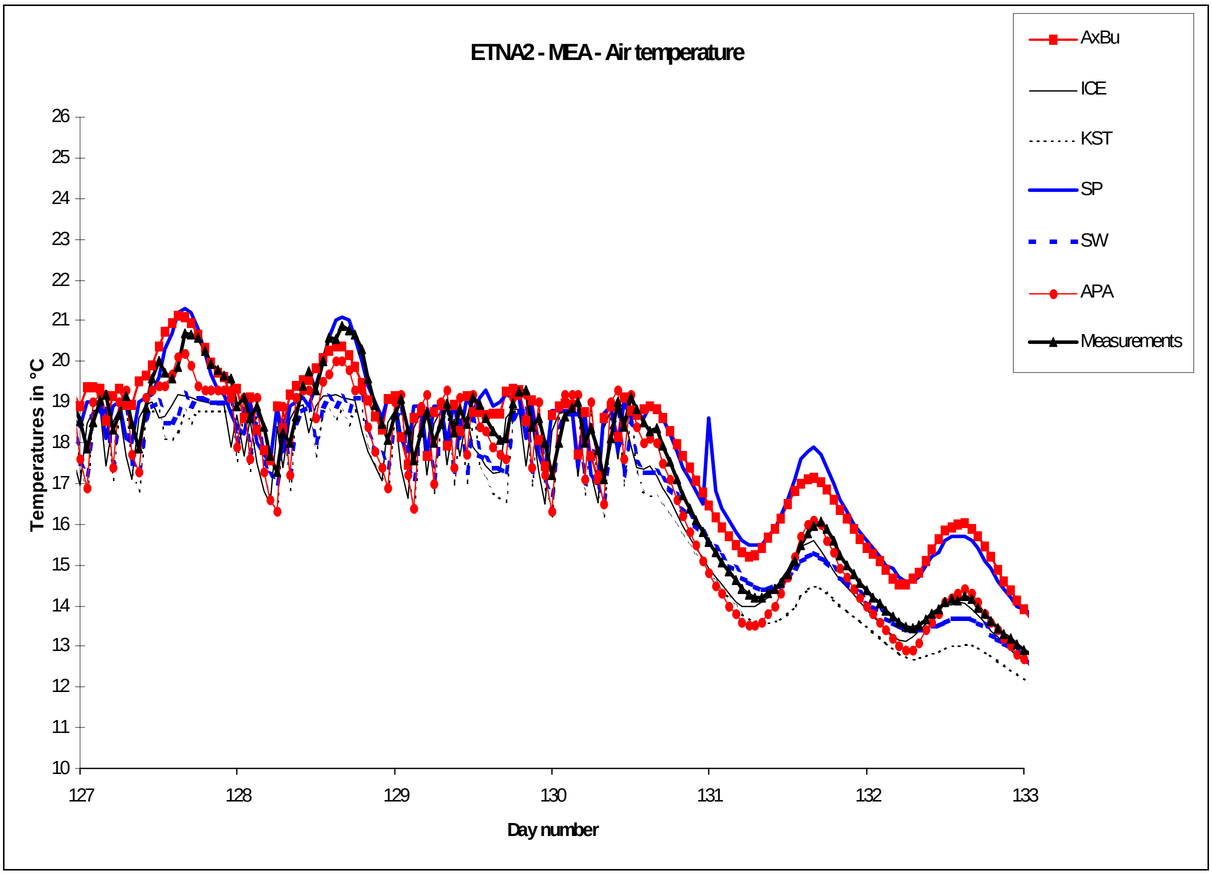


*Figure 11 : Air temperature for MEASURE test cell. ETNA2.*

### *II.6.2.2 REFERENCE Cell*

| Air temperature - REF | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | ICE | KST | SP | SW | SER | MEAS. |
| DTMIN | -0.86 | -2.17 | | -1.40 | -1.54 | -3.00 | -1.25 | | |
| DTMAX | 2.25 | 3.32 | | 1.61 | 2.75 | 3.85 | 2.29 | | |
| MEANDT | 0.34 | 0.41 | | -0.16 | 0.20 | 0.07 | -0.09 | | |
| MIN | 10.70 | 11.15 | | 10.63 | 10.46 | 11.40 | 10.70 | | 10.95 |
| MAX | 21.40 | 20.80 | | 20.21 | 21.28 | 21.50 | 20.80 | | 20.12 |
| MEAN | 17.33 | 17.40 | | 16.82 | 17.19 | 17.31 | 16.90 | | 16.99 |
| AB MEAN DT | 0.55 | 0.81 | | 0.46 | 0.74 | 0.88 | 0.45 | | |
| SQ MEAN DT | 0.72 | 1.10 | | 0.61 | 0.94 | 1.20 | 0.62 | | |
| STDERR | 0.63 | 1.02 | | 0.58 | 0.92 | 1.20 | 0.62 | | |

*Table 37 : Statistical comparison of air temperature to measurements for REFERENCE test cell.*

The statistics are presented in Table 37. Figure 12 and Figure 13 show that the same conclusion can be stated for the REFERENCE cell as for the MEASURE cell.

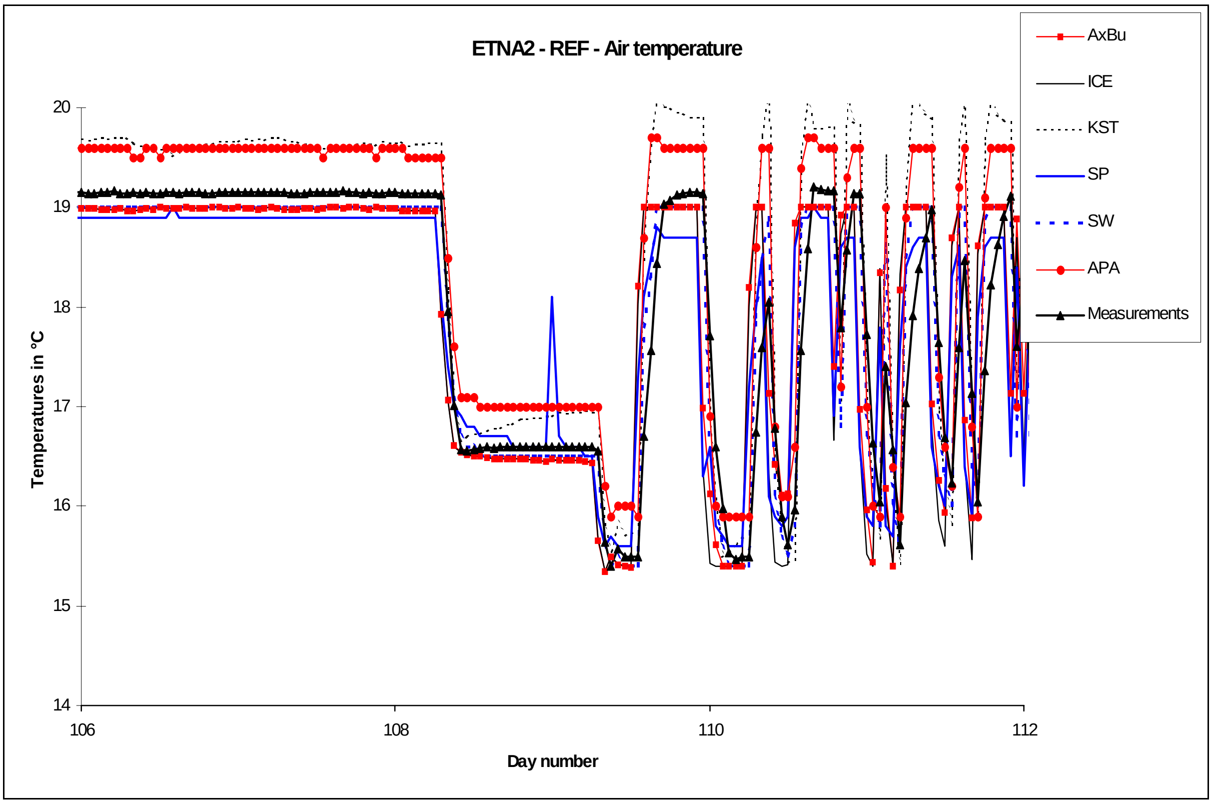


*Figure 12 : Air temperature for REFERENCE test cell. ETNA2.*

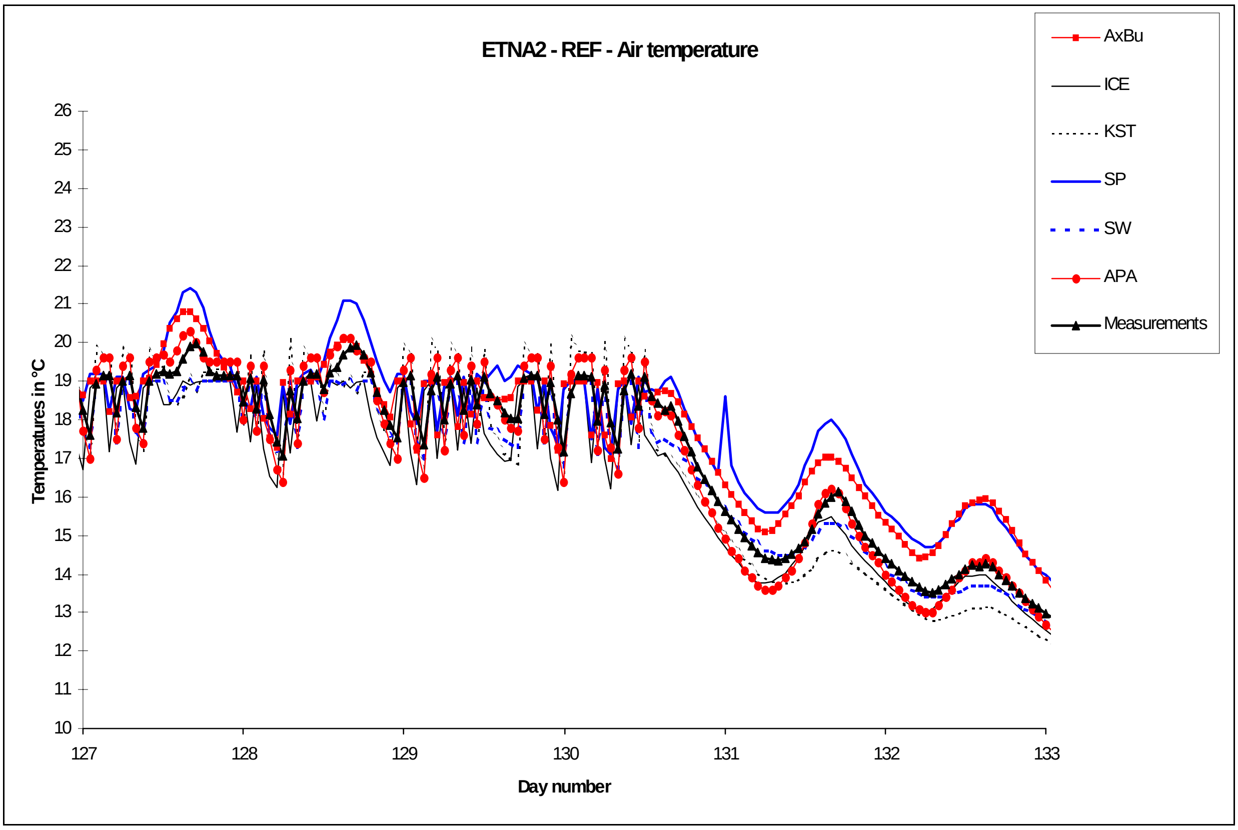


*Figure 13 : Air temperature for REFERENCE test cell. ETNA2.*

### II.6.3. Mean radiant temperatures

#### *II.6.3.1 MEASURE Cell*

| Radiant temperature - MEA | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | ICE | KST | SP | SW | SER | MEAS. |
| DTMIN | | | | | | | | | |
| DTMAX | | | | | | | | | |
| MEANDT | | | | | | | | | |
| MIN | 10.60 | 11.26 | | 10.70 | 10.40 | | | 11.56 | |
| MAX | 21.00 | 21.05 | | 20.21 | 20.08 | | | 21.16 | |
| MEAN | 16.56 | 16.99 | | 16.16 | 15.96 | | | 16.90 | |
| AB MEAN DT | | | | | | | | | |
| SQ MEAN DT | | | | | | | | | |
| STDERR | | | | | | | | | |

*Table 38 : Statistical comparison of mean radiant temperature to measurements for MEASURE test cell.*

No measurements are available, and we did not recalculate the radiant temperature knowing operative and air temperatures. The results presented in Table 38 show similar results for mean radiant temperature to those stated for air temperature.

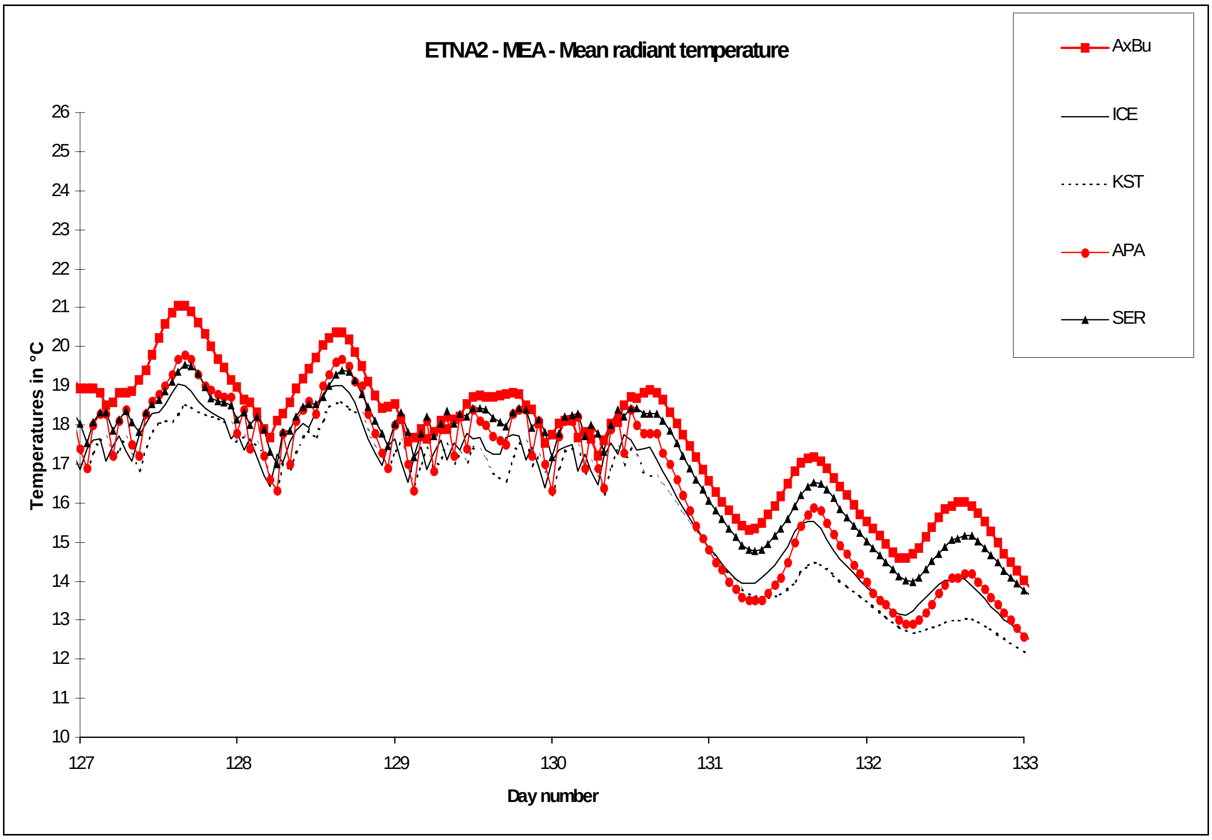


*Figure 14 : Mean radiant temperature for MEASURE test cell. ETNA2.*

### *II.6.3.2 REFERENCE Cell*

| Radiant temperature - REF | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | ICE | KST | SP | SW | SER | MEAS. |
| DTMIN | | | | | | | | | |
| DTMAX | | | | | | | | | |
| MEANDT | | | | | | | | | |
| MIN | 10.70 | 11.25 | | 10.69 | 10.46 | | | 11.62 | |
| MAX | 20.40 | 20.74 | | 18.93 | 20.05 | | | 20.39 | |
| MEAN | 16.60 | 16.88 | | 15.83 | 16.32 | | | 17.01 | |
| AB MEAN DT | | | | | | | | | |
| SQ MEAN DT | | | | | | | | | |
| STDERR | | | | | | | | | |

*Table 39 : Statistical comparison of mean radiant temperature to measurements for REFERENCE test cell.*

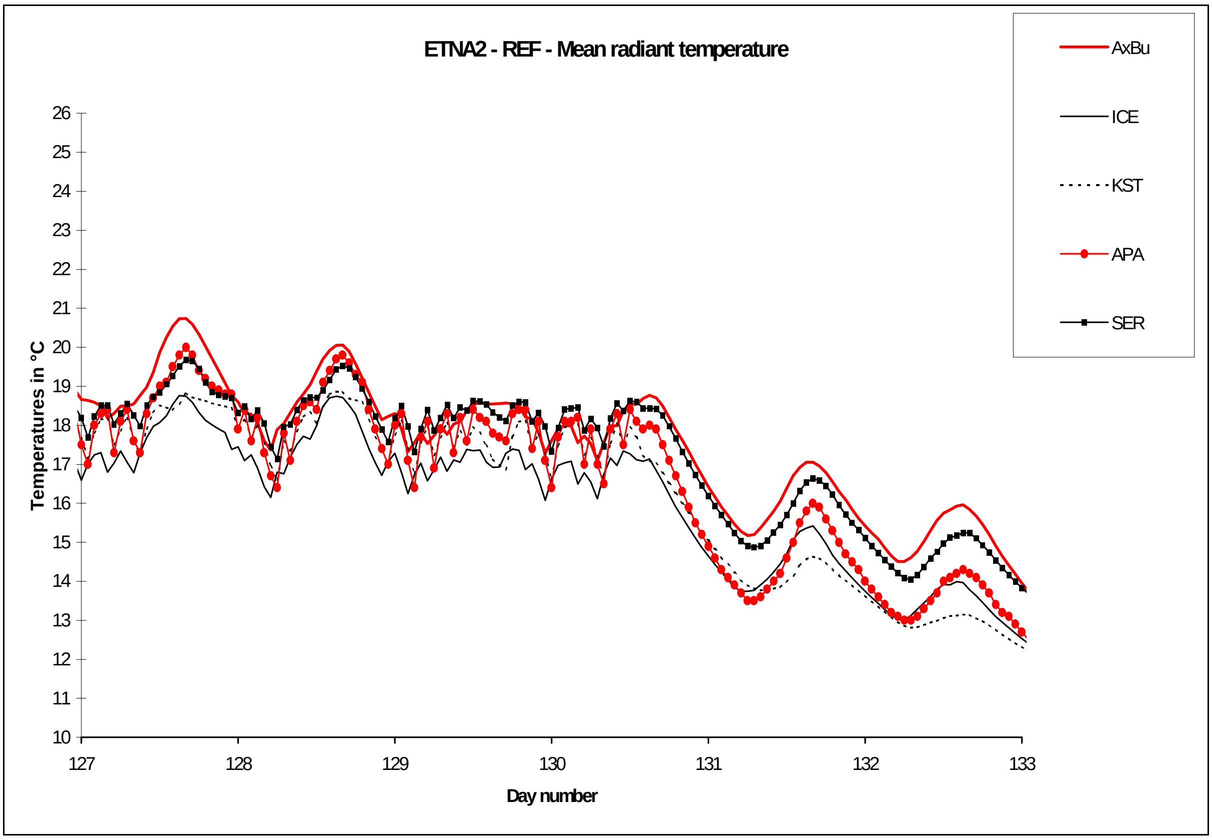


*Figure 15 : Mean radiant temperature for REFERENCE test cell. ETNA2.*

## II.6.4. Operative temperatures

### *II.6.4.1 MEASURE Cell*

| Enclosure temperature - MEA | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | ICE | KST | SP | SW | SER | MEAS. |
| DTMIN | -1.67 | -1.54 | -2.10 | -2.26 | -2.83 | | | -1.91 | |
| DTMAX | 1.67 | 2.54 | 2.04 | 1.80 | 1.69 | | | 2.46 | |
| MEANDT | -0.08 | 0.29 | -0.02 | -0.43 | -0.61 | | | 0.26 | |
| MIN | 10.60 | 11.20 | 10.72 | 10.68 | 10.40 | | | 11.53 | 10.90 |
| MAX | 21.70 | 21.08 | 21.93 | 20.97 | 20.97 | | | 21.90 | 21.70 |
| MEAN | 16.84 | 17.21 | 16.90 | 16.48 | 16.31 | | | 17.18 | 16.92 |
| AB MEAN DT | 0.50 | 0.64 | 0.41 | 0.57 | 0.79 | | | 0.53 | |
| SQ MEAN DT | 0.65 | 0.81 | 0.59 | 0.72 | 0.96 | | | 0.70 | |
| STDERR | 0.64 | 0.76 | 0.59 | 0.58 | 0.74 | | | 0.65 | |

*Table 40 : Statistical comparison of operative temperature to measurements for MEASURE test cell.*

The analysis of the results shows no significant discrepancy between program predictions and actual data.

The Table 40 and Figure 16 show that :

- In terms of MEANDT and STDERR, all simulations are very close together ;
- AxBU has probably too low a U-Value (too high temperature in free float) ;
- KST results show a too low sensitivity to solar effects ;

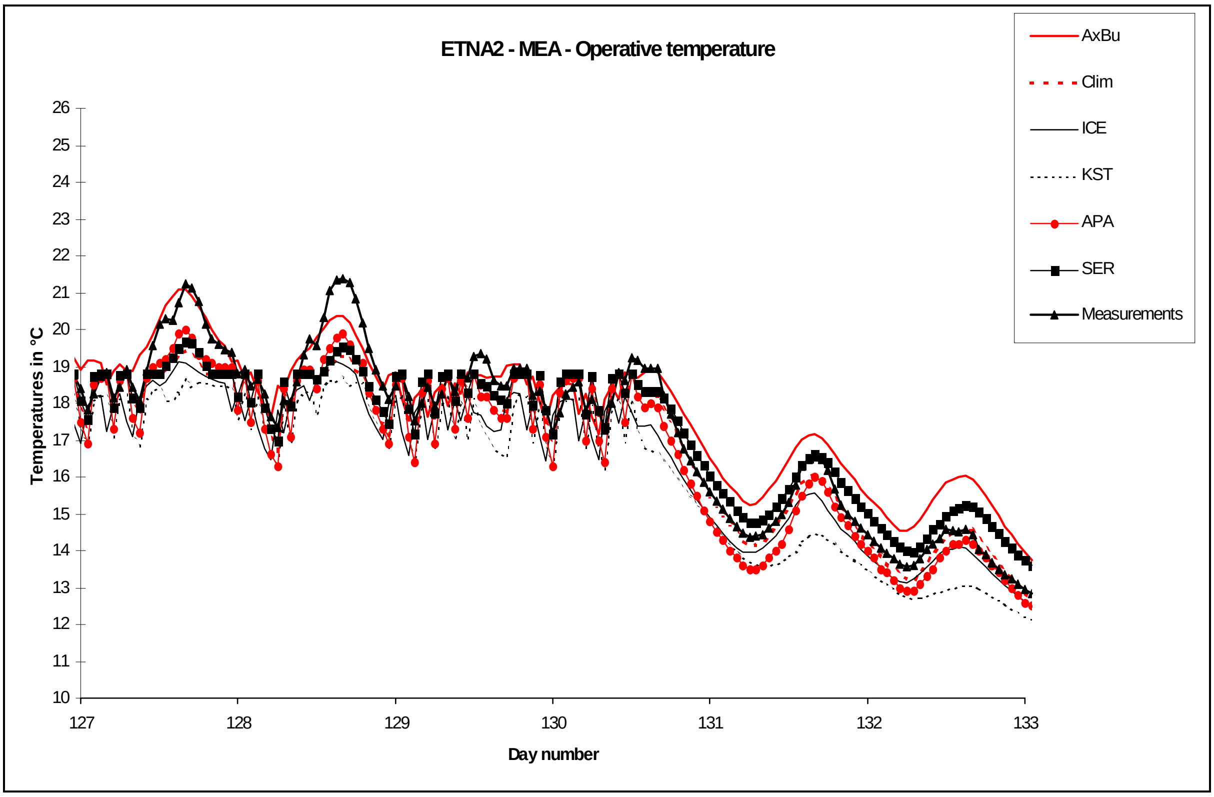


*Figure 16 : Operative temperature for MEASURE test cell. ETNA2.*

### *II.6.4.2 REFERENCE Cell*

| Enclosure temperature - REF | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | ICE | KST | SP | SW | SER | MEAS. |
| DTMIN | -1.19 | -1.97 | -1.24 | -2.14 | -2.06 | | | -1.00 | |
| DTMAX | 1.55 | 2.31 | 1.47 | 0.95 | 1.58 | | | 1.88 | |
| MEANDT | -0.07 | 0.11 | -0.02 | -0.70 | -0.28 | | | 0.26 | |
| MIN | 10.70 | 11.20 | 10.78 | 10.66 | 10.46 | | | 11.60 | 11.08 |
| MAX | 20.90 | 20.77 | 20.75 | 19.57 | 20.66 | | | 20.80 | 20.80 |
| MEAN | 16.96 | 17.14 | 17.01 | 16.32 | 16.75 | | | 17.29 | 17.03 |
| AB MEAN DT | 0.39 | 0.67 | 0.25 | 0.77 | 0.57 | | | 0.38 | |
| SQ MEAN DT | 0.53 | 0.83 | 0.38 | 0.86 | 0.75 | | | 0.53 | |
| STDERR | 0.52 | 0.82 | 0.37 | 0.50 | 0.70 | | | 0.47 | |

*Table 41 : Statistical comparison of operative temperature to measurements for REFERENCE test cell.*

The same results are shown in Table 41 for the REFERENCE test cell, and we can add that the statistics show, in general, an accuracy of the prediction, which is similar for the two cells, in the case of the operative temperature.

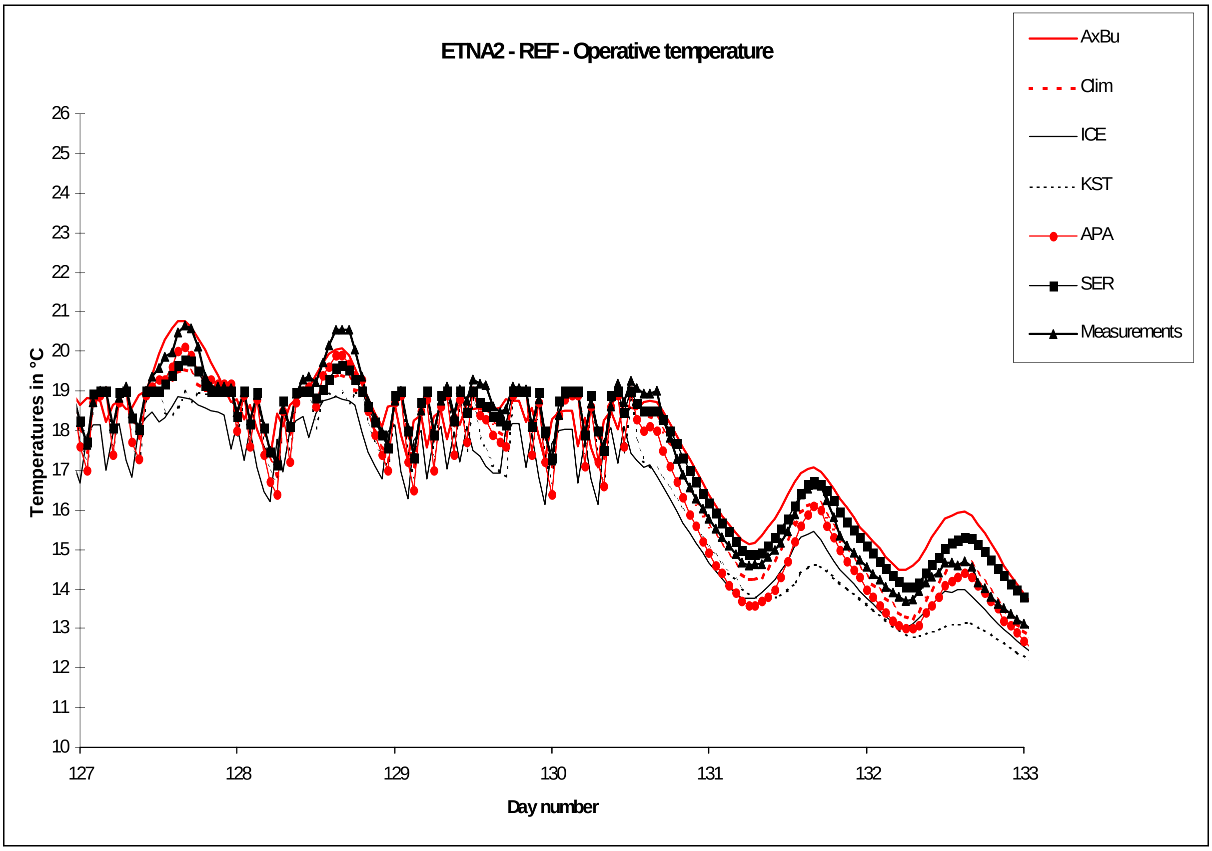


*Figure 17 : Operative temperature for REFERENCE test cell. ETNA2.*

## II.6.5. Surface temperatures

### *II.6.5.1 MEASURE test cell*

| South wall temperature - MEA | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | ICE | KST | SP | SW | SER | MEAS. |
| DTMIN | -1.56 | -1.18 | -1.75 | -1.65 | | | | -1.52 | |
| DTMAX | 1.87 | 2.10 | 1.62 | 1.52 | | | | 2.18 | |
| MEANDT | 0.07 | 0.29 | 0.05 | -0.40 | | | | 0.39 | |
| MIN | 10.46 | 10.99 | 10.43 | 10.55 | | | | 11.28 | 10.52 |
| MAX | 21.48 | 20.86 | 21.29 | 20.17 | | | | 21.34 | 21.07 |
| MEAN | 16.63 | 16.86 | 16.61 | 16.15 | | | | 16.95 | 16.56 |
| AB MEAN DT | 0.52 | 0.59 | 0.40 | 0.52 | | | | 0.57 | |
| SQ MEAN DT | 0.70 | 0.75 | 0.55 | 0.65 | | | | 0.72 | |
| STDERR | 0.70 | 0.69 | 0.55 | 0.51 | | | | 0.61 | |

*Table 42 : South wall.*

| West wall temperature - MEA | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | ICE | KST | SP | SW | SER | MEAS. |
| DTMIN | -0.97 | -0.84 | -1.01 | -1.08 | | | | -0.79 | |
| DTMAX | 2.21 | 2.74 | 2.20 | 1.98 | | | | 2.71 | |
| MEANDT | 0.42 | 0.76 | 0.56 | 0.01 | | | | 0.89 | |
| MIN | 10.64 | 11.19 | 10.72 | 10.71 | | | | 11.59 | 10.47 |
| MAX | 21.28 | 20.66 | 21.61 | 20.32 | | | | 21.46 | 20.69 |
| MEAN | 16.56 | 16.90 | 16.70 | 16.14 | | | | 17.03 | 16.14 |
| AB MEAN DT | 0.59 | 0.82 | 0.63 | 0.33 | | | | 0.92 | |
| SQ MEAN DT | 0.76 | 1.03 | 0.75 | 0.46 | | | | 1.04 | |
| STDERR | 0.64 | 0.70 | 0.49 | 0.46 | | | | 0.54 | |

*Table 43 : West wall.*

| North wall temepratureature - MEA | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | ICE | KST | SP | SW | SER | MEAS. |
| DTMIN | -1.36 | -1.05 | -1.14 | -1.23 | | | | -1.07 | |
| DTMAX | 1.91 | 2.33 | 1.81 | 1.61 | | | | 2.21 | |
| MEANDT | 0.08 | 0.42 | 0.22 | -0.32 | | | | 0.41 | |
| MIN | 10.63 | 11.20 | 10.75 | 10.74 | | | | 11.49 | 10.85 |
| MAX | 21.27 | 20.54 | 21.52 | 20.24 | | | | 21.28 | 21.03 |
| MEAN | 16.52 | 16.86 | 16.66 | 16.11 | | | | 16.85 | 16.44 |
| AB MEAN DT | 0.51 | 0.60 | 0.37 | 0.43 | | | | 0.51 | |
| SQ MEAN DT | 0.67 | 0.79 | 0.50 | 0.54 | | | | 0.65 | |
| STDERR | 0.66 | 0.67 | 0.45 | 0.43 | | | | 0.51 | |

*Table 44 : North wall.*

| East wall temperature - MEA | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | ICE | KST | SP | SW | SER | MEAS. |
| DTMIN | -3.72 | -3.14 | -3.96 | -4.06 | | | | -3.91 | |
| DTMAX | 1.81 | 2.31 | 1.77 | 1.47 | | | | 2.08 | |
| MEANDT | 0.02 | 0.33 | 0.15 | -0.41 | | | | 0.22 | |
| MIN | 10.75 | 11.31 | 10.82 | 10.82 | | | | 11.48 | 10.87 |
| MAX | 21.40 | 20.76 | 21.69 | 20.38 | | | | 21.36 | 22.82 |
| MEAN | 16.69 | 17.00 | 16.82 | 16.25 | | | | 16.89 | 16.67 |
| AB MEAN DT | 0.51 | 0.62 | 0.44 | 0.57 | | | | 0.51 | |
| SQ MEAN DT | 0.72 | 0.80 | 0.64 | 0.74 | | | | 0.70 | |
| STDERR | 0.72 | 0.73 | 0.62 | 0.61 | | | | 0.67 | |

*Table 45 : East wall.*

| Ceiling temperature - MEA | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | ICE | KST | SP | SW | SER | MEAS. |
| DTMIN | -1.48 | -1.58 | -1.61 | -1.82 | | | | -1.46 | |
| DTMAX | 1.53 | 2.26 | 1.81 | 1.63 | | | | 2.25 | |
| MEANDT | -0.24 | 0.14 | -0.09 | -0.66 | | | | 0.12 | |
| MIN | 10.65 | 11.20 | 10.74 | 10.74 | | | | 11.52 | 10.75 |
| MAX | 21.58 | 20.93 | 21.88 | 20.51 | | | | 21.67 | 21.97 |
| MEAN | 16.70 | 17.08 | 16.85 | 16.28 | | | | 17.06 | 16.94 |
| AB MEAN DT | 0.54 | 0.69 | 0.35 | 0.73 | | | | 0.49 | |
| SQ MEAN DT | 0.64 | 0.85 | 0.49 | 0.86 | | | | 0.61 | |
| STDERR | 0.60 | 0.84 | 0.48 | 0.56 | | | | 0.60 | |

*Table 46 : Ceiling.*

| Floor temperature - MEA | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | ICE | KST | SP | SW | SER | MEAS. |
| DTMIN | -2.28 | -1.30 | -2.52 | -3.23 | | | | -1.89 | |
| DTMAX | 2.18 | 3.51 | 3.13 | 2.54 | | | | 3.61 | |
| MEANDT | 0.51 | 1.13 | 0.55 | 0.05 | | | | 1.09 | |
| MIN | 10.91 | 11.83 | 11.11 | 11.01 | | | | 12.04 | 10.83 |
| MAX | 20.98 | 21.51 | 20.99 | 19.92 | | | | 21.29 | 21.76 |
| MEAN | 16.73 | 17.35 | 16.77 | 16.26 | | | | 17.30 | 16.21 |
| AB MEAN DT | 0.65 | 1.14 | 0.69 | 0.38 | | | | 1.14 | |
| SQ MEAN DT | 0.79 | 1.30 | 0.83 | 0.62 | | | | 1.25 | |
| STDERR | 0.61 | 0.64 | 0.62 | 0.62 | | | | 0.61 | |

*Table 47 : Floor.*

Table 42 to 47 show that, in general, surface temperatures are underestimated for ICE (except for the floor).

For the other programs, surface temperatures are overestimated for all surfaces, except the ceiling.

#### *II.6.5.2 REFERENCE test cell*

| South wall temperature - REF | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | ICE | KST | SP | SW | SER | MEAS. |
| DTMIN | -1.47 | -1.52 | -1.10 | -1.53 | | | | -0.78 | |
| DTMAX | 1.98 | 1.75 | 1.26 | 0.65 | | | | 1.71 | |
| MEANDT | 0.06 | 0.09 | 0.05 | -0.68 | | | | 0.39 | |
| MIN | 10.52 | 10.98 | 10.48 | 10.54 | | | | 11.34 | 10.94 |
| MAX | 20.99 | 20.56 | 20.45 | 19.33 | | | | 20.60 | 20.61 |
| MEAN | 16.72 | 16.75 | 16.71 | 15.97 | | | | 17.05 | 16.66 |
| AB MEAN DT | 0.49 | 0.51 | 0.36 | 0.72 | | | | 0.48 | |
| SQ MEAN DT | 0.67 | 0.64 | 0.46 | 0.81 | | | | 0.61 | |
| STDERR | 0.67 | 0.63 | 0.45 | 0.44 | | | | 0.48 | |

*Table 48 : South wall.*

| West wall temperature - REF | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | ICE | KST | SP | SW | SER | MEAS. |
| DTMIN | -1.09 | -1.25 | -0.69 | -1.37 | | | | -0.52 | |
| DTMAX | 2.08 | 2.02 | 1.93 | 0.70 | | | | 2.13 | |
| MEANDT | 0.27 | 0.38 | 0.53 | -0.50 | | | | 0.74 | |
| MIN | 10.71 | 11.18 | 10.87 | 10.70 | | | | 11.65 | 10.94 |
| MAX | 20.80 | 20.33 | 20.67 | 19.10 | | | | 20.56 | 19.98 |
| MEAN | 16.66 | 16.77 | 16.92 | 15.88 | | | | 17.13 | 16.39 |
| AB MEAN DT | 0.55 | 0.54 | 0.58 | 0.59 | | | | 0.76 | |
| SQ MEAN DT | 0.72 | 0.72 | 0.71 | 0.67 | | | | 0.88 | |
| STDERR | 0.66 | 0.60 | 0.47 | 0.44 | | | | 0.47 | |

*Table 49 : West wall.*

| North wall temeprature - REF | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | ICE | KST | SP | SW | SER | MEAS. |
| DTMIN | -1.14 | -1.27 | -0.35 | -1.19 | | | | -0.06 | |
| DTMAX | 2.06 | 1.75 | 1.49 | 0.81 | | | | 1.70 | |
| MEANDT | 0.23 | 0.37 | 0.38 | -0.47 | | | | 0.57 | |
| MIN | 10.69 | 11.20 | 10.80 | 10.73 | | | | 11.54 | 11.03 |
| MAX | 20.75 | 20.24 | 20.57 | 19.17 | | | | 20.40 | 19.23 |
| MEAN | 16.61 | 16.75 | 16.76 | 15.90 | | | | 16.95 | 16.38 |
| AB MEAN DT | 0.51 | 0.56 | 0.42 | 0.52 | | | | 0.57 | |
| SQ MEAN DT | 0.68 | 0.72 | 0.51 | 0.60 | | | | 0.67 | |
| STDERR | 0.64 | 0.62 | 0.34 | 0.36 | | | | 0.35 | |

*Table 50 : North wall.*

| East wall temperature - REF | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | ICE | KST | SP | SW | SER | MEAS. |
| DTMIN | -0.62 | -0.98 | -0.28 | -1.03 | | | | -0.15 | |
| DTMAX | 2.38 | 2.18 | 1.96 | 1.24 | | | | 1.98 | |
| MEANDT | 0.60 | 0.73 | 0.63 | -0.11 | | | | 0.83 | |
| MIN | 10.81 | 11.31 | 10.79 | 10.83 | | | | 11.56 | 10.74 |
| MAX | 20.88 | 20.48 | 20.62 | 19.12 | | | | 20.48 | 19.38 |
| MEAN | 16.78 | 16.91 | 16.81 | 16.06 | | | | 17.01 | 16.18 |
| AB MEAN DT | 0.68 | 0.78 | 0.64 | 0.36 | | | | 0.83 | |
| SQ MEAN DT | 0.84 | 0.97 | 0.74 | 0.44 | | | | 0.91 | |
| STDERR | 0.59 | 0.64 | 0.38 | 0.43 | | | | 0.39 | |

*Table 51 : East wall.*

| Ceiling temperature - REF | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | ICE | KST | SP | SW | SER | MEAS. |
| DTMIN | -0.93 | -1.35 | -0.64 | -1.15 | | | | -0.44 | |
| DTMAX | 1.88 | 1.95 | 1.55 | 0.92 | | | | 1.81 | |
| MEANDT | 0.22 | 0.41 | 0.38 | -0.51 | | | | 0.59 | |
| MIN | 10.71 | 11.20 | 10.79 | 10.72 | | | | 11.57 | 10.86 |
| MAX | 21.05 | 20.63 | 20.85 | 19.36 | | | | 20.75 | 20.11 |
| MEAN | 16.80 | 16.99 | 16.95 | 16.06 | | | | 17.17 | 16.58 |
| AB MEAN DT | 0.44 | 0.61 | 0.42 | 0.57 | | | | 0.61 | |
| SQ MEAN DT | 0.62 | 0.79 | 0.54 | 0.67 | | | | 0.74 | |
| STDERR | 0.58 | 0.68 | 0.39 | 0.43 | | | | 0.44 | |

*Table 52 : Ceiling.*

| Floor temperature - REF | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | ICE | KST | SP | SW | SER | MEAS. |
| DTMIN | -4.65 | -4.02 | -4.84 | -6.18 | | | | -4.25 | |
| DTMAX | 1.58 | 1.95 | 1.49 | 0.79 | | | | 2.06 | |
| MEANDT | 0.02 | 0.42 | 0.06 | -0.92 | | | | 0.61 | |
| MIN | 10.97 | 11.81 | 11.16 | 11.00 | | | | 12.11 | 11.26 |
| MAX | 20.41 | 21.18 | 20.02 | 18.74 | | | | 20.52 | 24.23 |
| MEAN | 16.82 | 17.23 | 16.87 | 15.87 | | | | 17.41 | 16.80 |
| AB MEAN DT | 0.61 | 0.66 | 0.51 | 0.95 | | | | 0.83 | |
| SQ MEAN DT | 0.84 | 0.87 | 0.79 | 1.23 | | | | 0.96 | |
| STDERR | 0.84 | 0.76 | 0.79 | 0.82 | | | | 0.74 | |

*Table 53 : Floor.*

Table 48 to 53 show the same results for the REFERENCE test cell as for the MEASURE test cell :

- all surface temperatures (the floor as well) are underestimated for ICE ;
- for all other programs, surface temperatures are overestimated for all surfaces (the ceiling as well).

### II.6.6. Surface fluxes

We present here hourly integrated energies, in Wh.m$^{-2}$. No measurements are available.

#### *II.6.6.1 MEASURE Test cell*

| Energies in Wh/m2 | APA | AxBU | Clim | ICE | KST | SP | SW | SER | MEAS. |
|---|---|---|---|---|---|---|---|---|---|
| South flux | 1622.72 | 2210.83 | 2282.51 | 1651.10 | | | | -1861.05 | |
| West flux | 2158.46 | 2052.03 | 2213.63 | 1973.29 | | | | -1281.25 | |
| North flux | 2447.81 | 2315.03 | 2494.03 | 2233.40 | | | | -2552.54 | |
| East flux | 1204.05 | 1035.58 | 1249.83 | 1140.48 | | | | -2272.21 | |
| Ceiling flux | 1111.79 | 938.94 | 1121.00 | 1006.90 | | | | -1141.51 | |
| Floor flux | 940.88 | -1859.58 | 1623.74 | 1464.54 | | | | -1019.62 | |

*Table 54 : Surface fluxes for MEASURE cell.*

#### *II.6.6.2 REFERENCE Test cell*

| Energies in Wh/m2 | APA | AxBU | Clim | ICE | KST | SP | SW | SER | MEAS. |
|---|---|---|---|---|---|---|---|---|---|
| South flux | 1655.96 | 2210.83 | 2317.27 | 1588.08 | | | | -1898.56 | |
| West flux | 2104.03 | 2052.03 | 1301.74 | 2076.89 | | | | -1331.76 | |
| North flux | 2474.14 | 2315.03 | 2519.67 | 2145.82 | | | | -2580.20 | |
| East flux | 1255.71 | 1035.58 | 2159.89 | 982.57 | | | | -2220.81 | |
| Ceiling flux | 1138.91 | 938.94 | 1148.07 | 984.33 | | | | -1169.67 | |
| Floor flux | 955.42 | -1859.58 | 1646.40 | 1389.56 | | | | -1014.37 | |

*Table 55 : Surface fluxes for REFERENCE cell.*

Table 54 and 55 show problems of sign convention on heat fluxes.

As for the measurement of the temperatures, the measurement of heat fluxes on large surfaces is very difficult, and it would be difficult to draw conclusions on these results.

## II.7. Conclusions for ETNA2 Rounds

### *Validity of the data*

For this round, no problems were detected for the data provided, which were all included in this comparison exercise.

For the calculation of the vertical solar radiation, a problem has been detected for ICE simulations (predictions too high).

### *General discussion about the results*

For all the programs the energy consumptions are about 10-30% lower than the measurements in both test cells. This supports the indication of a problem characterizing overall UA-value of the test cells previously noted. For all programs, except for AxBU and SP, the simulated temperatures have close agreement, but are often lower than the measurements during the daytime. For AxBU and SP the temperature results in the day-light period are closer to empirical data, but the free float period (at the end of the experiment) shows these programs are more sensitive to solar radiation than the measured data and the other simulations.

For all programs, the magnitude of predicted values are close to actual data in terms of air temperature and operative temperature in both cells.

In general, for most of the data, the measurements are more sensitive to solar radiation than the simulation predictions. The similarity in the modelled results for a large group of programs together with differences from measured results suggests that there could be some difference in the experimental sequence or in its regulation which has not been taken into account for the corresponding simulations.

### *Coherence of the results between ETNA2 and ETNA1 results*

**AXBU :** In terms of temperatures, AxBU results for ETNA1 show temperatures higher than empirical data. This is not the case in the ETNA2 sequence during the free float evolution at the end of the sequence. Also for ETNA1 the AxBU temperatures are generally lower than for the other simulations. However for ETNA2, the energy consumption is also lower for AxBU than for the other programs, but the air temperatures are higher than for the other simulations. For AxBU results to be consistent with the other simulations and have consistency between ETNA1 and ETNA2 results (considering the disagreement regarding overall test cell UA identified previously), we should have observed a higher energy consumption for AxBU in ETNA2.

**CLIM :** The results of CLIM2000 for the two sequences are consistent. In ETNA1, the predicted temperatures are higher than the empirical data, and the energy consumption in ETNA2 is lower than empirical data.

**ICE :** For the REFERENCE cell, ICE shows a probable problem of set-point or control (too low set-point).

**SER :** The results of SERI-RES runs are consistent in terms of energy consumption. A lower energy consumption in ETNA2 is consistent with the fact that operative temperatures in ETNA1 are higher than empirical data. In addition, SER consumptions are lower than CLIM2000 consumption for ETNA2. This is consistent with the fact that operative temperatures in ETNA1 for SER are higher than CLIM2000 operative temperatures in ETNA1.

**APA, KST, SW and SP :** The lower consumption predicted by these simulations in ETNA2 are consistent regarding the higher temperature reached in ETNA1 sequence.

# III. EXPERIMENT ON GENEC TEST-CELLS

## III.1. General description of the FAI test cells

The GENEC test facility consists of 7 test cells in outdoor conditions. Three cells are made using sandwich prefabricated walls (Concrete, insulation, concrete) and are called FAI test cells. They can be used for testing building envelope components like windows, solar shading devices or solar walls, or for more fundamental studies (effect of night ventilation, effects of architectural shading devices, heating or cooling floor...).

The test facility was erected in 1986. Since this date numerous test experiments have been carried out primarily on "solar" building components which use solar energy to heat the building during the heating season.

The three test-cells can be used simultaneously for comparison tests on different products. The tests presented here were in test-cell 2 (FAI2).

## III.2. Participants of the FAI2 experiment (GENEC)

This round was then to compare test-cells models developed with 6 programs. The Table 56 presents the list of the participants of all the rounds, with the files analysed and presented in the corresponding reports.

In this report, we include only the latest results, which were provided before 08/98. For the teams that provided more than one set of results, please refer to previous reports to find discussions about it.

| **Notation** | **Program / Contributors** | **Report of 03/98** | **Report of 11/98** |
|---|---|---|---|
| AXBU | AxBU<br>Univ. Dresden, Germany | Cellfai2.axb<br>(file of 02/98) | Id. |
| APA | APACHE<br>BRE, Great Britain | Cellfai2.apa<br>(file of 01/97) | cellfai2.apa<br>(file of 08/98) |
| CLIM | CLIM2000<br>EDF, France | Cellfai2.clm<br>(file of 12/95) | Id. |
| SP | DOE-2<br>CIEMAT, Spain | fai2_t22.doe<br>(file of 12/97) | Id. |
| M2M | M2M<br>GISE, Marne la Vallée, France | Cellfai2.m2m.txt<br>(file of 02/98) | Id. |
| KST | PROMETHEUS<br>KlimaSystemTechnik, Germany | Cellfai2.kst<br>(file of 09/97) | Id. |

*Table 56 : List of the participants and files corresponding*

## III.3. The GENEC experimental sequence

An experiment has been carried out in GENEC cells to validate the calculation of solar gains by glazed surfaces. The experiment was obviously in a natural climate. Only data for cell number 2 will be presented in this section.

The experiment began on 04/10/1994 (day 278) and finished on 18/10/1994 (day 291). During this experiment, the cells were in natural climate and in **free float** (only solar heating). For each cell, there was no air infiltration and the air inside the test-cell was not stirred.

The attics, the crawl spaces and the gaps between the cells are called "guard zones".

## III.4. Available data to compare

**GENEC FAI2 AVAILABLE DATA**

| | Global solar radiation | Air temperature | Radiant temperature | Enclosure temperature |
|---|---|---|---|---|
| APA | | | | |
| AxBU | | | | |
| Clim | N/A | N/A | N/A | |
| M2M | | | | |
| KST | | Same data for air, radiant and enclosure temperature | | |
| SP | | | N/A | N/A |
| MEASUREMENTS | | | N/A | |

| | South wall temperature | South flux | West wall temperature | West flux | North wall temperature | North flux |
|---|---|---|---|---|---|---|
| APA | N/A | N/A | N/A | N/A | N/A | N/A |
| AxBU | | | | | | |
| Clim | | N/A | | N/A | | N/A |
| M2M | | | | | | |
| KST | N/A | N/A | N/A | N/A | N/A | N/A |
| SP | N/A | N/A | N/A | N/A | N/A | N/A |
| MEASUREMENTS | | N/A | | N/A | | N/A |

| | East wall temperature | East flux | Ceiling temperature | Ceiling flux | Floor temperature | Floor flux |
|---|---|---|---|---|---|---|
| APA | N/A | N/A | N/A | N/A | N/A | N/A |
| AxBU | | | | | | |
| Clim | | N/A | | N/A | | N/A |
| M2M | | | | | | |
| KST | N/A | N/A | N/A | N/A | N/A | N/A |
| SP | N/A | N/A | N/A | N/A | N/A | N/A |
| MEASUREMENTS | | N/A | | N/A | | N/A |

*Table 57 : Available data for GENEC 2 test-cell files.*

## III.5. Data period analysis

We excluded from analysis a pre-conditioning period of about 4 days.

The statistics are calculated from the beginning of day 282 to the end of the day 291.

# III.6. GENEC : Data analysis and comparison

## III.6.1. South facing solar radiation flux

| Global solar radiation | | | | | | | |
|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | M2M | KST | SP | MEAS. |
| DTMIN | -270.95 | -173.45 | | -222.02 | -181.00 | -117.42 | |
| DTMAX | 331.00 | 182.73 | | 60.83 | 67.27 | 319.93 | |
| MEANDT | 0.61 | 2.10 | | -19.68 | -7.97 | 14.86 | |
| MIN | 0.00 | 0.00 | | 0.00 | 0.00 | 0.00 | 0.00 |
| MAX | 858.00 | 844.82 | | 781.33 | 826.79 | 857.71 | 864.46 |
| MEAN | 178.21 | 179.70 | | 157.92 | 169.63 | 192.46 | 177.60 |
| AB MEAN DT | 64.70 | 22.76 | | 27.60 | 17.81 | 35.22 | |
| SQ MEAN DT | 111.89 | 42.92 | | 51.04 | 33.94 | 69.12 | |
| STDERR | 112.13 | 42.96 | | 47.19 | 33.06 | 67.64 | 277.70 |
| Energies in Wh/m2 | | | | | | | |
| | APA | AxBU | Clim | M2M | KST | SP | MEAS. |
| Global solar radiation | 42592.00 | 42948.80 | | 37742.30 | 40541.88 | 45998.12 | 42446.96 |

*Table 58 : South facing solar radiation flux. GENEC.*

The analysed data for south solar radiation indicate large differences between models (Table 58) :

– M2M and KST give predictions with correct azimuth assumptions but with smaller magnitude compared with actual data ;

– SP and AXBU give estimations with a similar error. Both models behave as if the azimuth angle of the south wall was erroneous. The models probably supposed a wall more to the west. Nevertheless, the magnitude of predicted solar radiations is correct ;

– APA (which derived an erroneous calculation in the previous round), was well corrected for this exercise.

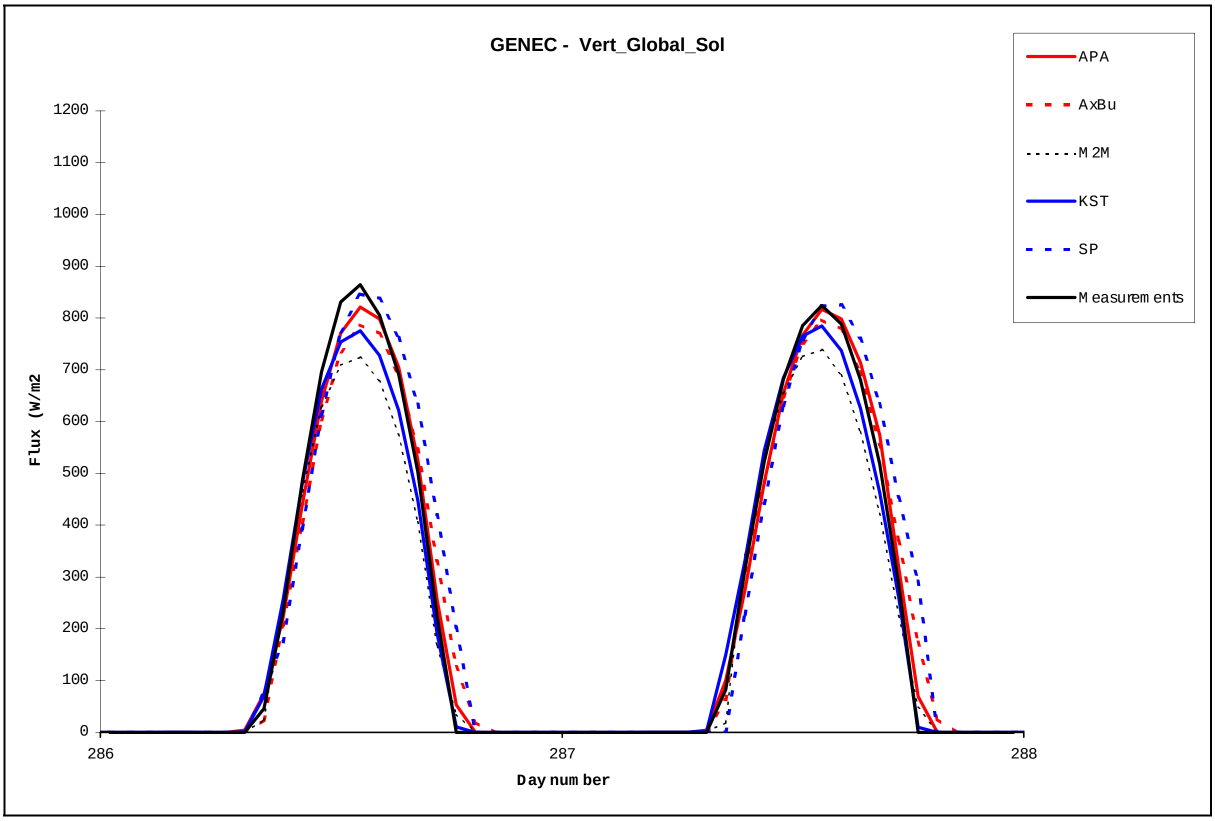


*Figure 18 : Vertical South facing radiation flux.*

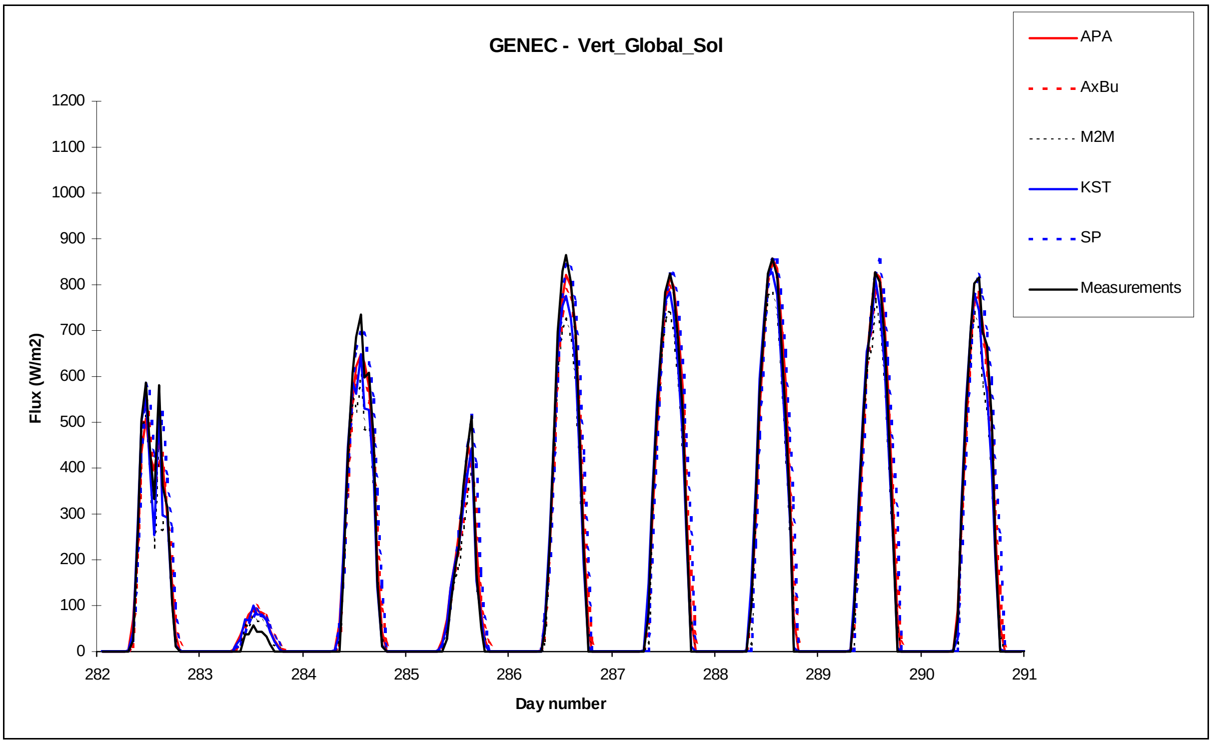


*Figure 19 : Vertical South facing radiation flux.*

Figure 18 and 19 show the good agreement of the simulated results with measured data.

### III.6.2. Air temperature

| Air temperature | | | | | | | |
|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | M2M | KST | SP | MEAS. |
| DTMIN | -3.90 | -2.03 | | -2.20 | -1.46 | -4.81 | |
| DTMAX | 1.49 | 3.85 | | 7.29 | 2.54 | 0.74 | |
| MEANDT | -0.86 | 1.34 | | 0.45 | 0.94 | -1.19 | |
| MIN | 15.70 | 16.67 | | 15.65 | 16.70 | 16.10 | 15.92 |
| MAX | 34.30 | 36.10 | | 39.45 | 35.96 | 30.80 | 34.58 |
| MEAN | 22.53 | 24.73 | | 23.84 | 24.33 | 22.21 | 23.39 |
| AB MEAN DT | 0.95 | 1.53 | | 1.55 | 1.08 | 1.27 | |
| SQ MEAN DT | 1.30 | 1.82 | | 2.38 | 1.27 | 1.68 | |
| STDERR | 0.97 | 1.24 | | 2.34 | 0.85 | 1.19 | 4.75 |

*Table 59 : Air temperatures. GENEC.*

The analysed data for air temperature show the following discrepancies (Table 60) :

- M2M predictions are close to actual data, M2M mean prediction is larger than actual data ;
- M2M predictions show a low accuracy dynamics response (large STDERR). M2M predictions suffer too high an increase in daytime and too high a decrease in night-time. The inertia as modelled is lower than the actual one ;
- KST and AxBU predictions are higher than actual data as mean predictions are 1°C and 1.3°C higher than actual data ;
- SP predictions are lower than actual data as mean predictions are 1.2°C lower than actual data ;
- APA predictions are in good agreement with actual data.

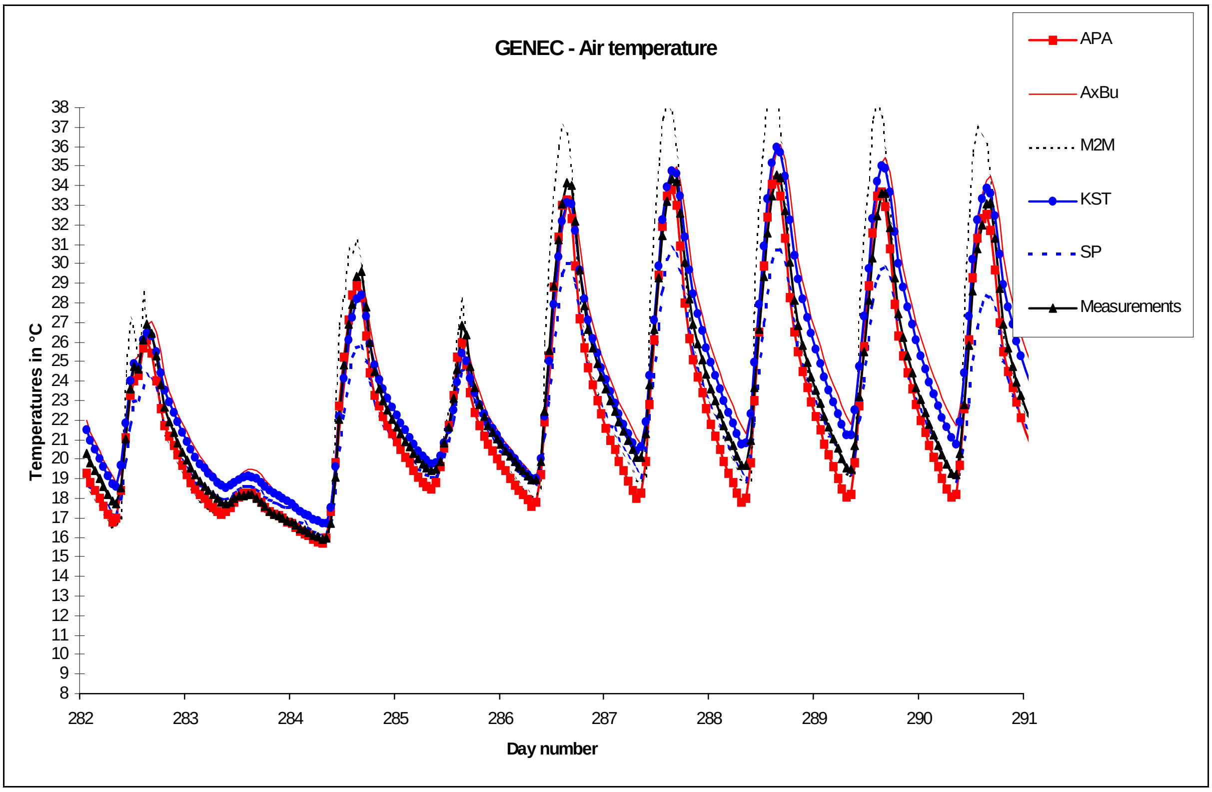


*Figure 20 : Air temperatures. GENEC.*

### III.6.3. Mean radiant temperature

| Radiant temperature | | | | | | | |
|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | M2M | KST | SP | MEAS. |
| DTMIN | | | | | | | |
| DTMAX | | | | | | | |
| MEANDT | | | | | | | |
| MIN | 15.70 | 16.98 | | 15.72 | 16.70 | | |
| MAX | 32.90 | 36.49 | | 36.09 | 35.96 | | |
| MEAN | 22.30 | 25.17 | | 23.27 | 24.33 | | |
| AB MEAN DT | | | | | | | |
| SQ MEAN DT | | | | | | | |
| STDERR | | | | | | | |

*Table 60 : Mean radiant temperatures. GENEC.*

The analysed data for radiant temperature show the following discrepancies (Table 60) :

- the behaviour for radiant temperature predictions is similar to that of air temperature ;
- a group of simulations are close together (KST, M2M and AxBU) ;
- APA predictions are lower than the other program’s predictions.

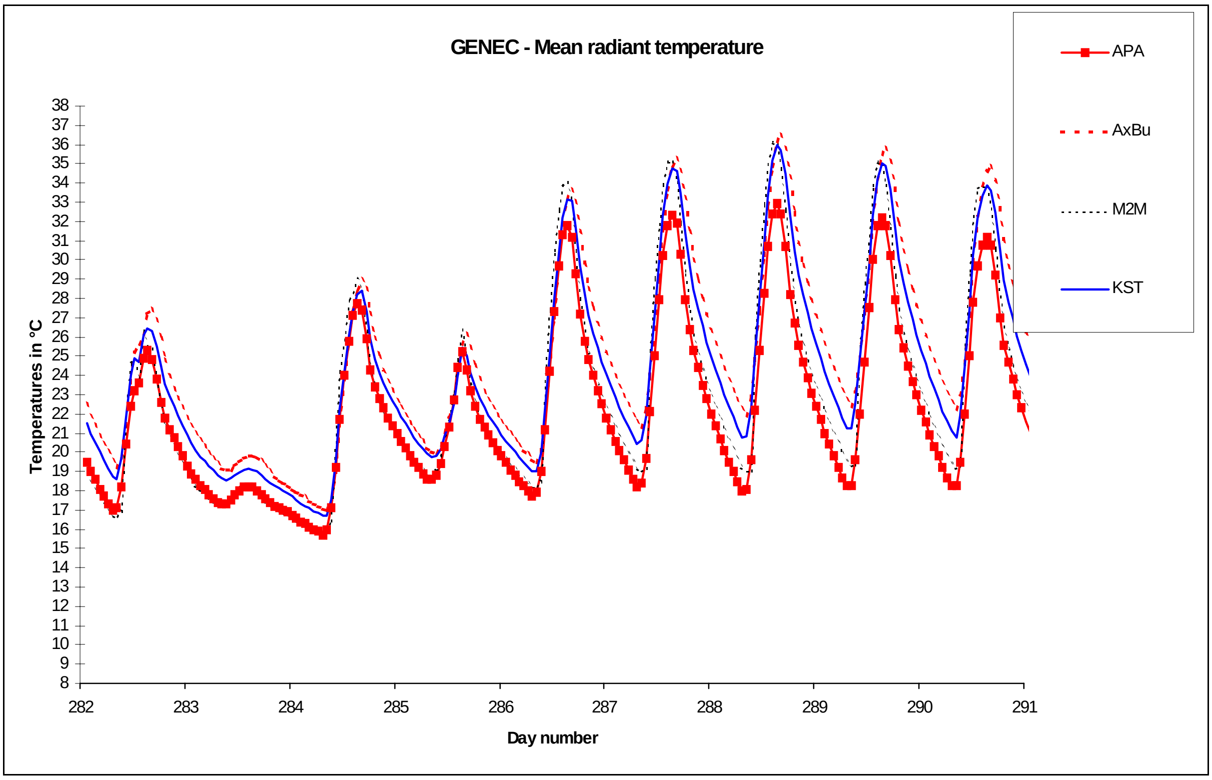


*Figure 21 : Mean radiant temperatures. GENEC.*

### III.6.4. Operative temperature

| Enclosure temperature | | | | | | | |
|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | M2M | KST | SP | MEAS. |
| DTMIN | -4.65 | -2.54 | -2.81 | -2.48 | -2.17 | | |
| DTMAX | 1.01 | 3.96 | 0.68 | 5.18 | 2.42 | | |
| MEANDT | -1.21 | 1.32 | -0.68 | -0.07 | 0.71 | | |
| MIN | 15.70 | 16.83 | 15.14 | 15.69 | 16.70 | | 16.01 |
| MAX | 33.60 | 36.30 | 34.54 | 37.77 | 35.96 | | 35.35 |
| MEAN | 22.42 | 24.95 | 22.94 | 23.56 | 24.33 | | 23.62 |
| AB MEAN DT | 1.24 | 1.63 | 0.87 | 1.16 | 1.00 | | |
| SQ MEAN DT | 1.70 | 1.94 | 1.06 | 1.63 | 1.19 | | |
| STDERR | 1.20 | 1.43 | 0.82 | 1.63 | 0.96 | | |

*Table 61 : Operative temperatures. GENEC.*

The analysed data for operative temperature show the following discrepancies (Table 61) :

- M2M predictions are close to actual data. During daytime, however, the model overestimates the magnitude of the operative temperature (see Figure 22). It is noticeable that this model's predictions are very close to actual data during the night ;
- AxBU and KST give day-time predictions similar to actual data but predict higher temperatures at night-time. The predicted mean temperature is higher than actual data. This can be explained by smaller heat losses ;
- CLIM predictions are in good agreement with empirical data, in terms of MEANDT and dynamic behaviour (STDERR) ;
- APA results show that the decrease of operative temperature during the night is too fast (high STDERR, and large negative MEANDT). In day-light period, APA results are in good agreement with actual data.

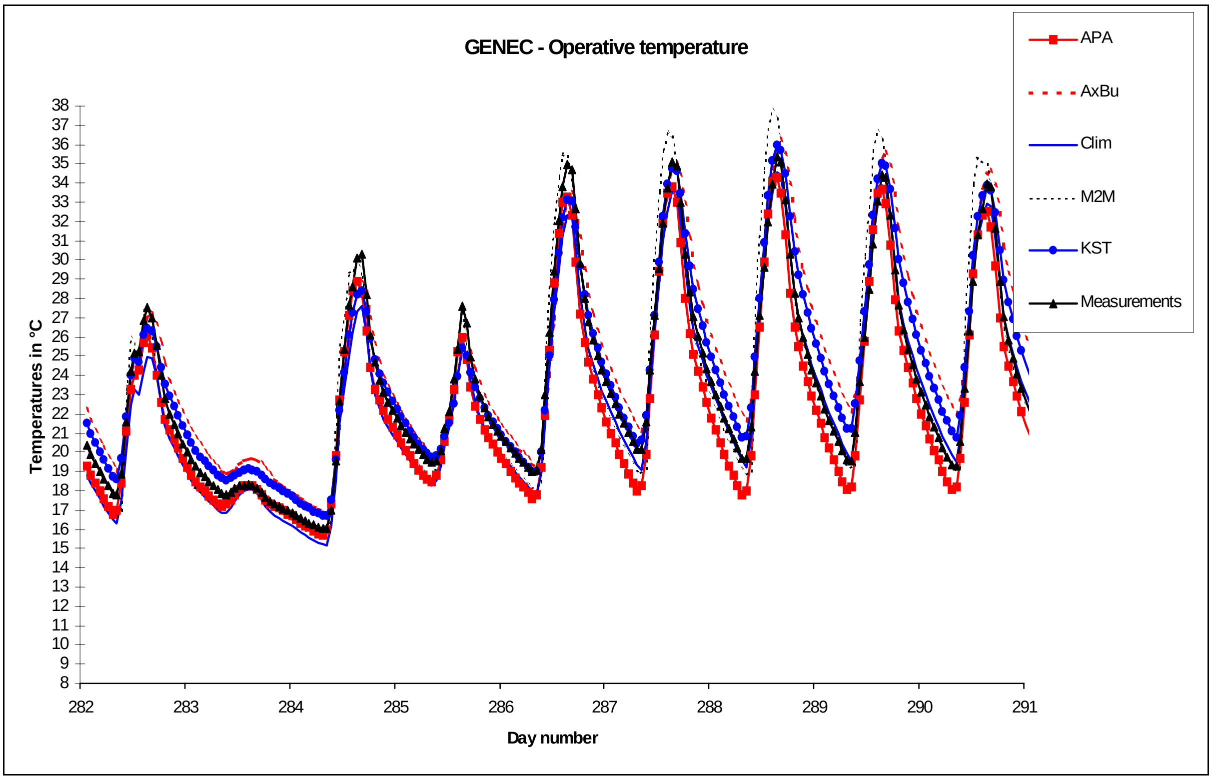


*Figure 22 : Operative temperatures. GENEC.*

### III.6.5. Surface temperatures

| South wall temperature | | | | | | | |
|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | M2M | KST | SP | MEAS. |
| DTMIN | | 0.14 | -2.07 | -2.50 | | | |
| DTMAX | | 4.85 | 1.27 | 7.79 | | | |
| MEANDT | | 2.13 | -0.70 | 0.38 | | | |
| MIN | | 17.05 | 14.83 | 15.54 | | | 15.88 |
| MAX | | 36.51 | 33.11 | 37.61 | | | 32.75 |
| MEAN | | 25.17 | 22.35 | 23.42 | | | 23.04 |
| AB MEAN DT | | 2.13 | 0.88 | 1.83 | | | |
| SQ MEAN DT | | 2.45 | 1.05 | 2.60 | | | |
| STDERR | | 1.23 | 0.78 | 2.58 | | | |

*Table 62 : South wall.*

| West wall temperature | | | | | | | |
|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | M2M | KST | SP | MEAS. |
| DTMIN | | -5.99 | -1.46 | -2.50 | | | |
| DTMAX | | 3.39 | 3.22 | 6.96 | | | |
| MEANDT | | -0.49 | 0.03 | 0.40 | | | |
| MIN | | 15.86 | 15.36 | 15.80 | | | 16.10 |
| MAX | | 32.18 | 35.01 | 37.58 | | | 32.84 |
| MEAN | | 22.67 | 23.19 | 23.56 | | | 23.16 |
| AB MEAN DT | | 1.64 | 0.83 | 1.38 | | | |
| SQ MEAN DT | | 2.17 | 1.04 | 2.11 | | | |
| STDERR | | 2.12 | 1.04 | 2.08 | | | |

*Table 63 : West wall.*

| North wall temperature | | | | | | | |
|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | M2M | KST | SP | MEAS. |
| DTMIN | | -1.75 | -1.65 | -1.72 | | | |
| DTMAX | | 4.65 | 4.11 | 6.57 | | | |
| MEANDT | | 2.00 | 0.13 | 0.43 | | | |
| MIN | | 16.92 | 15.16 | 15.70 | | | 16.04 |
| MAX | | 36.35 | 35.49 | 37.38 | | | 32.17 |
| MEAN | | 25.02 | 23.15 | 23.45 | | | 23.02 |
| AB MEAN DT | | 2.03 | 1.01 | 1.42 | | | |
| SQ MEAN DT | | 2.36 | 1.30 | 2.09 | | | |
| STDERR | | 1.24 | 1.29 | 2.05 | | | |

*Table 64 : North wall.*

| East wall temperature | | | | | | | |
|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | M2M | KST | SP | MEAS. |
| DTMIN | | -4.98 | -1.71 | -1.83 | | | |
| DTMAX | | 3.31 | 3.60 | 7.32 | | | |
| MEANDT | | -0.52 | -0.01 | 0.36 | | | |
| MIN | | 15.91 | 15.41 | 15.84 | | | 16.15 |
| MAX | | 32.08 | 34.97 | 37.62 | | | 34.85 |
| MEAN | | 22.72 | 23.23 | 23.60 | | | 23.24 |
| AB MEAN DT | | 1.62 | 0.92 | 1.51 | | | |
| SQ MEAN DT | | 2.08 | 1.20 | 2.32 | | | |
| STDERR | | 2.02 | 1.20 | 2.30 | | | |

*Table 65 : East wall.*

| Ceiling temperature | | | | | | | |
|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | M2M | KST | SP | MEAS. |
| DTMIN | | 0.27 | -1.41 | -1.51 | | | |
| DTMAX | | 4.31 | 3.46 | 7.73 | | | |
| MEANDT | | 2.35 | 0.31 | 0.79 | | | |
| MIN | | 17.02 | 15.18 | 15.69 | | | 15.74 |
| MAX | | 36.47 | 35.35 | 38.28 | | | 33.33 |
| MEAN | | 25.14 | 23.11 | 23.58 | | | 22.79 |
| AB MEAN DT | | 2.35 | 0.91 | 1.46 | | | |
| SQ MEAN DT | | 2.59 | 1.18 | 2.48 | | | |
| STDERR | | 1.10 | 1.14 | 2.35 | | | |

*Table 66 : Ceiling.*

| Floor temperature | | | | | | | |
|---|---|---|---|---|---|---|---|
| | APA | AxBU | Clim | M2M | KST | SP | MEAS. |
| DTMIN | | -0.14 | -1.72 | -2.44 | | | |
| DTMAX | | 4.52 | 2.09 | 1.08 | | | |
| MEANDT | | 2.25 | 0.35 | -0.30 | | | |
| MIN | | 17.44 | 16.01 | 16.39 | | | 16.37 |
| MAX | | 36.13 | 33.26 | 31.40 | | | 32.16 |
| MEAN | | 25.79 | 23.89 | 23.25 | | | 23.55 |
| AB MEAN DT | | 2.25 | 0.84 | 0.63 | | | |
| SQ MEAN DT | | 2.54 | 1.05 | 0.81 | | | |
| STDERR | | 1.18 | 0.99 | 0.75 | | | |

*Table 67 : Floor.*

We can see in Tables 62 to 67 that CLIM results shows a very agreement with the experimental data. This is probably due to the fact that the CLIM modelling used the solar patch effect. M2M presents also a good accuracy in terms of surface temperatures. AxBu shows a lower accuracy than the others software programs.

## III.7. Conclusion on GENEC results

For the GENEC results, only some participants have performed two rounds.

The different program simulations show less accurate results than for the ETNA1 and ETNA2 rounds, but the results show that they are roughly equivalent. M2M simulations suggest insufficient inertia is represented.