EMPIRICAL VALIDATION OF BUILDING ENERGY ANALYSIS TOOLS BY USING TESTS CARRIED OUT IN SMALL CELLS

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ABSTRACT

A large empirical validation exercise was recently completed in the framework of International Energy Agency (IEA) Solar Heating And Cooling (SHAC) Task 22 (Building Energy Analysis Tools) (Sub-task A3 « Empirical validation »). It includes a set of 10 modelling teams using different software programs from Europe and USA. ETNA test cells (EDF-France) have been used for this exercise. Four rounds have been completed, only the first round in blind way. At the end, different modelling problems have been corrected. This exercise has been totally useful for each participant to evaluate and compare its code to other ones.

1 - INTRODUCTION

One of the issues of International Energy Agency (IEA) Solar Heating And Cooling (SHAC) Task 22 (Building Energy Analysis Tools) is to investigate the availability and accuracy of building energy analysis tools and engineering models to evaluate the performance of solar and low-energy buildings. Tool evaluation activities include analytical, comparative and empirical methods, with emphasis given to blind empirical validation using measured data from test rooms. The documentation of engineering models uses existing standard reporting formats and procedures. In order to accomplish the stated goal and objectives, the Participants carry out research in the framework of two different Subtasks: Subtask A: Tool evaluation, Subtask B: Model Documentation.

This paper focuses on the empirical validation work carried out in subtask A.3 « Empirical validation ». The work was directed and managed by EDF (France). It began in January 1997 and was completed in February 1999. The final report is going to be published.

Three different validation exercises were carried out by using experimental data measured in EDF ETNA test cells and CEA GENEC test cells. This paper describes the data sets (only ETNA cells in this paper), the organization and management of the exercises, the participating software programs and their teams, and finally the comparison between simulated results and measured data. The work discussed in this article reflects the views of IEA Task 22 participants.

2 - VALIDATION EXERCISE

2-a - ETNA test cells

Since 1990, the EDF R&D Division has at its disposal a thermal and aeraulic test laboratory which consists of two semi-detached cells set adjacent to each other and built in accordance with the 1989 French building thermal regulations. This laboratory is called "ETNA" (Essais Thermique en climat Naturel et Artificiel) cells. The modular configuration of one of the surrounding heat seals makes it fit for carrying out tests under natural or artificial climatic conditions (Figure 1).

Figure 1 : ETNA test cells

This laboratory has two main purposes: to carry out thermal or aeraulic tests and comparisons on components, taking advantage of their semi-detached configuration to make real-time comparisons (natural climate), and to contribute to the experimental validation of building thermal models.

2-b - First experiment ETNA 1 (open loop)

An experiment has been carried out in ETNA test-cells to measure the difference between a realistic convector (15% radiative & 85% convective), located under the window, without stirring of the internal air and a purely convective heat source (100% convective), put in the centre of the room, with stirring of air (when the source is “ on ”, approximately 6/7 ac/h provided by the fan), for which hypotheses are close to the model used in the most software programs. During this experiment, the cells configuration was as follows (Figure 2) :

- guard zone temperatures controlled at 10°C,
- no air infiltration,
- pseudo random binary sequence at a nominal value of 500W,

- for REFERENCE cell, the air inside the cell was stirred using a fan to guarantee temperature homogeneisation and the heating system was assumed to be a pure convective heater (ideal reference heat source),
- for MEASURE cell, the air inside the cell was not stirred and the heating system was a "classical" electrical convector, commonly used in France.

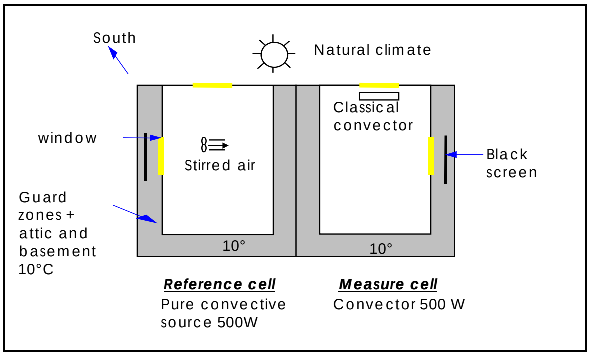

Figure 2 : First experimental sequence in ETNA

Different parameters were 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), ambient air temperature, wind speed and direction, relative humidity.

The following variables were also 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. Note that this operative temperature should be named operative temperature as recommended by several standards. Two surface temperatures per wall and a surface heat flux per wall were measured. Surface temperatures were taken as the average of the two sensors.

2-c - 2nd experiment ETNA2 (closed loop)

The configuration of this experiment is the same than the previous one except that there was a PRBS (pseudo-random binary sequence) on the setpoint temperature : this one varied randomly between the high setpoint and the low setpoint (Figure 3). For the end of the sequence, the two cells were in free float mode (the setpoint is put to zero).

2-d-Statistical measures used for comparison

Simple statistical measures were used to quantify the differences between the measurements and the predictions. They are given in Table 1. 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.

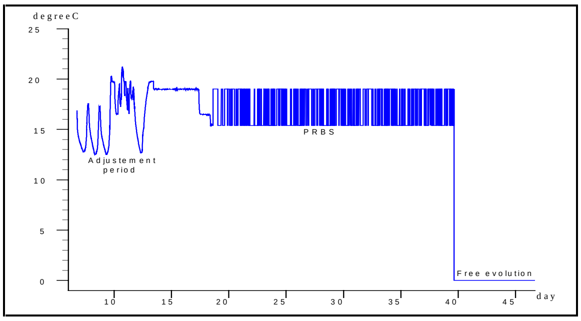

Figure 3 : Setpoint temperature evolution

Table 1: Statistical measures used in empirical validation

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	$D_t = X_t - M_t$ $D_t = REF_t - MEA_t$
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	$\lvert\overline{D}\rvert = \sum_{t=1}^{N} \lvert D_t / N\rvert$
Root Mean Square Difference	RSQMEANDT s	$\sqrt{D^2} = \sqrt{\sum_{t=1}^{N} D_t^2 / N}$
Standard Error	STDERR	$\sigma = \sqrt{\frac{1}{N}\sum_{t=1}^{N}(D_t - \overline{D})^2}$

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.

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.

2-e - Participating teams

The models were developed on different software programs from Europe and USA. Ten teams have participated :

- DOE-2, CIEMAT (Spain) (ETNA1 & 2),
- DOE-2, ZTL (Switzerland) (ETNA1 & 2),
- M2M, ENPC/GISE (France) (ETNA1),
- PROMETHEUS, KST (Germany) (ETNA1 & 2),
- AxBU, TU Dresden (Germany) (ETNA1 & 2),
- SERI-RES, NREL (USA) (ETNA1 & 2),
- APACHE, BRE (UK) (ETNA1 & 2),
- ICE, KTH (Sweden and Finland) (ETNA1 & 2),
- CA-SIS, EDF (France) (ETNA1),
- CLIM2000, EDF (France) (ETNA1 & 2).

In the following sections, the presentation of the results will be done in semi-anonymous form due to confidentiality matters. We will use the S1, S2, ... notations to describe results obtained from software 1, software 2, ... Obviously, the rank of the previous list is not respected.

2-f - Management of the exercises

The exercise were conducted and managed by EDF. The participants had the same « empirical validation package » containing an handbook giving the full description of the cells and the values for all site data, a description document for experimental sequence and electronic files given the climate data, the guard zones temperatures and the PRBS sequence. An hot-line was present during the exercises. All information given to one participant were immediately disseminated to all others. Each participant were asked to produce hourly predicted results in the same consistent format. All the data have been archived by EDF. In first round, all the predictions were made *blind* i.e. without any knowledge of experimental data. As requested by most of participants, the three last rounds were made *unblind*. Only three programs have performed this exercise in real blind conditions (Apache-BRE, CA-SIS-EDF and CLIM2000-EDF). In addition to that, the calculations for EDF were carried out by different teams than the ones which carried out the experiments.

3 - RESULTS

We only present here the results related to solar fluxes, air temperature, operative temperature, surface temperatures and energy consumption.

3-a - First experiment ETNA 1

Solar flux inside the cell

The energies presented in Table 2 show large differences between the different simulations. For S6, we can state that the value given as Flux_inside_cell (i.e. incoming solar radiation) is in fact Vert_glob_sol. (i.e. vertical global radiation on south wall). The “ Global radiation flux behind glazing inside test cell ” is not available among the outputs of the model. The indicated value is the one of the “ External "south" facing vertical radiation flux ”. As there is no measurement for solar flux inside the test-cell, we compare simulation results to the mean of all results.. The lowest error are given by S1 and S8 (3% and –1% respectively) and the higher errors are for S7 (-29%). For S7, the solar flux inside is not a standard output. This value has to be determined “manually”. Thus, the low value of the solar flux inside is a result of a wrong interpretation of the definition rather than a result of a bad simulation. (the result is given in W instead of W/m²). Nevertheless, even in the manual calculation was wrong, it does not impact the results of the simulation. For some programs like S4, the prediction of the vertical global solar radiation are too high for low values of the solar height (end of the day), and seem to be a little lower elsewhere. This result in an interesting example how compensating disagreements can achieve an agreeing result.

Air temperature

Apart from the transient period of 4 days, the established results in Table 3 and Figure 4 demonstrate in most cases, all simulations over-estimate the air temperature. Two groups are detected : “ large ” MEANDT for S1, S6, S7 and S8 simulations (probably a bad reproduction of static heat losses, due to a low U-Value for the modelled test-cell), and “ smaller ” MEANDT for other programs. Note here that the results of S9 are better for this round than for the previous. There is a very accurate prediction for static and dynamic response for air temperature for S4, S2 and S9. For the REFERENCE cell, the statistics presented in Table 4 show (see also Figure 5) that the results for S5 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 the REFERENCE cell as for the MEASURE cell. In addition, we conclude that the calculation for all programs are less accurate except S6. 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 S2 and S9 (in terms of mean difference).

Operative temperature

The statistics shown in Table 5 (MEASURE) based on simulations point out that 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 S1, S6, and S10 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 that listed thermal properties would indicate), and “ smaller ” MEANDT for other programs. There is also a very agreeing qualitative response for S2 and S5, in terms of MEANDT. The same results are shown in Table 6 for REFERENCE cell, and we can add that the statistics show, in general, less accurate results for this cell than for MEASURE cell, for all programs.

Table 2 : Statistical comparison for the vertical radiation flux calculation.

Flux inside cell (W/m2)										N/A : Non Available	
	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	N/A
MAX	610.00	562.17	577.67	513.10	538.71	825.69	530.83	518.24	564.30	626.11	N/A
MEAN	60.06	54.58	62.35	56.37	48.03	88.50	41.31	57.59	52.07	61.93	N/A
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 3 : Statistical comparison of air temperature to measurements for MEASURE test cell (ETNA1)

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

Table 4 : Statistical comparison of air temperature to measurements for REFERENCE test cell (ETNA1)

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

Table 5 : Statistical comparison of operative temp. to measurements for MEASURE test cell (ETNA1)

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

Table 6 :Statistical comparison of operative temp. to measurements for REFERENCE test cell (ETNA1)

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

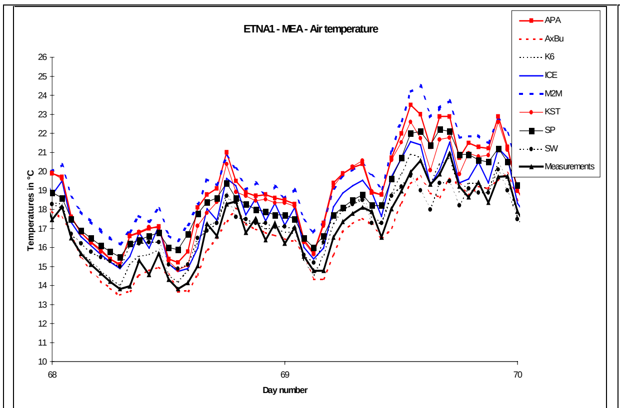

Figure 4 : Air temp., MEASURE cell (ETNA1)

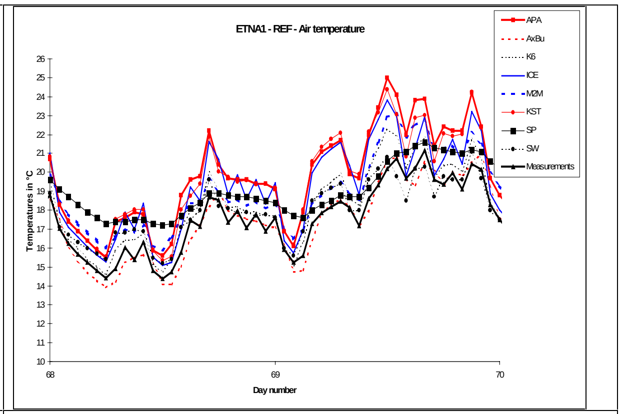

Figure 5 : Air temp., REFERENCE cell (ETNA1)

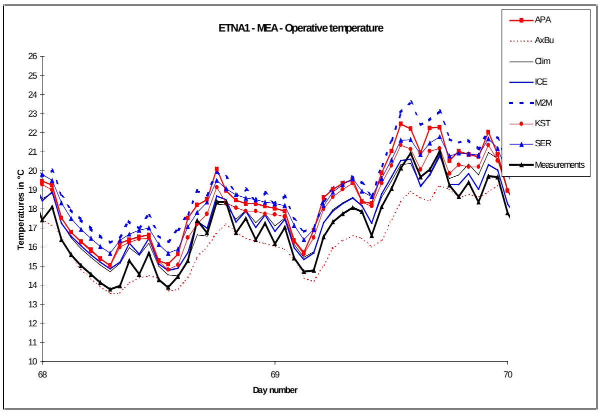

Figure 6 :Operative temp., MEASURE (ETNA1)

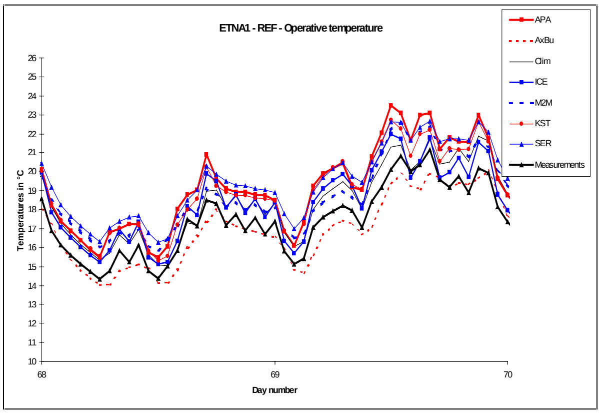

Figure 7 : Operative temp., REFERENCE (ETNA1)

Surface temperatures

The analysis of results for MEASURE cell show that in general, surface temperatures are over-predicted, except for the south wall (only S1 and S10 over estimate this temperature). In this test cell, the convector is located on the south wall. These differences on surface temperature predictions is consistent with the hypothesis of an existing thermal bridges in the test cell. Note that the surface temperature " measured " is the mean of two temperatures taken behind heater and away from heater. The measurements from the different sensors (not presented here) show that on the south wall, the differences between the sensors reach 8°C (difference due to the position of sensors). Then, these two different sensors do not represent precisely the surface temperature of each wall (they did not take into account the solar patch effect and the effect of corners). Then, it is difficult to say that these measured values represent the standard of truth. 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 the reality (measurements), this should result in a radiant temperature often higher than measurements. However, this is not the case for S2. For the REFERENCE cell, the analysis 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 radiant temperature are not systematically over estimated. It can be noted also that

Conclusions

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 best 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 the modelling errors ;
- the less agreeing results for REFERENCE cell simulation indicate difficulties to describe the simplified indoor physical phenomena ;
- the programs have difficulties to predict the real difference between the South wall surface temperature of MEASURE and REFERENCE cell.

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 4th 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 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.

To go deeper in the analysis, it would be interesting to define what the differences in fundamental methodology of each program are. Due to the limited size of this paper, we can't provide such an analysis. The reader is invited to see **[1]**.

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.

3 - b - Second experiment ETNA 2

Energy consumption

The established results (MEASURE) in Table 7 show that for all programs, predicted energy consumption is smaller than the actual data. Table 7 gives the relative difference of energy consumption to the measurement : S3 and S7 give the closest predictions, S1, S4, S5 and S8 give prediction with almost -20% deviation, S2 and S6 give predictions with about -30% deviation. Regarding ABMEANDT, we derive a similar classification but with enhanced discrepancies for S1 and S6 predictions. This is due to large standard-error for the latter prediction errors. The results in Table 8 (REFERENCE) show that the conclusions made for the MEASURE cell are the same here.

Air temperature

The analysis of the results (Tables 9 and 10) shows that 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. The Figures 9 and 10 show that S6 exhibit one time step advance in addition to an excessive response to solar radiation ; For S6 and S2, the simulations in free float mode at the end of the sequence show for these two programs higher temperatures than empirical data, pointing out an under-estimated U-value. For the other programs, the magnitude of the predicted variations are close together, but temperature are lower than measurements when heating is on and in case of solar radiation. S6 shows an inaccurate response for dynamic events (large STDERR).

Operative temperature

The analysis of the results shows no significant discrepancy between program predictions and actual data. The Tables 11 and 12 show that in terms of MEANDT and STDERR, all simulations are very close together. S2 has probably a too low U-Value (too high temperature in free float). S5 results show a to low sensitivity to solar effects. 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.

Conclusions

For all programs, except for S2 and S6 the temperatures achieved in regulation period are close together, but often lower than measurement in day-light period. This is not the case for S2 and S6, for which the results in the day-light period are closer to empirical data, but the free float period show these programs are too sensitive to solar radiation. For all programs, the magnitude of predicted variations are close to actual data for air temperature. The same results are demonstrated for the other air temperatures and for the REFERENCE test-cell.

CONCLUSION

For these exercises, the first run has been made blind, the others in non blind. Only three programs have performed this exercise in real blind conditions (Apache-BRE, CA-SIS-EDF and CLIM-EDF). In the last round, no significant difference exists between program predictions. The discrepancies become too small to allow a reliable diagnosis. The higher the number of **non-blind** runs, more agreement between the results and the measured data. Nevertheless, these exercises allowed to focus on some modelling and algorithmic problems which have been checked and corrected. They have been very useful to improve the quality of some software programs. This huge empirical validation work in an international framework was also of a great interest to compare different software programs together.

AKNOWLEDGEMENTS

The authors would like to thank each IEA Task22 Participant and Mr Pascal GIRAULT from EDF, who carried out the experiments in ETNA cells.

REFERENCES

[1] Moinard S. and Guyon G., « Empirical validation of EDF ETNA and GENEC test cells models », Report IEA SHAC Task22, Project A3 Empirical validation, February 1999.

Table 7 : Heating consumption and solar fluxes inside the cell, MEASURE (ETNA2)

Energies in Wh/m2									N/A : Non available
	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	N/A
Flux inside cell	37233.00	45133.08	51000.86	36262.82	21880.13	44256.77	34930.10	43970.95	N/A
Heating power	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									N/A : Non available
	APA	AxBU	Clim	ICE	KST	SP	SW	SER	MEAS.
DTMIN	-355.90	-473.54	-409.34	N/A	N/A	-501.90	-501.90	-501.90	
DTMAX	163.90	418.63	145.37	N/A	N/A	506.60	167.10	97.95	
MEANDT	-35.43	-59.06	-20.31	N/A	N/A	-56.74	-22.31	-43.13	
MIN	0.00	0.00	0.00	N/A	N/A	0.00	0.00	0.00	0.10
MAX	493.00	508.21	500.04	N/A	N/A	507.00	520.00	500.00	506.80
MEAN	146.21	122.58	161.33	N/A	N/A	129.28	159.33	138.51	181.64
AB MEAN DT	39.01	128.78	31.80	N/A	N/A	161.84	32.29	48.63	
SQ MEAN DT	59.54	190.42	53.09	N/A	N/A	231.38	52.19	73.33	
STDERR	47.87	181.13	49.08	N/A	N/A	224.56	47.21	59.34	

Table 8 : Heating consumption and solar fluxes inside the cell, REFERENCE (ETNA2)

Energies in Wh/m2									N/A : Non available
	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	N/A
Flux inside cell	37233.00	45133.08	50327.80	36334.51	21880.13	44256.77	34930.10	43970.95	N/A
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									N/A : Non available
	APA	AxBU	Clim	ICE	KST	SP	SW	SER	MEAS.
DTMIN	-329.10	-501.80	-318.42	N/A	N/A	-509.90	-447.10	-460.13	
DTMAX	150.40	560.93	112.17	N/A	N/A	382.90	117.80	81.97	
MEANDT	-33.75	-59.27	-17.56	N/A	N/A	-58.87	-20.10	-41.66	
MIN	0.00	0.00	0.00	N/A	N/A	0.00	0.00	0.00	0.10
MAX	494.00	581.00	500.04	N/A	N/A	454.00	555.00	500.00	554.30
MEAN	147.49	121.97	163.69	N/A	N/A	129.08	161.14	139.58	181.25
AB MEAN DT	42.04	141.07	22.61	N/A	N/A	161.33	33.83	44.17	
SQ MEAN DT	66.27	214.74	39.15	N/A	N/A	224.78	56.69	69.64	
STDERR	57.06	206.52	35.01	N/A	N/A	217.17	53.04	55.83	

Table 9 : Air temp., MEASURE (ETNA2)

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

Table 10 : Air temp., REFERENCE (ETNA2)

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

Table 11 : Operative temp., MEASURE (ETNA2)

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

Table 12 : Operative temp., REFERENCE (ETNA2)

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

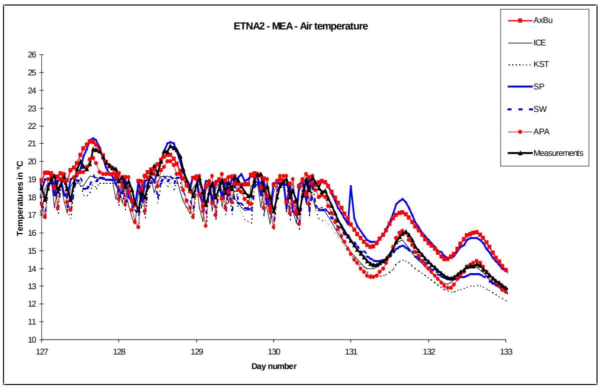

Figure 8 : Air temp., MEASURE cell (ETNA2)

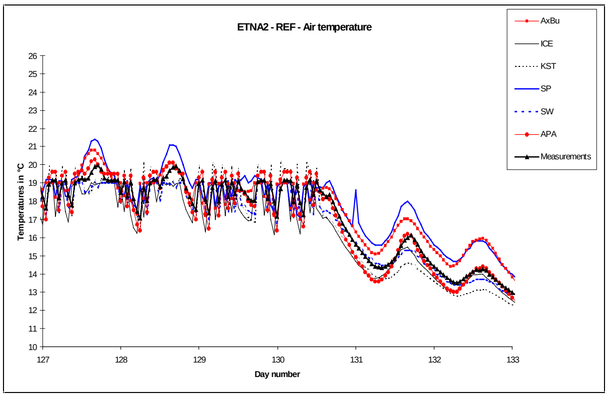

Figure 9 : Air temp., REFERENCE cell (ETNA2)

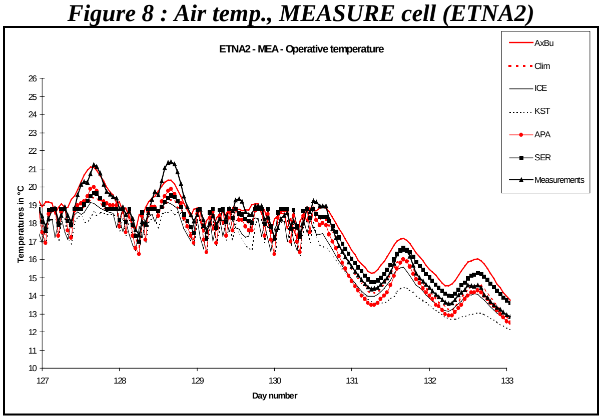

Figure 10 : Operative temp., MEASURE (ETNA2)

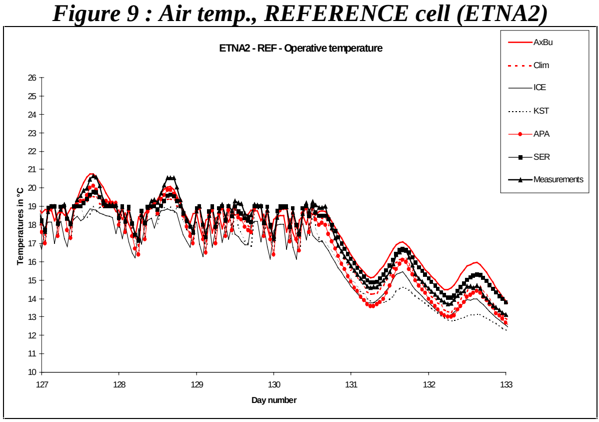

Figure 11 : Operative temp., REFERENCE (ETNA2)