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# HVAC BESTEST: Clim2000 and CA-SIS Results

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## ABSTRACT

The HVAC BESTEST has been developed within the framework of the IEA (International Energy Agency) It is a comparative test method developed for estimating the ability of whole building simulation programs to model the performance of unitary space cooling equipment. HVAC BESTEST, cases E100 – E200 (14 cases), consists of a series of steady-state tests using a carefully specified mechanical system (split system) applied to a highly simplified building envelope.
Two dynamic simulation programs, Clim2000 and CA-SIS, developed by the Research and Development Division of the French utility company EDF, participated in the HVAC BESTEST.
Clim2000 simulation program is essentially dedicated to R&D studies. CA-SIS simulation program was developed for engineering offices studies.
For the HVAC BESTEST, the split system models in Clim2000 and in CA-SIS are based on the same approach (based on performance data map normally provided by equipment manufacturers).

These results will be compared with analytical solutions and results from other software. Clim2000 and CA-SIS results are in agreement.

## INTRODUCTION

This work on the **B**uilding **E**nergy **S**imulation **TEST** for Mechanical Equipment (HVAC BESTEST) project is conducted by the Tool Evaluation and Improvement International Energy Agency (IEA) Experts Group.
The comparative test has been drawn up so that many different building simulation programs, representing different degrees of modelling complexity, can be tested.
Two dynamic simulation programs, Clim2000 and CA-SIS, developed by the Research and Development Division of the French utility company EDF, participated in the HVAC BESTEST.

### ✓ The Clim2000 software

Clim2000 simulation program is essentially dedicated to R&D studies. Clim2000 is based on a modular description of buildings and HVAC equipment. This description corresponds to an assembly of independent elementary models (doors, walls, windows, convectors, heat pumps,...) brought into relation by thermal phenomena or control channels. The algebraic and differential equations generated by Clim2000 are solved by the ESACAP solver, which automatically adapts its time step to the stiffness of the problem.
We have developed the so-called Clim2000 numerical simulation tool for conducting studies of heating strategies, air conditioning or ventilation options, insulating materials to be installed, bio-climatic and passive solar buildings. It uses the diagram of buildings of which physical behavior has been detailed. Each configuration studies can later give rise to an analysis of the energy invoice based upon the climatic conditions, the room occupancy but also upon the tariff option proposed to customers (day-tariff hours, night-tariff hours, ...).
Clim2000 is more specially oriented toward the study of the dynamic behavior of a set of technological

components than toward the fundamental study of heat exchanges. This global model, once it has been described, varies with the weather information, room occupation scenarios, internal temperature set points or electric power tariff-setting constraints.

**✓ The CA-SIS software**

CA-SIS simulation program was developed for engineering offices studies. Its main objective is to forecast the consumption and the operational costs in order to choose and optimize the appropriate HVAC equipment. CA-SIS is based on TRNSYS solver (time step of one hour).
A precise building description is given by the use of a graphical interface. A complete catalogue of HVAC system models is available (in comparison with Clim2000, CA-SIS elementary models are more based on « technology » than on « physics »).
In addition, the software package has a library of "solution types" including building types.
In order to carry out studies technical and economical, CA-SIS owns very model like heat pump, fan coil units, roof-top, central air system..., based on technology (performance map, ...).
To have many information about this software, see [9], [10], [11], [12].

**✓ Main differences**

Clim2000 runs on workstation UNIX. The building is described accurately. The algebraic and differential equations generated by Clim2000 are solved with time step automatically adapted to the stiffness of the problem. CLIM2000 models are more physical than technical. It allows to carry out fine studies on thermal and air flow phenomena of building.
CA-SIS runs on PC. The building's description is based on TRNSYS. The time step of simulation is fixed to one hour. CA-SIS comprises a rich library of flexible system. The models have a great technical dominant characteristic. CA-SIS allows to carry out technical and economical studies within short time.

## GENERAL DESCRIPTION OF TEST CASES

HVAC BESTEST, cases E100 – E200 (14 cases), consists of a series of steady-state tests using a carefully specified mechanical system (split system) applied to a highly simplified building envelope. The mechanical equipment load is driven by sensible and latent internal gains such that sensitivity of the simulation programs to a number of equipment performance parameters is explored. Output values for the cases such as compressor and fan electricity consumption, cooling coil sensible and latent loads, coefficient of performance (COP), zone temperature, and zone humidity ratio are compared and used in conjunction with diagnostic logic to determine the algorithms responsible for predictive differences. In these steady-state cases the following parameters are varied : sensible internal gains, latent internal gains, zone thermostat setpoint, and outdoor drybulb temperature. Parametric variations isolate the effects of the parameters singly and in various combinations, as well as the influence of : part-loading of equipment, varying sensible heat ratio, "dry" (no latent load) versus "wet" (with dehumidification) coil operation, and operation at typical Air-conditioning and Refrigeration Institute (ARI) industry rating conditions. In this way the models are tested in various regions of the performance map which describes the system's behavior.

**✓ Building zone description**

The configuration of the base case building (case E100) is a near adiabatic rectangular single zone with only user specified internal gains to drive cooling loads. The base building is a 48 m² floor area, single story, low mass building. Zone air volume is 129,6 $m^3$.
Materials properties are listed in table 1. The building insulation has been made very thick to effectively thermally decouple the zone from ambient conditions. Materials of the space have no thermal or moisture capacitance and there is no moisture diffusion through them. The floor has the same exterior film coefficient as the other walls, as if entire zone were suspended above the ground.

| Element | k (W/m.K) | thickness (m) | h (W/m².K) | R (m².k/W) |
|---|---|---|---|---|
| *int surf coef* | --- | --- | 8.29 | 0.121 |
| *insulation* | 0.010 | 1 | --- | 100 |
| *ext surf coef* | --- | --- | 29.3 | 0.034 |
| *TOTAL* | --- | --- | --- | 100.155 |

**Table 1: material specifications from inside to outside for exterior wall, floor and roof**

| Component | area (m²) | UA (W/K) |
|---|---|---|
| *wall* | 75.6 | 0.755 |
| *floor* | 48 | 0.479 |
| *roof* | 48 | 0.479 |
| *infiltration* | --- | 0 |
| ***TOTAL UA*** | --- | **1.713** |

**Table 2: summary of building**

## ✓ Mechanical system

The mechanical system represents a simple unitary vapor compression cooling system, or more precisely a split system, air-cooled condensing unit with indoor evaporator coil.

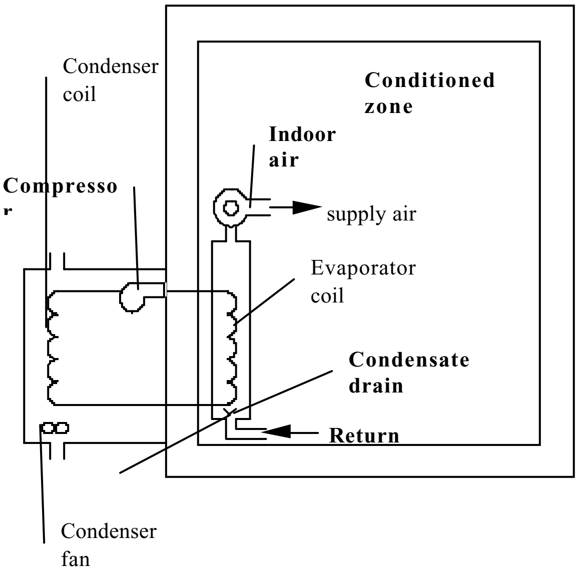



**Figure 1**: split system

Equipment full-load capacity and full-load performance data are given in performance table (data, courtesy Trane Co., tyler, Texas, USA).

The full load COP must be adjusted in part load operation. System coefficient of performance (COP) degradation due to part load operation is described in the following equation:. The COP Degradation Factor (CDF) is a multiplier to be applied to the full-load system COP at a given Part Load Ratio (PLR), where,

- full load COP: read in performance map according to ODB#, EWB#, EDB#
- CDF = 1-0.229 (1-PLR#) where 0≤PLR≤1
- COP = full load COP*CDF#

The equation is based on information provided by the equipment manufacturer. The efficiency degradation may be thought of as being caused by additional start-up run time required to bring the evaporator coil temperature down to its equilibrium temperature for the time(s) when the compressor is required to operate during an hour with part load [4], [6], [7], [8].

# cf glossary

## ✓ HVAC BESTEST case description

The table 2 summarizes all the cases.

| | zone | | | weather |
|---|---|---|---|---|
| | internal gains | | setpoint | |
| | sensible [W] | latent [W] | EDB | ODB |
| Case | dry zone series | | | |
| E100 | 5400 | 0 | 22.2 | 46.1 |
| E110 | 5400 | 0 | 22.2 | 29.4 |
| E120 | 5400 | 0 | 26.7 | 29.4 |
| E130 | 270 | 0 | 22.2 | 46.1 |
| E140 | 270 | 0 | 22.2 | 29.4 |
| | humid zone series | | | |
| E150 | 5400 | 1100 | 22.2 | 29.4 |
| E160 | 5400 | 1100 | 26.7 | 29.4 |
| E165 | 5400 | 1100 | 23.3 | 40.6 |
| E170 | 2100 | 1100 | 22.2 | 29.4 |
| E180 | 2100 | 4400 | 22.2 | 29.4 |
| E185 | 2100 | 4400 | 22.2 | 46.1 |
| E190 | 270 | 550 | 22.2 | 29.4 |
| E195 | 270 | 550 | 22.2 | 46.1 |
| | full load at ARI conditions | | | |
| E200 | 6120 | 1817 | 26.7 | 35 |

**Table 3: case descriptions**

## SIMULATION: CA-SIS AND CLIM2000 RESULT

The simulation is run for 2 months but we give output only for one month (February). The first month (January) of the simulation period serves as an initialization period.

For HVAC BESTEST, the split system model in Clim2000 and in CA-SIS are based on the same approach (based on performance data normally provided by equipment manufacturer). The difference between the two software rests in the building model itself and on the way the split system model is connected to the building model.

The results for different levels of modeling would be presented for both software:
➩ level 1: basic level (before "BESTESTing", blind test)
➩ level 2: basic level + COP degradation factor sensitivity to part load ratio (first improvement after "BESTESTing")
➩ level 3: level 1 + improvement on performance maps extrapolation (second improvement after "BESTESTing")

Results are presented for the 3 levels for each software. Each level in the process permitted to improve the model accuracy.

### ✓ CLIM2000 result:

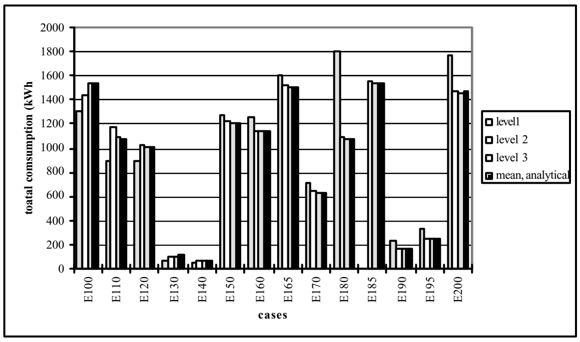



**Figure 2 : cooling energy consumption total**

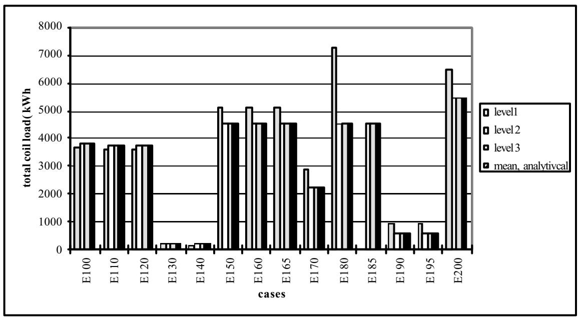



**Figure 3 : evaporator coil load total**

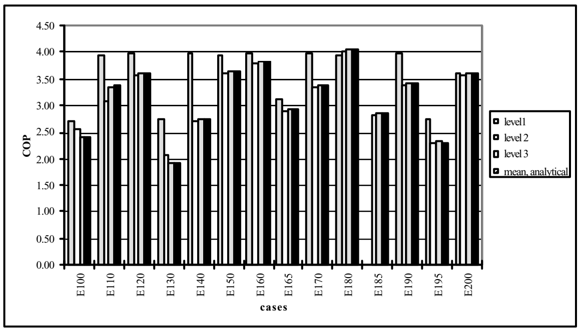



**Figure 4: mean COP**

For level 1, we couldn't achieve any result for case E185 because we had a numerical problem. In this case, the cooling system is under over-load conditions.

For level 1 the results obtained are not correct. The model was a basic model without the COP Degradation Factor and extrapolation of performance map.

For the level 2, we obtained better results but some problems remain because of the extrapolation of performance map.

For level 3, we extrapolated the performance map (using automated extrapolation of EWB and manual extrapolation of EDB) and we added a new performance map to indicate the limits of performance of the split system in dry coil conditions. These modifications permitted to reach agreement with the analytical solution results, excepted for the E200.

The figure 5 represent the different phases.

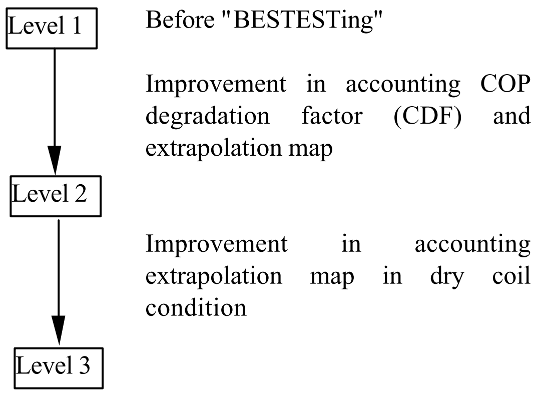



**Figure 5: BESTEST procedure for CLIM2000**

### ✓ CA-SIS Result

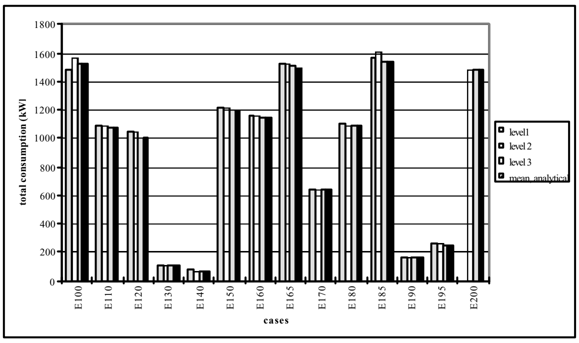



**Figure 6: cooling energy consumption total**

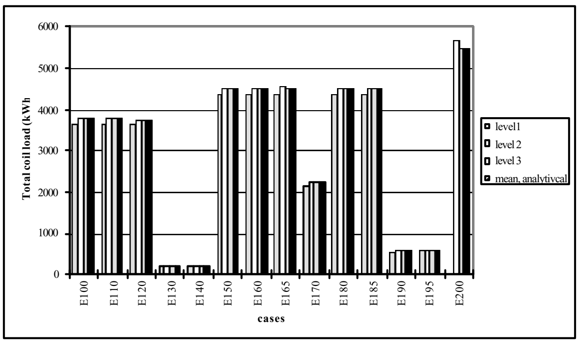



**Figure 7 : evaporator coil load total**

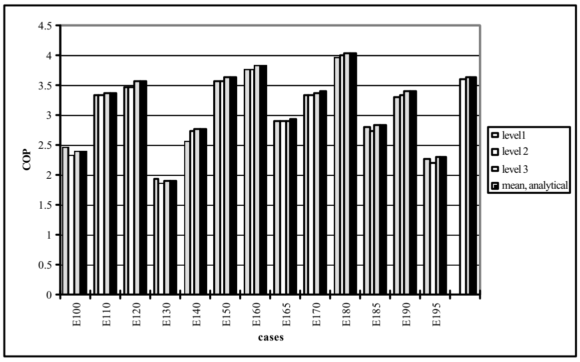


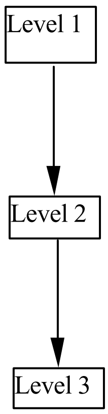

**Figure 8: mean COP**

For level 1 the result obtained are not correct as the COP Degradation Factor is absent and performance map has not been extrapolated. We couldn't achieve any result for case E200 because performance map was not extrapolated.

For the level 2, we obtain better result but problems remain because the extrapolation of performance map was done but not correctly completed for the dry coil conditions.

For level 3, we obtain good results. We improved extrapolation of performance map for dry coil conditions. We can notice that this factor have a great influence on results. These modifications permitted to reach agreement with the analytical solution results.

The figure 9 represent the different phases.




before"BESTESTing" but after "BESTESTing" for CLIM2000

Improvement in account COP degradation factor (CDF) and extrapolation map

Improvement in account extrapolation map in dry coil condition

**Figure 9: BESTEST procedure for CA-SIS**

## ANALYSIS: COMPARISON BETWEEN RESULTS

In this section, we compare the last CA-SIS and CLIM2000 results with the mean of results of other software and with analytical solutions.

✓ **Comparison on total cooling energy consumption**

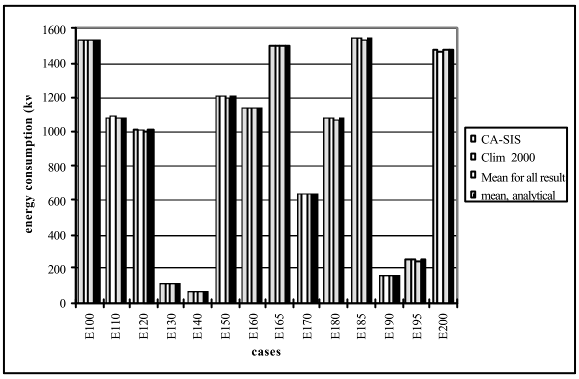



**Figure 10 : cooling energy consumption, total**

We can see in figure 10 that the CA-SIS and CLIM2000 results are good. We note that the difference between CA-SIS and analytical result are lower than 1 % and for CLIM 2000 1,2%.

✓ **Comparison on total cooling coil load**

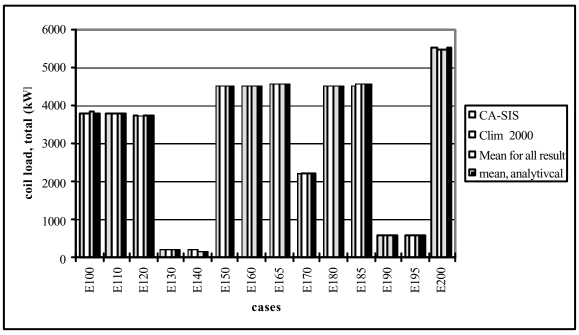



**Figure 11: cooling coil load, total**

We can see in figure 11 that the CA-SIS and CLIM2000 results are good. We note that the difference between CA-SIS and analytical result are lower than 0,6 % and for CLIM 2000 1,1%.

✓ **Comparison on mean COP**

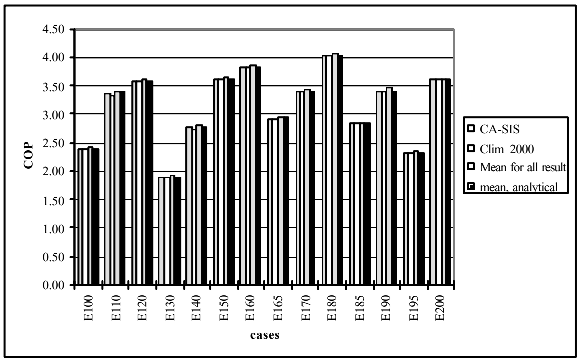



**Figure 12: Mean COP**

We can see in figure 12 that the results are correct. We note that the difference between CA-SIS and analytical result are lower than 0,5 % and for CLIM 2000 1,2%.

✓ **Conclusion**

For each output of the model (humidity, temperature,...), CA-SIS and CLIM2000 obtain good result in comparison with other software and with analytical results.

## CONCLUSION OF RESULTS

- CLIM 2000:

For the first round of simulations, we used a basic model which obtained very bad results. It normally because the model was not adapted but we did not want to miss "the train" of HVAC BESTEST. In the second model, we improve the basic model and we obtained better results but it was not satisfactory. After analysis with HVAC BESTEST procedure, we improved the model to obtain good results.
With HVAC BESTEST, we have been able to represent correctly a split system in CLIM2000.

- CA-SIS:

For the level 1, we used a model without taking into account COP degradation factor (CDF), extrapolation of performance map. The results were not very good. After analysis, we improved the model in level 2, taking into account extrapolation of performance map and CDF, but we still have problem in dry coil conditions. So we changed model in level 3, and we obtain good results. The final results are close to analytical solutions and to those of other software.
The HVAC BESTEST allowed to improve the model of split system in CA-SIS.

The first tests carried out with CA-SIS benefited from first tests results with CLIM2000 because they have been carried out subsequently. It's the reason why the first results with CA-SIS were closer to references values (analytical solutions) than those with CLIM2000.


## ACKNOWLEDGEMENTS

Thanks to J. NEYMARK for his help in diagnostic in result for HVAC BESTEST.
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## CONCLUSIONS

Over the three-year field trial effort there were several revisions to the HVAC BESTEST specifications and subsequent re-execution of computer simulations. This iterative process led to refinement of HVAC BESTEST, and the results of the tests led to improvement and debugging of the programs.
For EDF, IEA task22 represents a good opportunity to compare CA-SIS and CLIM2000 results with other available building energy analysis tools.
The models of split in CA-SIS and CLIM2000 have a good performance in comparison with other software and analytical solutions. With this case tests, we were able to validate the behavior of split under controlled load and weather conditions.

The HVAC BESTEST procedure is useful to diagnose a software program.

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## GLOSSARY

COP : coefficient of Performance for cooling (refrigeration) system is ratio, using same units, of the net refrigeration effect to the cooling energy consumption.

CDF: COP degradation Factor is a multiplier ($\leq$ 1) applied to full load system COP. CDF is a function of part load ratio.

PLR: Part Load Ratio is ratio of the net refrigeration effect to adjusted net total capacity for cooling coil.

EDB: Entering Drybulb Temperature (air entering the evaporator coil).

EWB: Entering Wetbulb Temperature (air entering the evaporator coil).

ODB: Outdoor Drybulb Temperature