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TESTING THE ENERGY SIMULATION BUILDING MODEL OF CONSOCLIM USING BESTEST METHOD AND EXPERIMENTAL DATA

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ABSTRACT

Consoclim is a building energy simulation software package which aims to simplify the input data.

The building is modelled by only one capacity and five resistances. The inputs related to the building are reduced to global U-values of the walls, solar factors of windows and two inertia parameters.

This building model is assessed using BESTEST method. The results show that only few inputs are sufficient to characterise the building.

A comparison with experimental data of building in operation shows a good agreement between the results on energy consumption of air conditioning system. The influence of input data on energy consumption has been assesed by a sensitivity study.

INTRODUCTION

In building simulation tools, the number of inputs to be provided is generally tedious for designers. ConsoClim has been developed in the aim to reduce the large amount of inputs as much as possible and to use input data which are easily available by designers such as data found in manufacturer's catalogs. Since the imput data are limited in Consoclim, this software package makes easier the sensibility studies. These sensibility studies are very useful for designers to find results associated with a level of uncertainty and to assess the most influent inputs to reduce the energy consumption of a given building.
First, ConsoClim is compared to BESTEST in order to check the relevance of the reduction of input number on building characterization.
Then, the software package is compared to experimental data. Since the input data are known with a level of uncertainty, a sensitivity study has been carried out. The level of uncertainty associated with the energy consumption results is so provided. The influence of each input on energy consumption has been assessed.

BUILDING MODEL

In ConsoClim (Bolher et al., 1999), the building model is based on the simplification of the heat transfer between internal and external environment. A R5-C1 equivalent electric representation of building components is used. The main advantage of the model is its simplicity. Inputs are easy to parametrize and it is easy to take into account phenomenons such as variable solar protection.

The building is described by three temperatures: T_a, indoor temperature, T_m, mass temperature and T_s mean temperature between indoor temperature and mean radiant temperature.

T_s is defined as $(hc.T_a + hr.T_{rm})/(hc + hr)$ and T_{rm} is mean radiant temperature.

Three outdoor temperatures allow to define heat exchange: T_e, outdoor temperature, T_{es}, solar equivalent temperature for light external components, T_{em}, solar equivalent temperature for heavy external components. T_e is an input and T_{es} and T_{em} are calculated with T_e, direct solar radiation, long wave sky radiation and wall characteristics.

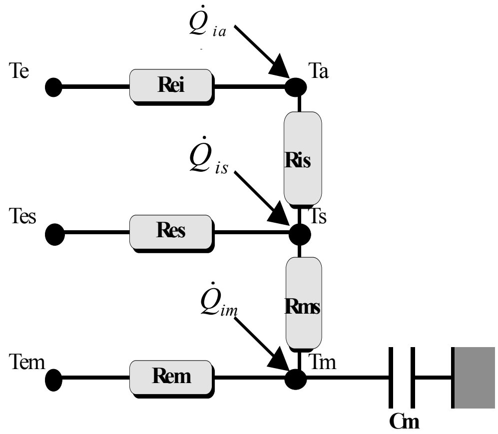


Figure 1 Equivalent electric representation of the building model

In figure 1, thermal resistances are :

- R_{ei} [K/W]: thermal resistance representing fresh air flow rate
- R_{es}, R_{em} : thermal resistance between indoor and outdoor of light and heavy components

- R_{is}, R_{ms} : thermal resistance between internal surfaces of light and heavy components and indoor air

Thermal resistances R_{is}, R_{ms} and R_{em} are constant and characterise the building. R_{ei} varies with time and depends on infiltration and ventilation management and R_{es} varies with solar protections management.

Heat flux $\dot{Q}_{ia}$, $\dot{Q}_{is}$ and $\dot{Q}_{im}$ represent heat flux on indoor air, light component and heavy component due to internal gains and solar radiation. Internal gains and solar radiation are split into a convective part and a radiative part.

The inputs are reduced to the U-values of the heavy and light components, the solar factor relative to long and short wave of solar radiation of the windows and two inertia parameters defined as in the standard ISO13786. A pre-processor calculates resistances, equivalent temperatures and heat flux of the building model thanks to meteorological data and the building inputs defined above.

BESTEST COMPARISON

ANSI/ASHRAE Standard 140-2001, (2001), Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs, proposes a comparison procedure to evaluate building energy codes. The method is made of simulation benchmark test cases with the results of other codes (BLAST-3.0 level 193 vl, DOE-2.ID14, ESP-RV8, SRES/SUNCODE5.7, SERIRES 1.2, S3PAS, TASE, TRNSYS13.1) already compared on the same tests. Benchmarks allows to compare free floating temperature and heating and cooling requirements. Note that none of the codes is absolutely validated : so, the aim of the BESTEST is limited to look for major errors of the software package.

"*This standard method of test can be used for identifying and diagnosing differences in predictions for whole building energy simulation software that may possibly be caused by software errors*" (ANSI/ASHRAE Standard 140-2001, 2001).

Determination of the agreement between the tested software and the BESTEST is not fixed in the standard. Two methods could be used to analyze the results:

- magnitude of result
- magnitude and direction of sensibility.

The basis case is a rectangular room and different variations are tested to check the correct answer of the model. Firstly, window orientation, solar protections, temperature set-points are modified. Two inertia are used. Then, model response without any HVAC system is compared. At last, detailed tests allow to check algorithms. We only present here the results for the first step of simulation test.

The meteorological data used are given under Typical Meteorological Year format (TMY). The chosen climate is cold during winter with a minimal temperature of -24,4°C, and hot and dry during summer with a maximal temperature of 35°C, latitude is 39,8° North, altitude is 1609 m.

Diffuse solar radiation is not given in the meteorological file nor than sky temperature. Sky temperature is an input that allows to calculate heat exchange with the sky. The ConsoClim model requires these data. That is the reason why the diffuse solar radiation has been calculated from global horizontal solar radiation and direct normal solar radiation. Sky temperature has been fixed equal to outdoor temperature minus 12°C.

Principal characteristics of the room are summarized in Table 1.

Table 1 Building description

Dimensions	Single stair zone L = 8m, P = 6m, h = 2,7m S = 48m² V = 129,6m^3
Walls	U_{wall} = 0,514 W/(m².K), U_{roof} = 0,318 W/(m².K), U_{floor} = 0,039 W/(m².K)
Permeability	0,5 Vol/h constant, no dependance on wind velocity or outdoor temperature.
Internal gains	200W constant 60% radiation and 40% convection
Absorptivity	0,6 inside and outside. Emissivity is 0.9
Surface heat transfer coefficients	Outside : 29,3 W/(m².K) and 21 W/(m².K) Inside : 8,29 W/(m².K)
Windows	U_{window} = 3 W/(m².K) S_{normal} = 0,789
System	Ideal air heating and cooling system, no losses, no auxiliaries
Setpoints	Heating 20°C, Cooling 27°C, no night setback

- (ANSI/ASHRAE Standard 140-2001, 2001) specifies that a large floor insulation is chosen to prevent from difficulties to model ground heat transfer. The supposed ground temperature is 10°C.
- Infiltration air flow rate is corrected according to the altitude.
- Value of surface convective heat transfer coefficient is chosen to 21W/(m².K) for all outdoor surface instead of 29,3 W/(m².K) for walls and 21W/(m².K) for windows.
- The test case allows to calculate solar factor for the different wavelengths.

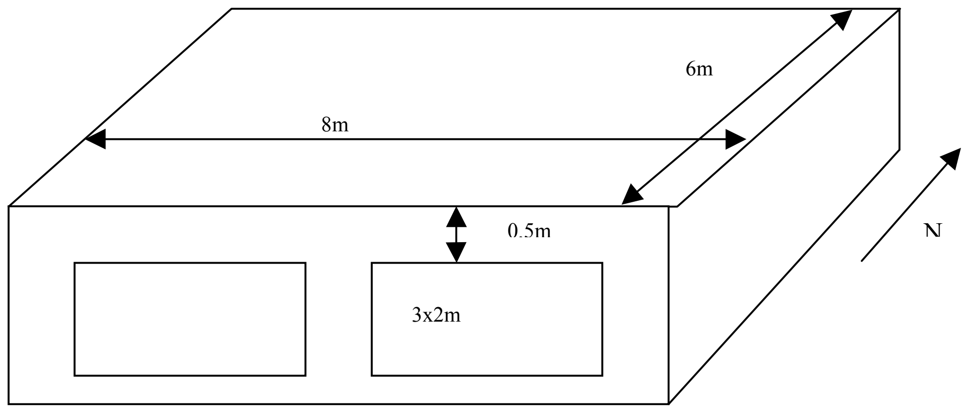


Figure 2 Building scheme and solar protections

Tableau 2 Variations of parameters for different tests

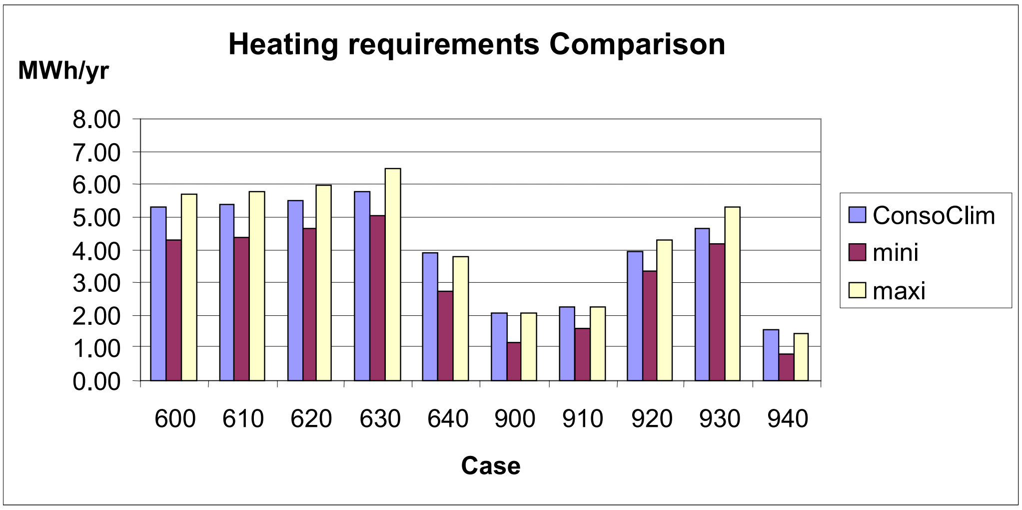
Case 600 = base case	Indoor insulation : light inertia 2 windows of 6m² on the south frontage
Case 610	Case 600 with a roof recess of 1m
Case 620	Case 600 with one window on east and one on west
Case 630	Case 620 with a roof recess over each window and vertical protection
Case 640	Case 600 with night setback : 10°C from 23h to 7h
Case 900	Case 600 with outdoor insulation : heavy inertia
Case 910	Case 610 with outdoor insulation : heavy inertia
Case 920	Case 620 with outdoor insulation : heavy inertia
Case 930	Case 630 with outdoor insulation : heavy inertia
Case 940	Case 640 with outdoor insulation : heavy inertia

Inertia is calculated from French Th-I rules (Th-Bat, 2000). Table 3 gives value of two parameters of inertia. Cm is the daily thermal capacity per ground area and Am is the exchange area per ground area. Indoor insulation on every wall leads to a very light inertia. Outdoor insulation of roof and walls leads to a heavy inertia.

Results of comparison with BESTEST are summarized in figure 2 that include ConsoClim result and minimal and maximal values.

Table 3 Values of inertia parameters according to French Th-I rules

INERTIA	**Cm** **kJ/K.m²**	**Am** **m²/m²**
Very light	80	2.5
light	110	2.5
medium	165	2.5
heavy	260	3.0
Very heavy	370	3.5



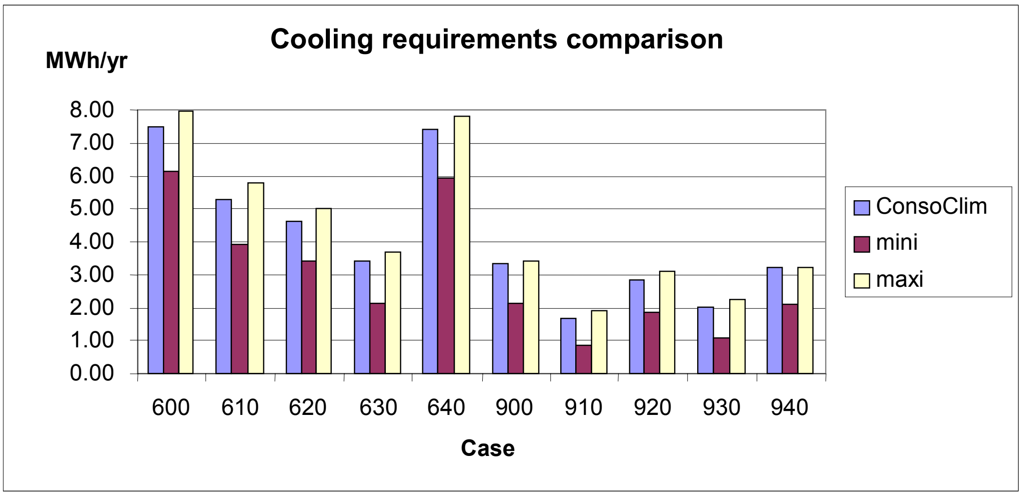


Figure 2 Test results

Except for Case 640 and Case 940 in heating mode, Consoclim is inside the range, rather close to the high limit. The variation of input data induces effects on the results in the same magnitude as the other building codes.

This result shows that a simplified model of building with very few and simple imputs allows to reach a sufficient accuracy of cooling and heating requirements. The use of French standard to evaluate inertia is sufficient.

EXPERIMENTAL VALIDATION

Three instrumented buildings have also been used to compare simulated and measured energy consumption during summer season (Enertech, 2002). Because of uncertainty on some input data, a sensibility study and a valuation of uncertainty on result have been carried out.

The office buildings are located in the South of France. The air conditioning system in the three cases is a central chilled water system with fan coil units. Table 4 shows the major characteristics of buildings and the absorbed energy rate by the chiller during summer period.

Table 4 Characteristics of buildings used for experimental validation

	COMPACTNESS FACTOR	IGS	INTERNAL GAINS W/m²	INERTIA	CHILLER CONSUMPTION kWh/m²/month
BUILDING 1	1.15	0.05	20	medium	7.4
BUILDING 2	0.8	0.042	18	heavy	7.4
BUILDING 3	1.4	0.15	15	medium - heavy	8.9

Compactness factor is the ratio of outdoor surfaces on floor area. IGS is the solar gains index equal to the solar factor of the window multiplied by window area and divided by floor area.

We focus here on results for building 1 which is a three floor office building located in city center (see Figure 3). The other building results are presented (Alessandrini et al, 2002).

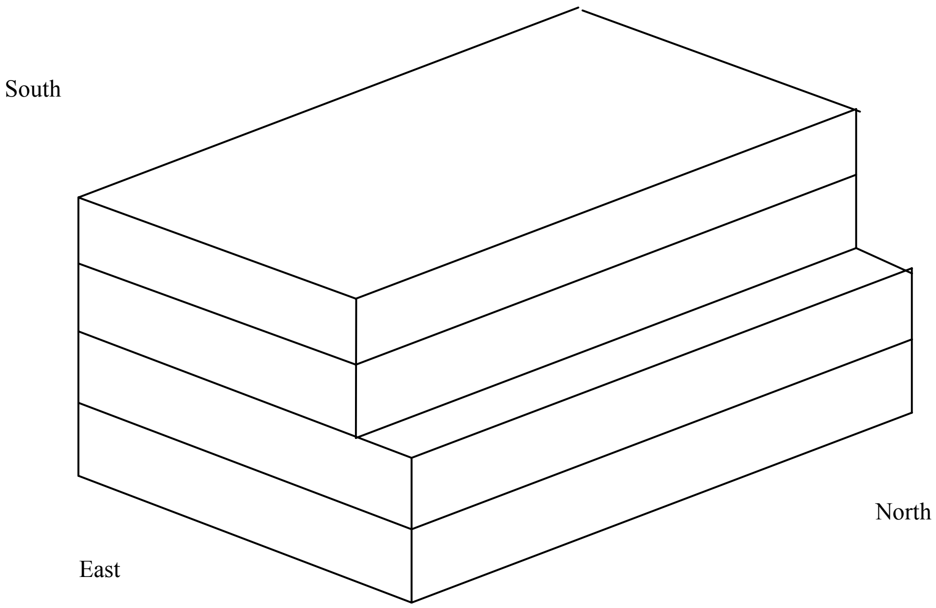


Figure 3 Building 1 Scheme

Instead of calculating one single value of energy consumption of the building, a probabilistic distribution of input data has been determined. Without complementary information about distribution of input, it is assumed that distribution is gaussian. Table 5 presents average values and absolute and relative uncertainties at 90% of level of confidence.

Table 5 Input data uncertainty

VARIABLE		AVERAGE VALUE	ABSOLUTE UNCERTAINTY	RELATIVE UNCERTAINTY	UNIT
Albedo		0.3	0.1	33%	
Set point Temperature		25	0.5		°C
Chilled water Temperature		7.5	0.5		°C
Solar Factor		0.35	0.10	30%	
Inertia		200	100	50%	kJ/m²
Internal gains during occupancy		10000	1000	10%	W
Internal gains during inoccupancy		2500	500	20%	W
Hydric gains		1.54	0.2	13%	kg/h
Ratio convection / radiation		0.7	0.2	30%	
U	walls	0.5	0.1	20%	W/m²K
	windows	5.6	1	18%	W/m²K
Indoor surface heat transfer Coefficient		4	1.5	38%	W/m²K
Outdoor surface heat transfer Coefficient		19	6	31%	W/m²K
Fan coil unit flow rate		0.115	0.025	22%	m^3/s
Fan coil heat coefficient	UA air side	236	23.6	10%	W/K
	UA water side	593	59.3	10%	W/K
Permeability		1000	330	33%	m^3/h
Extracted air flow rate		0.15	0.05	33%	m^3/s
Part load coefficient		0.9	0.1	11%	
Rating EER (Energy Efficient Ratio)		2.8	0.1	5%	

Part load coefficient is a corrective factor introduced in chiller model in order to take into account effect of part load running on EER of chiller (Alessandrini et al., 2002).

Effect of input data on chiller cooling energy rate P_c and electrical input power $P_{a\text{-chiller}}$ is investigated using an experimental design (Goupy, 1999). If s is the output variable and e_1, …e_n the input variables, the model is :

$$s = a_0 + a_1 \cdot e_1 + a_2 \cdot e_2 ..... + a_{12} \cdot e_1 \cdot e_2 ....$$

Figure 4 shows simple effect of input uncertainty on cooling energy rate and electrical input power of chiller. Result of experimental design indicates that coupled effect between several input could be neglected.

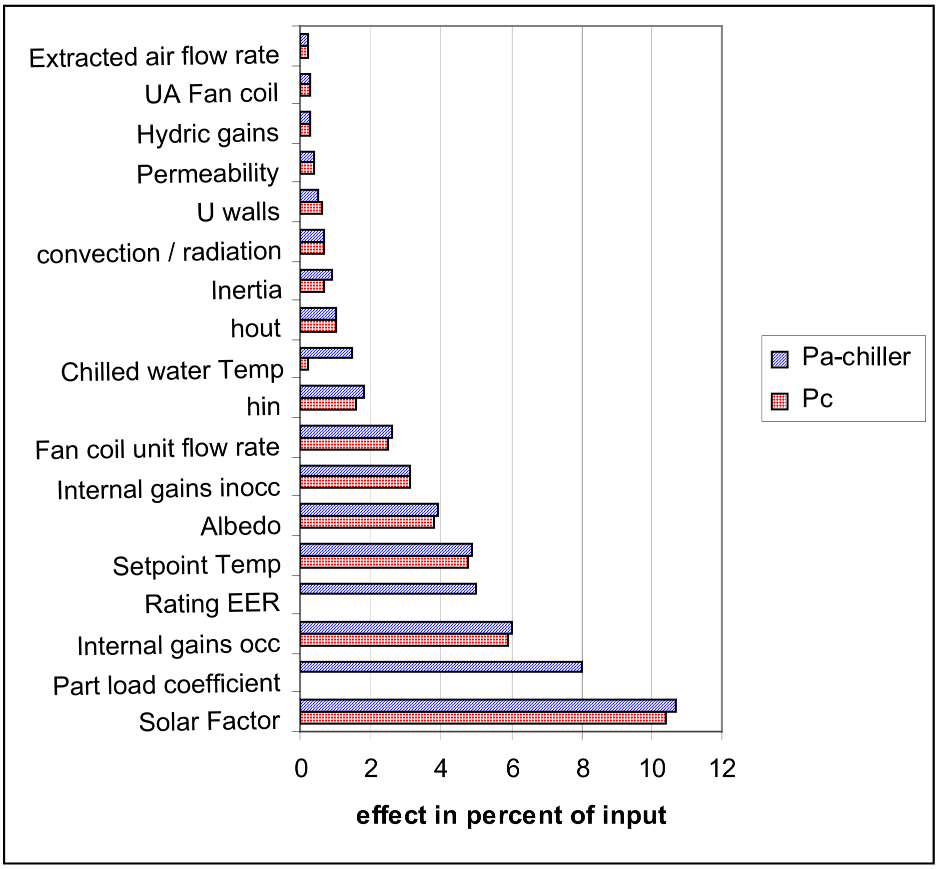


Figure 4 Simple effects on chiller cooling power and electrical input power

The total chiller energy consumption on the summer season is **3500 kWh**, and the limits of confidence interval at 90% are **4400 kWh** et **3160 kWh**.

Confidence interval is obtained by using following equation defined in (NF ENV 13 005, 1999):

$$\xi_s = \sqrt{\sum_i \left(a_i \cdot \xi_{e_i}\right)^2}$$

ξ represents uncertainty of input or output

a is the simple effect of input

Compared to Monte Carlo method, experimental design produces total uncertainty and individual parameter sensibility, but needs the system to be roughly linear. (Lomas and Eppel, 1992)

The effects of inputs on cooling requirements have repercussions on electrical input power in same order of magnitude.

The most influent input variables are :

- Setpoint temperature
- Solar factor
- Internal gains
- Part load coefficient
- Rating EER

Results show that some parameters are not crucial in calculation of cooling requirements, such as convection / radiation repartition, extracted air flow rate, infiltration, U walls. This is certainly due to few temperature difference between outdoor and indoor.

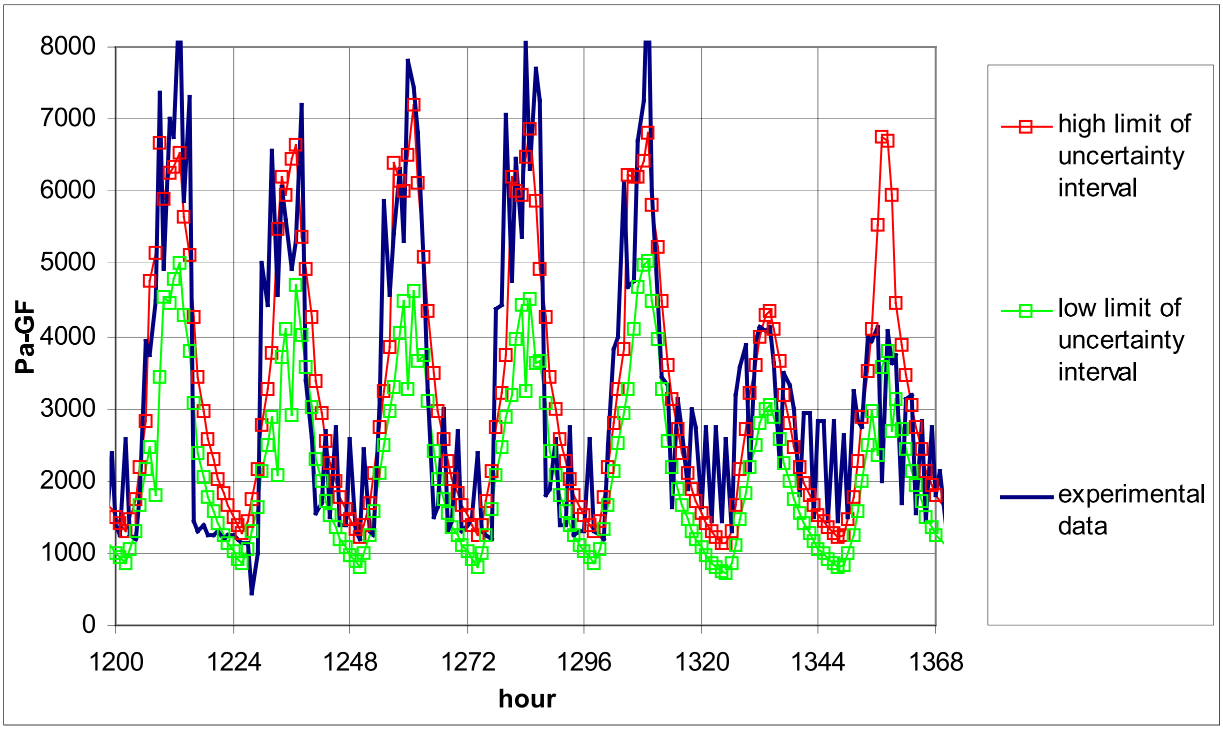


Figure 5 Comparison between simulated and measured $P_{a\text{-}GF}$

At each hour, confidence interval at 90% has been evaluated. Figure 5 shows a good agreement between ConsoClim and measurements. Uncertainty on chiller input power is more important during occupancy period because of large uncertainty on solar gains. Some oscillations in measured values are due to the existence of a chilled water storage on the chilled water loop. This storage is not taken into account in ConsoClim.

Results expressed in terms of chiller electricity consumption are rather good. Measured input power is in the range between minimal and maximal calculated values. Uncertainties on input variables lead to an uncertainty on chiller consumption of + / - 17%.

CONCLUSION

BESTEST comparison shows that building model implemented in ConsoClim does not suffer of its simplification, and is easy to parameterize. The use of French standard to valuate inertia is sufficient.

The comparison between ConsoClim and experimental data on different types of office buildings shows a good agreement.

The use of aggregated inputs for inertia and insulation requires more expertise by the user but it is faster and it limits the error risks in data capture. Moreover, these inputs are required in the French thermal Regulation (Th-Bat, 2000). In case of an use by a non expert, an user guide can help to determine these aggregated inputs from basic properties of walls.

A sensitivity study has been carried out with the use of experimental design. Setpoint temperature, solar factor, internal gains, part load coefficient, rating EER have a large impact on chiller consumption.

The other parameters have a very few impact on chiller consumption such as convection / radiation repartition or air flow rate, infiltration, U-values of the walls.

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