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Full-scale experimental validation of a building thermal model in the CLIM2000 simulation software

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ABSTRACT

Within the framework of full-scale experimental validation of the global building energy simulation software programme CLIM2000 developed by Electricity Applications in Residential and Commercial Buildings Branch of Electricité De France (EDF is the French utility company) Research and Development Division, an experimentation has been carried out in a 100 m² real house from Oct 95 to May 96. The first step was to predict in « blind way » the total electrical power consumption of the house on the basis of three different meteorological situations (cold, hot and medium). The second step was to compare the simulated results with the experimental results and to see if the prediction is in a good agreement with the real conditions. The final step was to identify the sources of the different discrepancies by using an error analysis method.

This validation exercise has showed that simulated results and experimental results are in a good agreement (error≈5%). Nevertheless, the error analysis shows that the major accuracy gains can be expected from improvements of the modelling solar gains.

1. INTRODUCTION

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

Up to 1994, the validation work on CLIM2000 was based on tests carried out in small cells where each parameter was controlled or was well-known. The objective is to validate the models in CLIM2000 with respect to physical phenomena taken one by one. The results have been acceptable and in some cases the improvement of some models has been achieved by using an error analysis method.

A new complementary way for EDF to treat the CLIM2000 validation is to address the end-users concerns, i.e. to treat the validation in a more global fashion with full-scale experimental building. To meet this, two houses have been rented so that experiments could be carried out with particular attention paid to energy-related measurements made on the electric heating system. These houses are new cottages situated at Lisses (30 km south of Paris) complying with the 1989 French thermal

regulations, equipped with electric convectors. They are fully representative of all new dwelling units in France according to a survey carried out in 1994 (SOFRES).
The first house Valeriane is intended for global comparisons of energy consumption over a complete statutory heating season, namely from October 1st to May 21st. The second house Venus is reserved for shorter experiments aimed to evaluate on full-size basis the dynamic effect of parameters involved (intermittency, closing of shutters, ...) and for tests that take into account aeraulic transfer from room to room (vertical and horizontal openings).
The tests were carried out in Valeriane from October 1st 1995 to May 21st 1996. Each room is heated to obtain 19°C constant temperature.
Last October 1995, in order to give credibility to our validation work, we have fixed the modelling of Valeriane on CLIM2000 and we have predicted the limits of the total electrical power consumption of Valeriane on the basis of three different meteorological situations (cold, hot and medium) of the closest METEO FRANCE station (30 kms west of Lisses) **[1]**. This prediction was made in a « blind » way because at that time we didn't know the experimental data.
In this paper, we will first describe the experimental house and the experimental sequence. We will present the comparison between simulated results and experimental results. We will present briefly the error analysis method and the conclusions that can be drawn in our case.

2. EXPERIMENT DESCRIPTION

2.1. House description

This house Valeriane is a new cottage complying with the 1989 French thermal regulations and is equipped with electric convectors. It is fully representative of all new dwelling units in France according to the survey carried out by SOFRES (floor area 100 m²)**[2]**.
Valeriane is situated in Lisses about 30 km South of Paris, France. The house is part of an allotment (urbanized area) rather airy free of nearby obstacles and with a clear view especially to the south. It is a one-storey cottage with a garage attached. The ground floor corresponds to the day area (entrance, kitchen, living room and toilets), and the first floor to the night area (4 bedrooms, bathroom and toilets) (Figure 1 and Figure 2).
The outer-walls consist of 20 cm thick hollow blocks. The outer walls insulation consists of an insulating compound made-up of a 100 mm thick layer of expanded polystyrene. The floor of the groundfloor consists of a 12 cm thick reinforced concrete floating coating poured over 4 cm thick layer of polystyrene insulating material. Ceiling consists of a plaster facing sheet and a 20 cm thick glasswool pad laid between trusses. Windows and French windows have a white PVC frame. They are fitted with white PVC roller blinds. Glazing is 4/12/4 double type.
Fresh air is admitted through openings made in roller blind boxes. Stale air is exhausted through controlled ventilation. Permeability measurements have been carried out. Leaks were stopped by applying polyurethane foam and silicon weather-strips so as to minimize the heat escape due to building defects.
A complete description of Valeriane is given in **[3]**.

2.2. Experimental sequence description

During one week before the beginning of experimental sequence, we adjusted the thermostat of each heater to obtain a 19 °C constant temperature in each room.
The thermostat adjustments were never modified during the experimental sequence from Oct 95 till May 96. There were no temperature control of heaters and no air mixing in order. These different points allowed us to be as close as a real situation in a real house.
There is no occupant inside.
The shutters were opened at 07:00 a.m. and closed at 07:00 p.m. each day.
The general extraction unit were in operation.

2.3. Measurements

The measurements were made from October 1st 1995 till May 21st 1996 (232 days). The sampling rate is one minute for each channel. The data are stored in file on the workstation hard disk each 10 minutes. They are averages or integrals of measurements over the 10 minutes preceding the time of storage.
Various weather data are measured by a local weather station : global and diffuse solar flows using pyranometers (Kipp & Zonen), air temperature using a temperature probe set in weather shelter, air relative humidity using an hygrometry probe set in weather shelter, wind speed using an anemometric sensor and atmospheric pressure.
Inside the test rooms air temperatures are measured at 1.5 m height from the floor, using temperature sensors (PT100) located on the geometrical center of each room, housed in radiation shields consisting of one PVC tube coated with reflective material. Black globe temperature is also measured in a matt black copper globe of diameter 100 mm. Some surface temperatures are measured using devices which are sealed to the surface and painted. One sensor is mounted on the living room floor, garage floor and side walls. Electrical power consumption of each heater is measured with kilo watt hour meter. A special kilo watt hour meter is dedicated to the measurement of the total electrical consumption of all convectors. The extraction air flow is measured directly on general extraction unit.

3. RESULTS

3.1. Simulation and measurements comparison

3.1.1. Weather data treatment

During the visual analysis of raw experimental weather data, it was shown that solar flukes presented some negative values during night periods. In addition, certain parameters like wind speed had nonsense negative values when wind was very low. These negative values were due to noise and has not physical signification.
Then, we treated the weather data in the way described in Table 1.

Table 1 : Treatments on weather data

Condition	Action	Explanation
Global < 10 W/m²	Global = 0	Pyranometer precision
Diffuse < 10 W/m²	Diffuse = 0	
date and month	shadowing correction of	Shadowing correction given in

	diffuse solar flow	Kipp & Zonen manual
Diffuse > Global	Diffuse = Global	
Sun not risen (morning)	Global = Diffuse = 0	
Sun down (evening)	Global = Diffuse = 0	Physical Incoherence
Relative Humidity > 100	Relative humidity=100	
Wind speed < 0	Wind Speed = 0	

3.1.2. *Comparison of simulated and measured results*

The Table 2 and the Figure 4 give the monthly distribution of the simulated and measured electrical consumption. The simulation was carried out with a set-point temperature equal to the average of measured temperatures in each house's room. It is important to say that we modelled the house on CLIM2000 with a simplified monozone model (i.e. one air volume representing the total volume of the house). The graph of the used model is given in Figure 3.

Table 2 : Simulated and measured results

	Oct 95	Nov 95	Dec 95	Jan 96	Fev 96	Mar 96	Apr 96	May 96	Total
Simul [kWh]	475	1672	2465	2349	2321	1679	815	584	12360
Meas. [kWh]	245	1517	2340	2282	2343	1666	833	496	11722
Error M/S [%]	-48	-9.3	-5.1	-2.9	+1	-0.8	+2.2	-15.1	-5.2

The comparison of simulated and measured total energy consumption shows a good agreement (error=5.2%). Nevertheless, we can see that the monthly error can be important especially for October. This can be due to the initialization process. Such a problem was already identified in an empirical validation exercise on tests cells (collaboration EDF/BRE, Building Research Establishment, U.K.) **[4]**.

We can see that the error is low in colder months. One reason can be the solar gains are low during these months. The modelling used in which there is no solar patch calculation and the solar direct is not reflected from the solar patch, appears efficient for low solar gains months but not precise enough for high solar gains months.

Nevertheless, these results show that the predicted results with CLIM2000 software are in good agreement with experimental results for a long period, even if this kind of experimental validation is made up of more uncertainties than for an experiment carried out in laboratory.

3.1.3. *Visual analysis*

The Figure 5 presents the time evolution of simulated and measured total power consumption and the evolution of the error between simulated and measured results. The model follows with a good precision the average behavior of the total energy consumption.

The Figure 6 and Figure 7 show the electrical consumption of the two convectors located in the living room (January 15th 1996) and the air stratification for the ground floor and the first floor respectively.
The two convectors have different behaviors. They cut off at different times. This can express an horizontal temperature gradient in the living room. We can see air vertical stratification which varies from 1° to 3°C.

The Table 3 contains the average and standard deviation values of measured and simulated consumption and the ones of error. The average error done by the model is not greater than 5%. This is in a good agreement with the Paragraph 0 conclusions, the model is considered precise enough to predict the average value of energy consumption (error : 5%). This conclusion is available for the total energy consumption over the entire heating season (value which quantify in a second way the error between the measured and simulated results).

Table 3 : Avg and Std values of measured and simulated consumption, and error

Variable	Average [kWh]	Standard deviation [kWh]
Predicted consumption	384	209
Measured consumption	365	220
Error measured/simulated	-19	54

3.2. Error analysis

The mathematical analysis of error between measured and simulated results (showed in Figure 5) was carried out by using the tool called DIANE, developed in the framework of collaboration between EDF and Créteil University (Paris XII, France) **[5][6][7]**. This residual disaggregation tool has been very powerful in a two year collaborative research programme on empirical validation between BRE (Building Research Establishment U.K.) and EDF to reveal deficiencies and or error in some of the participating software programs. Then, the modifications of modelling deficiencies in two of these software programs led to significant improvements in their predictive power **[8]**.
This tool allows to disaggregate the predictions and the measurements into a number of parts. Each part is due to one of the external influences (inputs) driving the simulation (and the building). Hence, the discrepancy between the predictions nad the measurements is the output of a system described by an input/output relationship in which the inputs are the excitations driving the building. Using this information it is possible to detect the excitations which are responsible for the major part of the simulation error. The total variance of at each frequency of interest can be decomposed to find the contribution from each input by computing the cross-spectrum between the error and each input **[5][6]**.

To analyse the present error, the excitations are the following one : direct solar flux, diffuse solar flux, external temperature, wind speed, relative humidity and atmospheric pressure. The analysis was carried out month by month. The frequency ranges selected for error disaggregation are given in Table 4.

Table 4 : Frequency ranges selected for error disaggregation

Frequency range (hour^{-1})	Comments
[0 - 0.021]	Very slow dynamic
[0.021 - 0.0625]	variation of 1 day period
[0.0625 - 0.104]	variation of 1/2 day period
[0.104 - 0.1458]	variation of 1/3 day period
[0.1458 - 0.23]	variation of ¼ or 1/5 day period
[0.23 - 0.321]	variation of 1/6 or 1/7 day period
[0.321 - 3]	variation of period smaller than 1/7

We studied the influence of excitations order on the variance decomposition to determine the most influent excitation on the error. The different orders are the following one:

1 External temperature, diffuse solar flux, direct solar flux, wind speed, atmospheric pressure, relative humidity,
2 Diffuse solar flux, direct solar flux, external temperature, wind speed, atmospheric pressure, relative humidity,
3 Direct solar flux, diffuse solar flux, , external temperature, wind speed, atmospheric pressure, relative humidity.

The disaggregation of the error variance of the simulated consumption versus the selected dynamic ranges is given in Figure 8. The error variance is given only for January 96. The disaggregation of error variance for the others months is quite identical.

We can see that :

- the variance is shared in the three first dynamic ranges,
- the solar fluxes explain the major part of error,
- the part related to wind speed is not so high but not negligible.

In conclusion, we can say that the solar radiation and external temperature are the most important external factors. It is difficult to say which of them is the most important because the outside temperature is strongly linked with the solar radiation. Nevertheless, we can say that we could probably improve the predicted energy consumption by improving the model for solar gains especially with the integration of modelling of the reflection from the solar patch.

3.3. Comparison with « blind prediction »

In October 1995, in order to give credibility to our validation work, we fixed the modelling of Valeriane on CLIM2000 and we have predicted the limits of the total electrical power consumption of Valeriane on the basis of three different meteorological situations (cold, hot and medium) of the closest METEO FRANCE station (30 kms west of Lisses) **[1]**. This prediction was made in a « blind » way because at that time we didn't know the experimental data.

The simulated results are given in Table 5.

Table 5 : Energy consumption predicted in October 1995

	Cold situation	Medium situation	Hot situation
Degrees days	71166	63906	58179
Consumption [kWh]	13004	11786	10439

We can say that the real heating season 95/96 in Lisses is a medium situation if we consider the degree-days criterion because the Lisses degrees-days is 64853. The real energy consumption 12360 kWh is to compare with the predicted value for medium situation 11786 kWh. The last value is obtained with the same model, the only difference with the prediction done in October 1995 is due to the weather data which are the real ones. This comparison is interesting because it allows to get a judgment on the representativity of standard meteorological situations we have defined as cold, medium and hot for our studies. The error between the prediction with the medium situation and the value calculated on the basis of the real weather data is only 5%.

4. CONCLUSION

This comparison between calculations on CLIM2000 software programme and the measurements carried out on a real building (Valeriane house) shows that the calculation overestimates (5.3%) the real consumption of the house over a long heating season period. This error is acceptable because this kind of experimental validation is made up of more uncertainties than for an experiment carried out in laboratory.
This result enhance credibility of models and programs among the program users because this is a realistic situation close from the studies they have to carry out.
The disaggregation of error shows that solar radiation and external temperature are the most important factors. They explain the major part of the error. To improve the behaviour of our model, we will have to take into account these conclusions by improving the solar gains with the integration of modelling of the reflection from the solar patch.
This full-scale experimental validation work will be continue with a particular focus on dynamical scenarii of set-point temperatures in day and night zone.

5. REFERENCES

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Submitted to CIBSE for National Conference October 1997

Figure 1 : Drawing of Valeriane ground floor

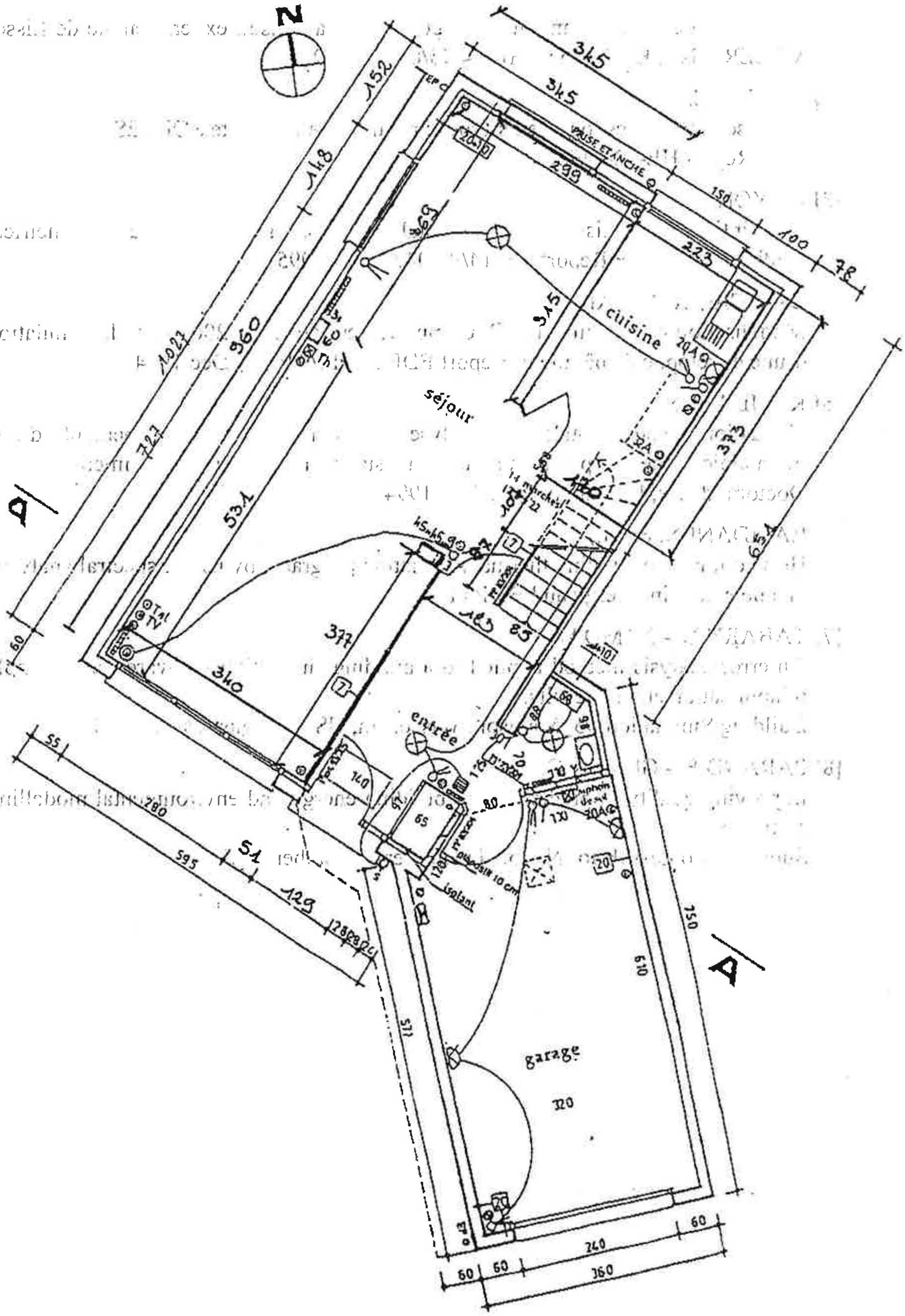
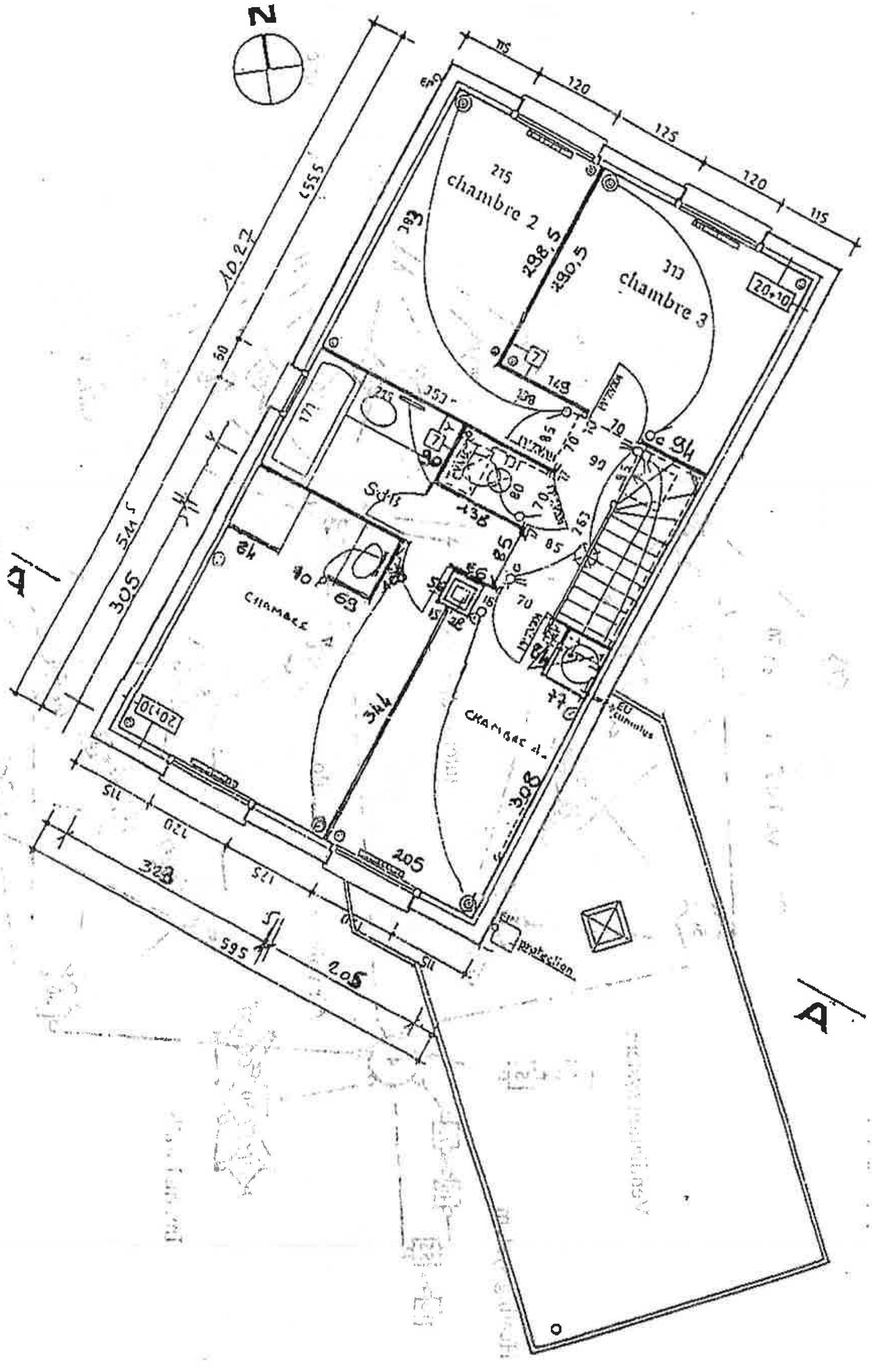


Figure 2 : Drawing of Valeriane first floor



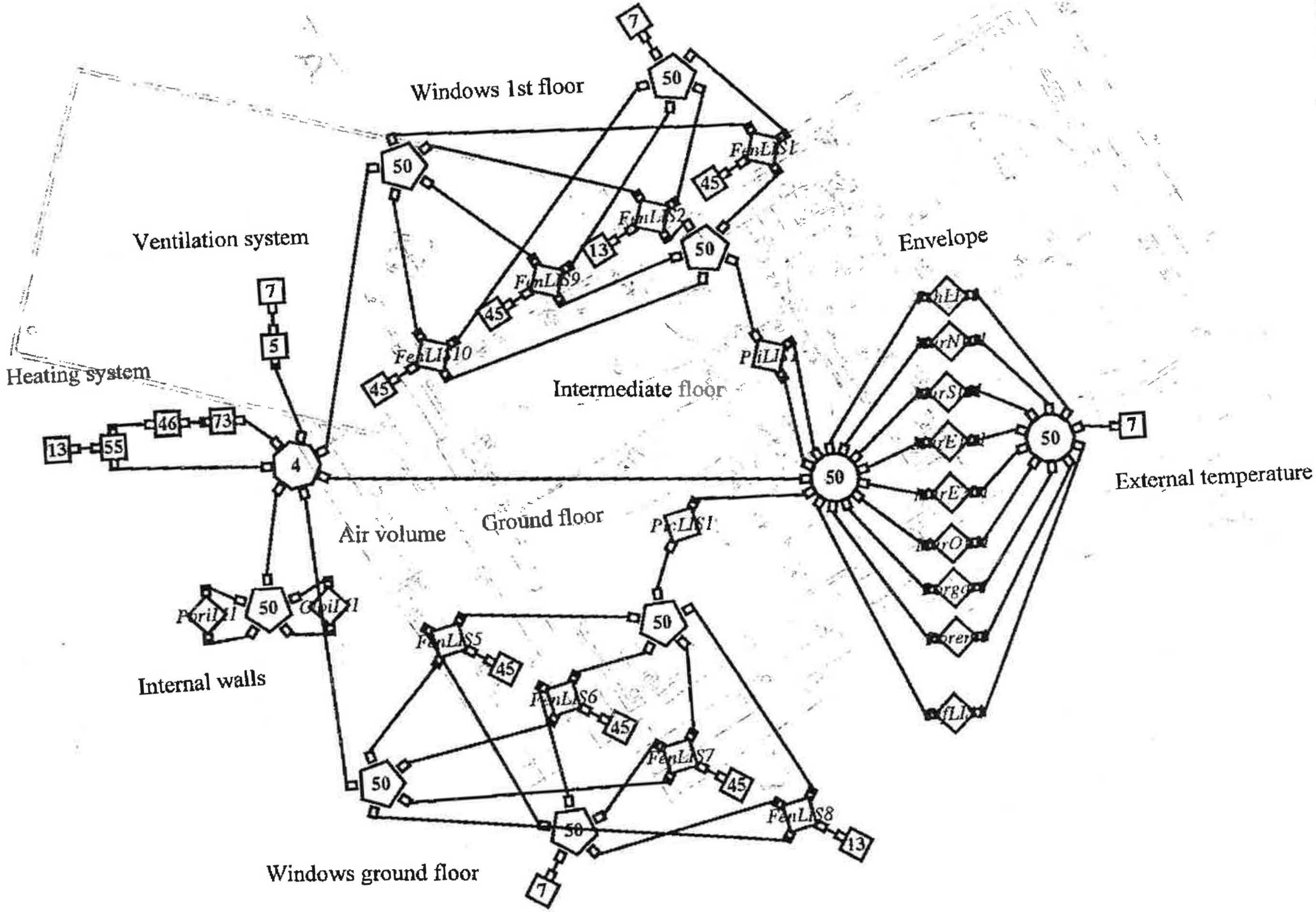


Figure 3 : Graph of CLIM2000 model

Figure 4 : Monthly sharing of power consumption

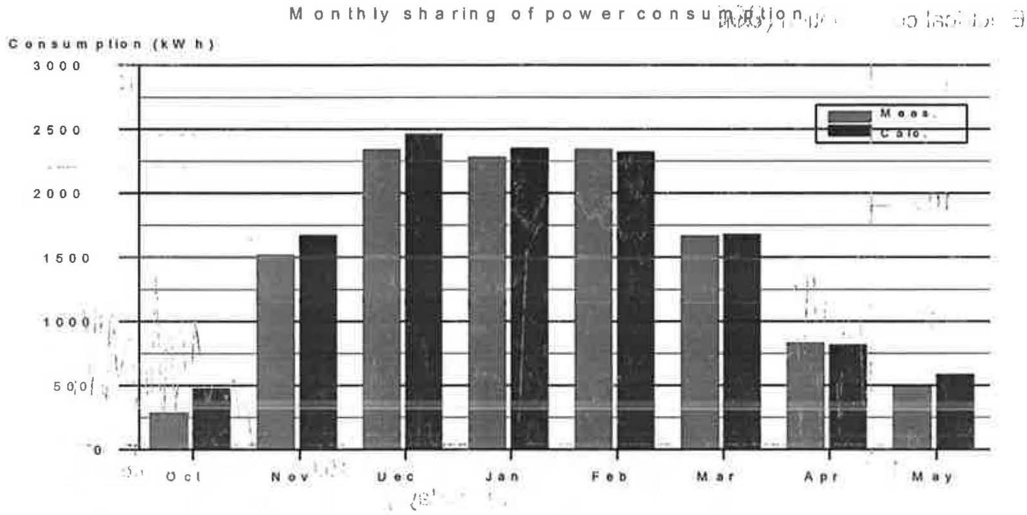


Figure 5 : Power consumption; simulated, measured and error

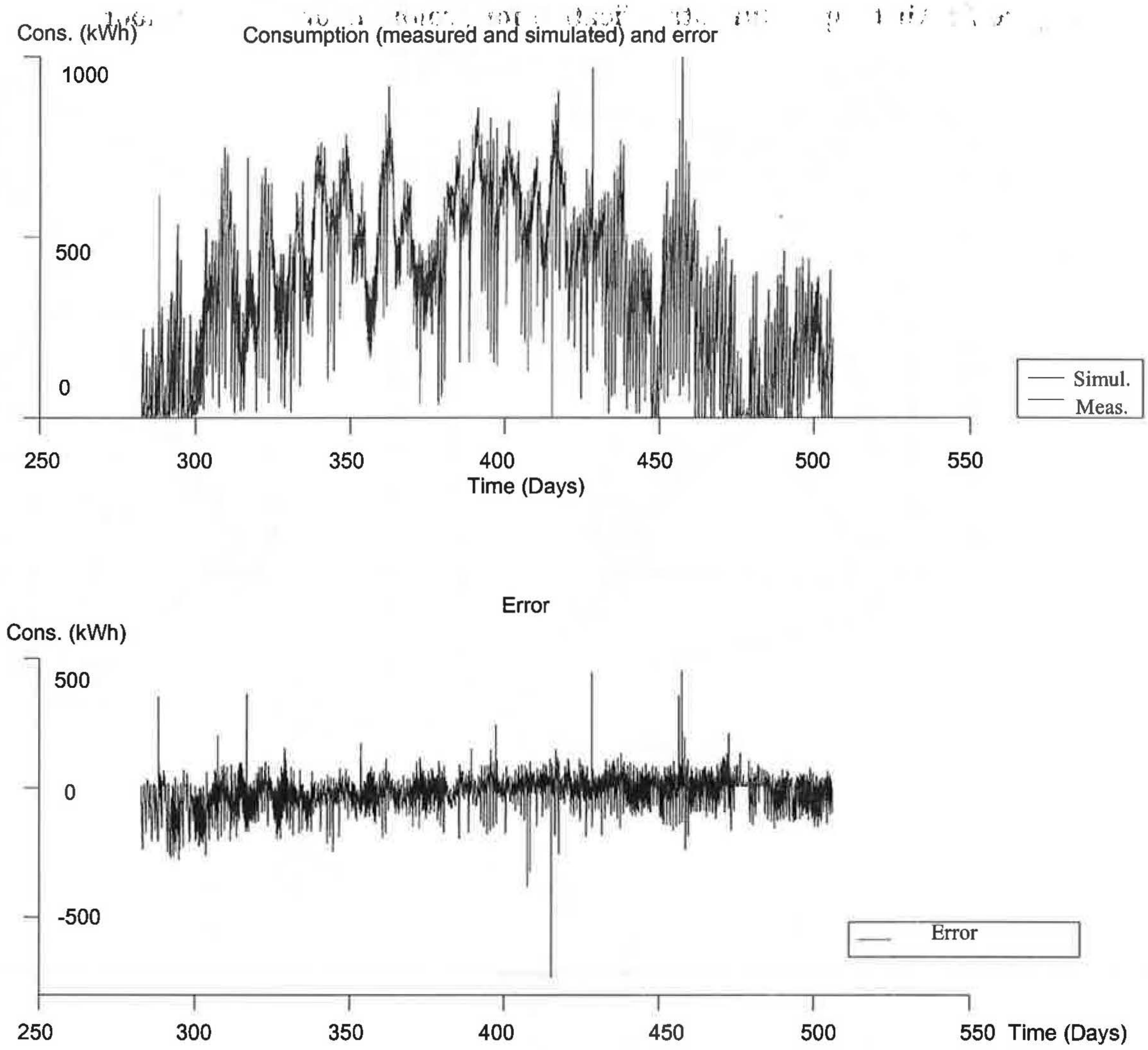


Figure 6 : Convectors consumption in living room - January 15th 1996

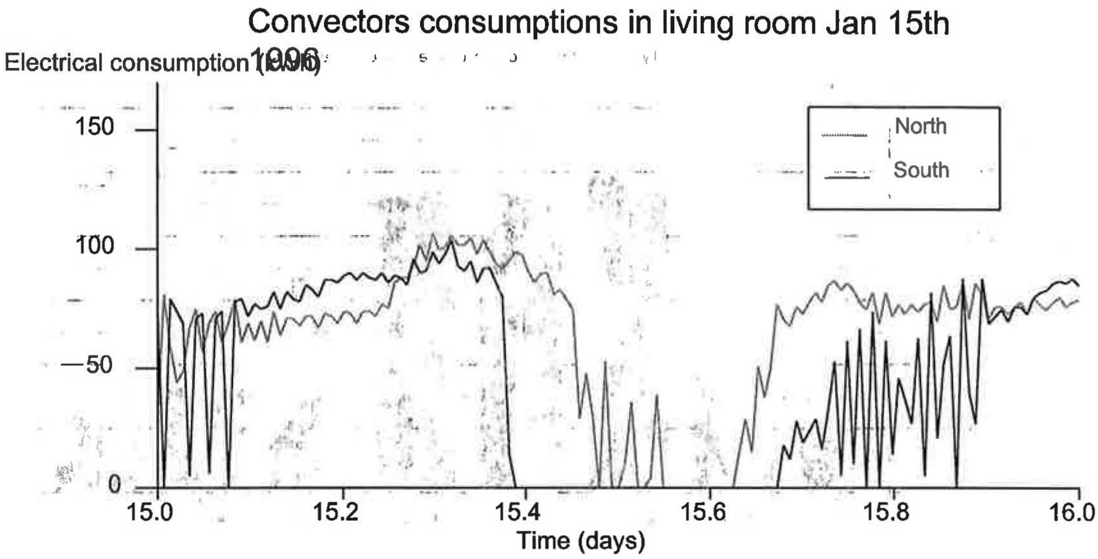


Figure 7 : Air temperature stratification for ground floor and first floor

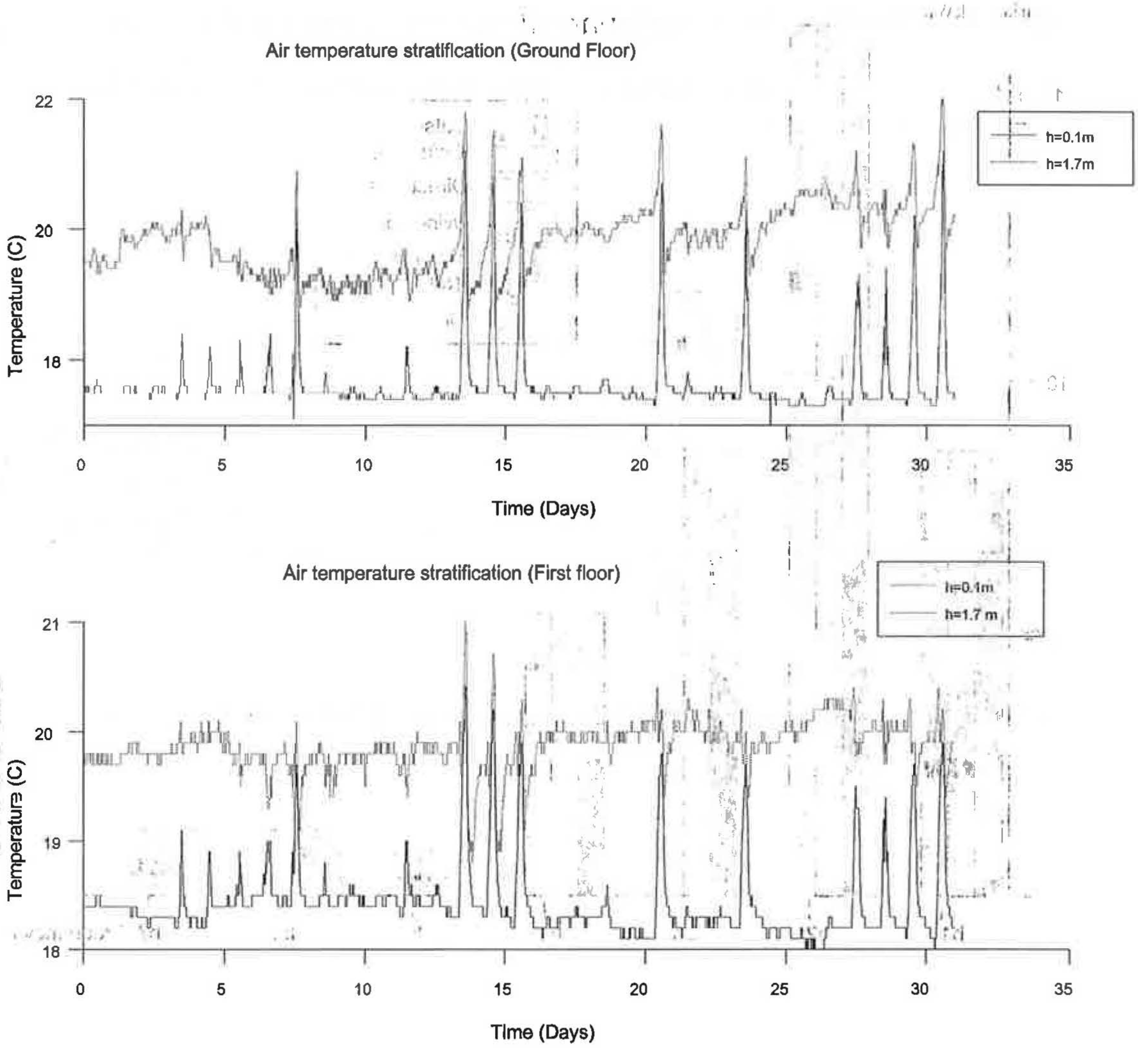
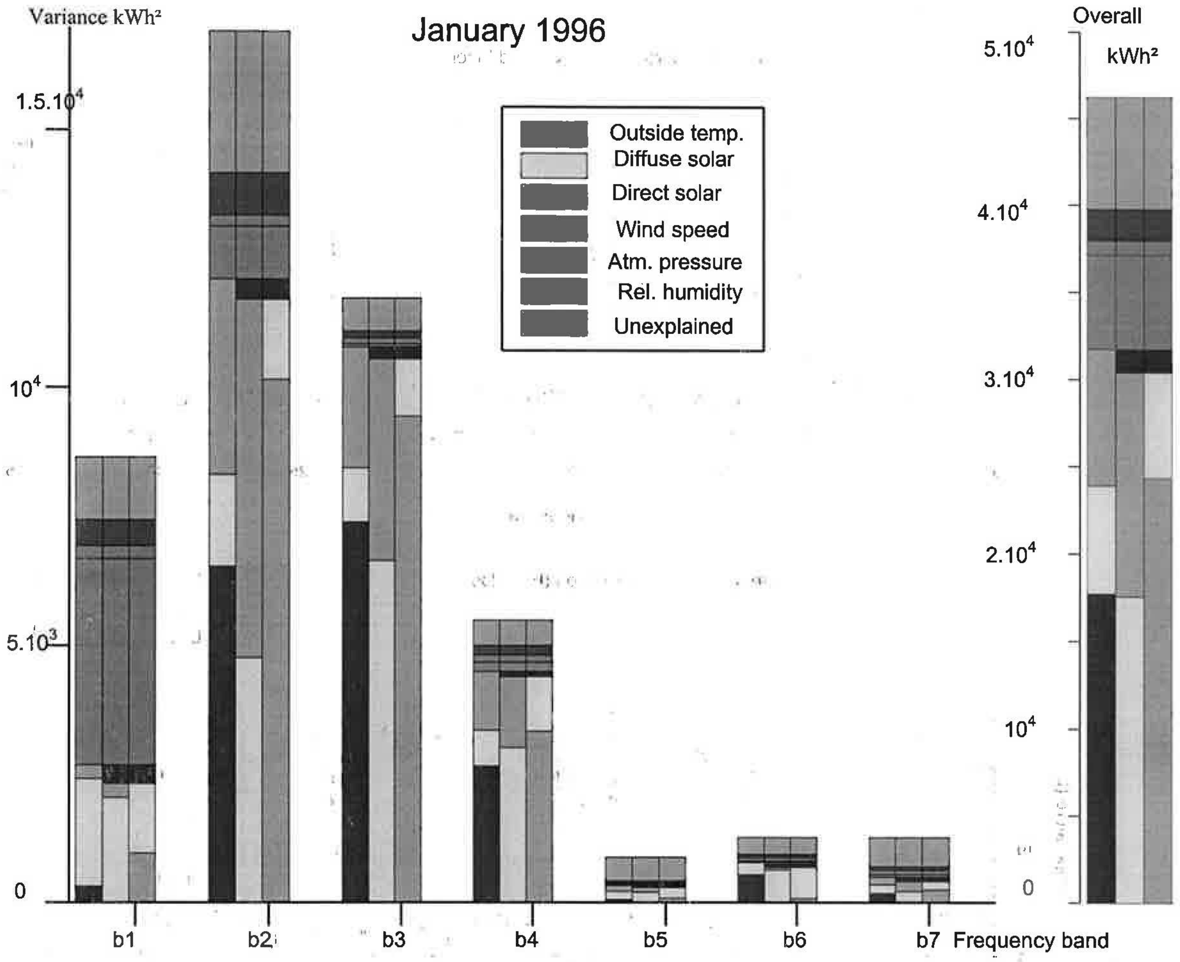


Figure 8 : Disaggregation of the error variance of the simulated consumption versus the selected dynamic ranges (January 1996).


January 1996
Variance kWh²
1.5.10⁴
10⁴
5.10³
0
b1
b2
b3
b4
b5
b6
b7
Frequency band
Outside temp.
Diffuse solar
Direct solar
Wind speed
Atm. pressure
Rel. humidity
Unexplained
Overall
kWh²
5.10⁴
4.10⁴
3.10⁴
2.10⁴
10⁴
0