MODELLING OF AN AIR CONDITIONING INSTALLATION IN A RESIDENTIAL BUILDING

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ABSTRACT

In this article, we present the dynamic modelling of a heating and air conditioning small output installation in a residential building.

The main aim of this modelling study is to acquire a better knowledge of all phenomena which govern the behaviour of small air conditioning installations for residential building using air as the fluid. In fact, to have an experimental knowledge of their behaviour over an entire heating or cooling season, extensive apparatus is required to measure precisely the air flow, and measurement times are very long since the output values must be recorded over a whole year. This explains why modelling and simulation were preferred. This study was performed using the modelling tool : ALLAN.Simulation.

INTRODUCTION

This study is a part of a project conducted by the Research and Development Division of Gaz de France for the purpose of promoting small air conditioning installations for residential building.

The technical system in this report is a real system inserted into as realistic as possible an environment. Our intention is to predict the performance characteristics of the overall system and to determine the parameters of the dynamic model which has an influence on its COP.

After a presentation of the modelling tool and of the modelling approach we used, we will describe all the models we have implemented, such as heating and air conditioning system models or building models. Then, we will define all simulation runs before concluding by the results.

CONTEXT OF THE STUDY

The study was performed on a heating and air conditioning small output device referred to "*the system*" for reasons of confidentiality in this article. We have modelled *the system* so as to evaluate its performance characteristics and theirs variations.

The system was placed in a realistic environment. For this, we used the virtual six main rooms house "GERSHWIN", typical of a French detached main home, located in Nice, in the South of France climatic area (in compliance with the 1989 insulation requirements). A design office recommends us the installation of two devices of *the system* in the living room and one in the mezzanine for winter heating and summer cooling even if it is over-sized. It is occupied by a family of five persons, therefore we also calculated the internal loads due to the equipment and human occupancy.

The dynamics of the building and the dynamics of "*the system*" start-up and shutdown are very important so we chose to perform this study with the dynamic modelling tool, ALLAN.Simulation.

TOOL AND METHOD

This study was performed using the modelling software ALLAN.Simulation, a pre- and post processor belonging to a generation of modular tools for the symbolic description of systems. It is devised by Gaz de France. It is currently coupled with CISI's NEPTUNIX solver.

ALLAN .Simulation

ALLAN. is a general purpose tool which uses "boxes and strings" representation (multi-variable, unoriented block diagrams). All or part of the models or analyses established at a previous time and stored in a library can be reused whenever necessary.

As a general rule, the complexity of the system makes it convenient, if not imperative, to break it down into elements. These elements are called models.

Neptunix

NEPTUNIX is a software package for the simulation of systems described by a set of differential algebraic equations. The software thus accepts formulations in the form of implicit equations which may contain discontinuities.

The modelling approach

The SEPA (Suivi d'une Etude Pour ALLAN.Simulation) modelling approach has been developed at Gaz de France for ALLAN.Simulation. It guides the modeller through the following stages:

- **drafting of the modelling specifications** based on requirements provided by the client commissioning the study;

- **breakdown**, during which the system to be modelled (main model) is analysed and broken down into sub-systems;.

- **writing and validation,** i.e. the expression in ALLAN language of the behaviour of the simple models obtained during the breakdown stage;

- **integration and validation** of models.

Figure 1 shows the V-cycle diagram giving an overview of the modelling approach we used.

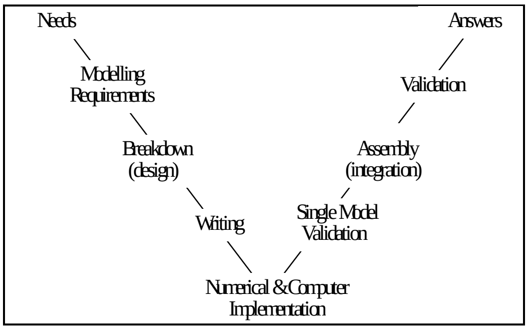

Figure 1 : The modelling approach

MODELLING

Aim of the modelling

We perform this study and thus this modelling, with a specific system but our main aim is to create a test bench. We want to be able to have comparative results of different systems in the same configuration or to have comparative results of the same system in different configurations.

So all the models, we have implemented, could be reused for another study. If we would like to have results for another system in the same configuration, we only have to adapt in simple model **system**, the technical data to the new manufacturer data of the new system. At the opposite, if we would like to have results for the same system in another configuration (with another air temperature set for example), we only have to modify the values of the corresponding parameter in the appropriate model (the air temperature set in simple model **regul** for example).

Models

We will describe all simple and compound models we have implemented and all hypotheses we made. All the given values meet our configuration choice.

Figure 2 shows the diagram of the global model made up of compound and simple models.

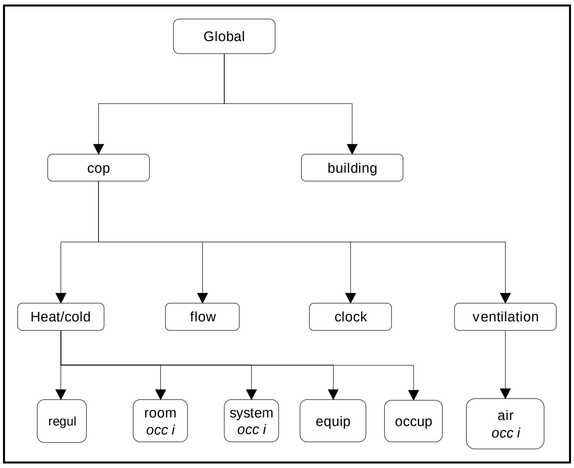

Figure 2 : The global model

*Compound model : **global***

This model represents the modelling of the system and its environment. It connects compound model **cop** to the building envelope of the simple model, **building**, described below.

*Simple model : **building***

This model represents the building envelope. It is directly obtained from two input files into an ALLAN.Simulation model using the C2A software. All used materials and all dimensions of building "GERSHWIN" are defined in the input files.

The main hypothesis of this model is that we only have one mesh per room with an air node at the centre of each mesh. The building dynamics is automatically integrated by the C2A software.

*Compound model : **cop***

Compound model **cop** is made up of compound models **ventilation** and **heat/cold,** and the simple models, **flow** and **clock**, defined below. It represents all the phenomena inside the building in contrast to phenomena at building envelope level described in the simple model, **building**.

*Simple model : **flow***

This model defines all air flows between the rooms. It depends mainly on the ventilation forced rate in the kitchen at cooking time.

Simple model : ***clock***
This model is just a clock which converts seconds into days, hours and minutes for the timetable.

Compound model : ***ventilation***
Compound model **ventilation** represents the ventilation system of the building and is made up of fifteen occurrences of the same simple model, **air**. There is one sample for each interaction between two areas.

Simple model : ***air***
This model evaluates heat flows due to aeraulic transfers between two adjoining meshes. It also takes into account the relative humidity of the indoor and outdoor air to calculate air temperatures and thermal flows.

We supposed that there is neither pressure drop nor dynamics.

Compound model : ***heat/cold***
Compound model **heat/cold** merges the house heating and cooling system and the internal loads. It is an assembly of the next simple models.

Simple model : ***system***
This model represents *the system*. We only had discrete manufacturers data at air fan top speed and in nominal conditions of operation. So we had to put forward the hypothesis that we were always at top fan speed. The performances of *the system* are strongly influenced by parameters such as the outdoor air temperature and the indoor humidified air temperature, so we verified that we were always allowed to make linear interpolation between discrete nominal data taking into account these parameters. Then *the system* has its own internal regulation system which has also been modelled, according to the difference between the ambient temperature in the room and its programmed setting.

The main modelled phenomena are mass transfers with flow conservation and heat transfers in the evaporator and the condenser. We also supposed that there is no loss to the outside environment.

Moreover, the system capacity is modelled as a first order system with a time constant for the start-up and another time constant for the shutdown. The time constant for the start-up was initialised to two minutes as in the literature, and those of the shutdown to twenty seconds. These two constants are very important because they affect directly the coefficient of performance. The instantaneous COP varies according to the difference between the constant for the start-up and the constant for the shutdown, and also according to the difference between the constants of the dynamics of the output power and the constants of the dynamics of the input power.

There is one occurrence of this model for the living-room and another one for the mezzanine.

Simple model : ***room***
This model evaluates the ambient air temperature and flow in the rooms where any device of *the system* is installed. In the wintertime, the air temperature of these rooms is fixed to be constant at 20 °C and in the summertime, its variations are let go free.

There is one occurrence of this model for each room without heating and air conditioning installation (kitchen, bathroom, toilets, bedroom1, bedroom2, bedroom3, bedroom4).

Simple model : ***regul***
This model evaluates the air temperature set of the living-room and the mezzanine according to the human occupancy in the house and the timetable.

Table 1 indicates the air temperature regulations according to the building occupancy and the season.

Temperature	Occupied time	Unoccupied time
Summer	25°C	27°C
Winter	20°C	16°C

Table 1 : Air temperature regulations

Simple model : ***equip***
This model evaluates the internal loads due to equipment as lights, cooker, oven, toaster, hairdryer, vacuum cleaner, iron, etc. ... Their output heat load depends on their nominal power and their operating time according to the timetable.

We included a first order dynamics with a two minutes constant time on the output heat load. We chose a two minutes constant time for numerical reasons.

Simple model : ***occup***
This model evaluates the internal loads due to human occupancy of the house by a family of five persons (two parents and three children which are going to school). It also defines the occupied time, when persons are present in the building, and the unoccupied time.

We included a first order dynamics with a two minutes constant time on the output heat load for the same reasons that in the previous model.

We try to recreate as realistic as possible an occupancy timetable over a whole year with holiday period.

VALIDATION

Each simple or compound previous model has been validated qualitatively, one by one, with simple excitations like steps.

Then, the global model has also been validated qualitatively, because the necessary apparatus to carry out an experiment is too extensive and the experiment delays are too long.

According to results presenting in the next section, we can conclude that our model gives consistent results.

Given the lack of experimental validation, the results of this study only constitute reference values to a comparative study with another device exactly in the same configuration for the environment or the same device in another configuration for the environment.

SIMULATION RUNS

We performed one simulation run for each month of a year. The simulation parameter set is : the numerical precision set once and for all to 0.001, the minimal step set to 0.0001s and maximal step set to 20s.

The commands of the simulator are the outdoor air temperature, the outdoor relative humidity and the solar flux from each direction on the different building side. These commands are read in a meteorological data file.

We only have access to meteorological data over a year which is the average of the thirty last years data. This represents the climate of Nice but because it is an average, we have data for a year which is neither very cold in winter nor very hot in summer. It produces a deterioration of our system performances because performances are optimal for nominal conditions which correspond to high outdoor air temperatures in summer and low ones in winter.

Further to these twelve first simulation runs, we performed twenty-four others. They correspond to daily simulation runs when *our system* has the best and the worst daily performances of each month.

RESULTS

The output variable is the coefficient of performance, COP.

$$COP = \frac{\int_{t_{start}}^{t_{end}} P_{output}(t)\,dt}{\int_{t_{start}}^{t_{end}} P_{input}(t)\,dt}$$

Monthly performances

Figure 3 shows the diagram of the results over a entire year, month by month.

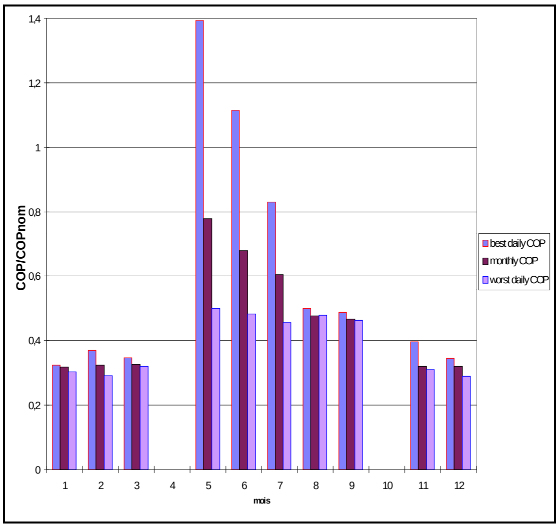

Figure 3 : The coefficient of performance

During the midseason, in April and October, the indoor air temperature regulation is naturally reached and thus the system doesn't start up.

In summer, the monthly COP is between 50% and 80% of the nominal COP. This is due to the high indoor air temperature regulation (25°C on occupied time) and the low outdoor air temperature (between 15°C and 28°C). In fact, we are not in an area of the operating conditions where the behaviour of *our system* is optimal.

In winter, the monthly COP is around 35% of the nominal COP because of our meteorological data represents not too cold a winter, and thus we are not in an area of the operating conditions where the behaviour of *our system* is optimal. And, moreover, *our system* was sized so as to meet the summer needs in cold. The working rate is low and the COP falls down.

In the summertime (wintertime respectively), the performances of *our system* are the best when the outdoor air temperature is high (low respectively). So the need are high and *our system* is operating with a low number of cycles and a high working rate. On the contrary, in the summertime (wintertime respectively), the performances of *our system* are the worse when the outdoor air temperature is low (high respectively). So the needs are low and *our system* is operating with a high number of cycles and a low working rate.

Thus, qualitatively, our model gives consistent results with monthly performances and it is similar with the number of cycle and the working rate (see next section). In fact, the COP is related to the number of cycles and the working rate. The COP increases when the number of cycles decreases and the working rate increases and the opposite.

Number of cycles and working rate

Table 2 indicates the number of cycles.

	Nov.	Dec.	Jan.	Feb	Mar.
Living-room	1359	3266	4365	2529	1027
Mezzanine	274	834	1161	604	118

	May	June	July	Aug.	Sept.
Living-room	2004	4361	6941	5923	2175
Mezzanine	2201	4088	6326	5888	3061

Table 2 : The number of cycles

Table 3 indicates the average cycle time and the working rate of *our system* over our simulation year which formulas are :

Average cycle time = maximal possible working time / number of cycles,

Working rate = actual working time / maximal possible working time.

	Nov.	Dec.	Jan.	Feb.	Mar.
Living-room	31'47" 1.4%	13'40" 3%	10'14" 4.4%	15'57" 2.5%	43'28" 0.88%
Mezzanine	157' 0.28%	57'31" 0.78%	38'27" 1.2%	66'45" 0.62%	378' 0.11%

	May	June	July	Aug.	Sept.
Living-room	22'16" 6%	9'54" 10.6%	6'26" 13.7%	7'32" 10%	19'52" 3.6%
Mezzanine	20'17" 9.3%	10'34" 11.7%	7'03" 13.2%	7'35" 10.6%	14'07" 5.7%

Table 3 : Average cycle time and working rate

The low working rate (10% in summer and 2.5% in winter) confirmed the argument that our installation has been over-sized by the design office.

Our system goes through a high number of start-up and shutdown so as to respect the indoor air temperature regulation. The number of cycles increases at the height of the season because it is the period when the thermal exchanges are the most important.

Indoor ambient air temperature observation

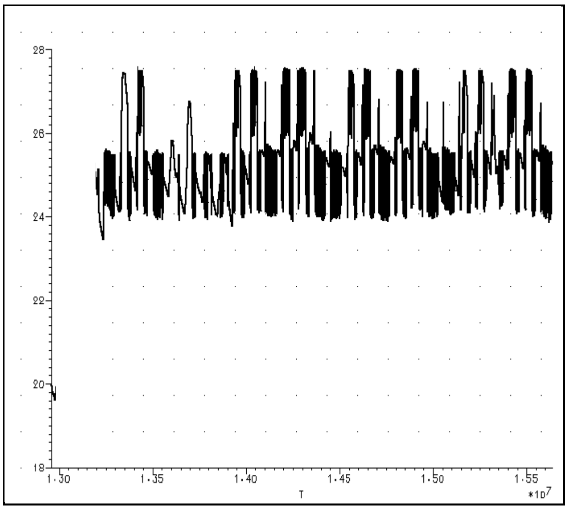

Figure 4 : The indoor ambient air temperature in the living room in July

The temperature is in degree Celsius and the time in seconds. The indoor air ambient temperature of the living room follows the regulation.

Input and output power observation

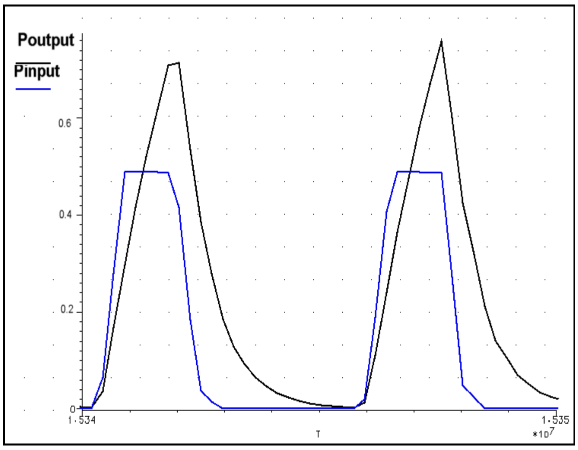

Figure 5 : The input and output power during two cycles

Figure 5 represents the evolution of the input and output powers divided by the nominal power during two cycles. The difference between the dynamics at the start-up and the shutdown and between the input power and the output power is very obvious. The COP is calculated by integration of these curves over the time. Thus**,** the dynamics are very important to evaluate the COP.

Finally, we have tested an ultimate configuration. The aim of this study was to acquire a better knowledge of the performances of *our system* but we did not really evaluate the needs of the building. We used the standard values of the internal loads due to equipment. We have also verified that these values did not interfere on the COP values. In fact, we did a simulation run without taking them into account to evaluate the monthly COP, we only had a less than 1% difference between the COP with the internal loads and the COP without them. Without the internal loads, the needs (thus the output load) are lower but in the same time the input load is lower too. So the COP remains quite unchanged.

ACKNOWLEDGEMENTS

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CONCLUSIONS

The main conclusions of this study are that we have a better knowledge of all phenomena which govern the behaviour of a heating and air conditioning small output installation in a residential building.

First of all, our results are qualitatively consistent and the conclusions on the performances and the COP are as follow.

The COP depends on the outdoor temperature and relative humidity. It will be close to the nominal COP if the meteorological data are close to the operating conditions of the installation.

Then, it is deeply influenced by the different dynamics which take place. In practical terms, it varies according the different values of the time constants on the input and output power during the start-up and the shutdown.

Moreover, when the COP decreases, it means that the performances are worse. It can be observed by the increase of the number of cycles and the decrease of the working rate. In fact, in this case, the system does not reach the steady state and it always works in the transient domain where the dynamics are important.

Finally, the COP can be evaluated regardless of the internal loads due to the equipment. On the other hand, they are essential to evaluate the needs of the building.
However, because of the lack of experimental validation, the results of this study only constitute reference values to a comparative study with another device exactly in the same environmental configuration or the same device in another configuration.

All the models can be reused for another study only by adapting the values of the different data or parameters to the ones of the new device or configuration.

Thus, ALLAN.Simulation allowed us to create a real software test bench for heating and air conditioning installation in a residential building.

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NOMENCLATURE

COP	coefficient of performance
COP_{nom}	coefficient of performance in nominal conditions
P_{input}	our system input load
P_{output}	our system output load
t_{start}	start simulation time
t_{end}	end simulation time