METHODOLOGY FOR MODELLING/SIMULATION OF AN OFFICE BUILDING EQUIPPED WITH AN AIR-CONDITIONING SYSTEM

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ABSTRACT

This article presents a study of a building-equipment coupled system performed at the Gaz de France R & D Division.

The commercial building under study is equipped with an air-conditioning installation which includes a gas-fired dual-service absorption machine. One of the aims of this study is to compare various air-conditioning systems on the basis of both technical and economic criteria.

The building, its air-conditioning installation and the large-scale experimental monitoring programme are presented. After an examination of the modelling methodology used, the modelling of the building and a part of the installation are also described.

INTRODUCTION

In association with its work on the development of gas-fired air-conditioning systems in the commercial sector, the Gaz de France R & D Division is performing a number of experimental and theoretical studies.

A "reference" air-conditioning system was installed and instrumented in a building on the premises of the R & D Division on the outskirts of Paris. A modelling/simulation study is being performed on this building and its air-conditioning system [1].

STUDY OBJECTIVES

The main objectives of this study are:

- firstly, to analyse building behaviour with respect to various criteria:

  - internal heat input,
  - weather conditions,
  - temperature settings,
  - insulation thickness,
  - surface area of glazing,

in order to quantify its heating and cooling requirements.

To this end, a simplified model of the installation was coupled with a model of the real building.

- secondly, to study the technical and economic aspects of the air-conditioning system (type of production, distribution, emission). The various air-conditioning equipment configurations are defined in table 1.

DESCRIPTION OF THE INSTALLATION

The building in question is typical of a modern office block, such as a company headquarters. It has a complex layout comprising around 50 offices covering a floor space of 1400 m² on three levels. It has relatively large glazed areas (300 m²) which means that the premises must be air conditioned in summer.

Warm and cold air are produced by a gas-fired dual-service absorption machine. A gas boiler provides inter-season makeup heat.

The air-conditioning system comprises a network of 4-pipe fan coils fed by either a dual-duct air handling unit for offices or two single-duct air handling units for meeting rooms.

In each office, one or more fan coils maintain the air temperature within a range set by the user. During winter and summer, the fan coils are fed with warm or chilled water only, and during the inter-season periods, they are fed with both warm and cold water. The temperature of the flowstream thus depends on the ambient temperature and on the individual air-conditioning and heating settings in each office.

System operation is controlled and programmed by a building management system.

Figure 1 describes the operating principle of the installation during the inter-season period.

Table 1: Equipment configurations

SIMULATOR	HEATING		AIR -CONDITIONING	EMISSION SYSTEM
	WINTER	MID-SEASON	SUMMER & MID-SAISON	
1	CHAM	GB	CHAM + CT	4P FC
2	CHAM	GB	CHAM + FC	4P FC
3	GB	GB	CAM	4P FC
4	GHP	GB	GHP	4P FC
5	GB	GB	ACCRM	4P FC
6	GB	GB	WCCRM	4P FC
7	GB	R	ACCRM	2P FC
8	CHAM	R	CHAM+CT	2P FC
9	R	R	ACCRM	2P FC
10	ACCHP	R	ACCHP	2P FC

2P FC 2 pipe with electric strip heat fan coil
ACCRM Air-cooled Compression Refrigerating Machine
ACCHP Air-cooled Compression Heat Pump
CAM Chiller Absorption Machine
CHAM Chiller/Heater Absorption Machine
CT Cooling tower
4P FC 4 pipe fan coil
FC Fluid cooler
GB Gas Boiler
GHP Heat Pump with gas engine
R Resistance
WCCRM Water-cooled Compression Refrigerating Machine

Figure 1: Diagram of the installation

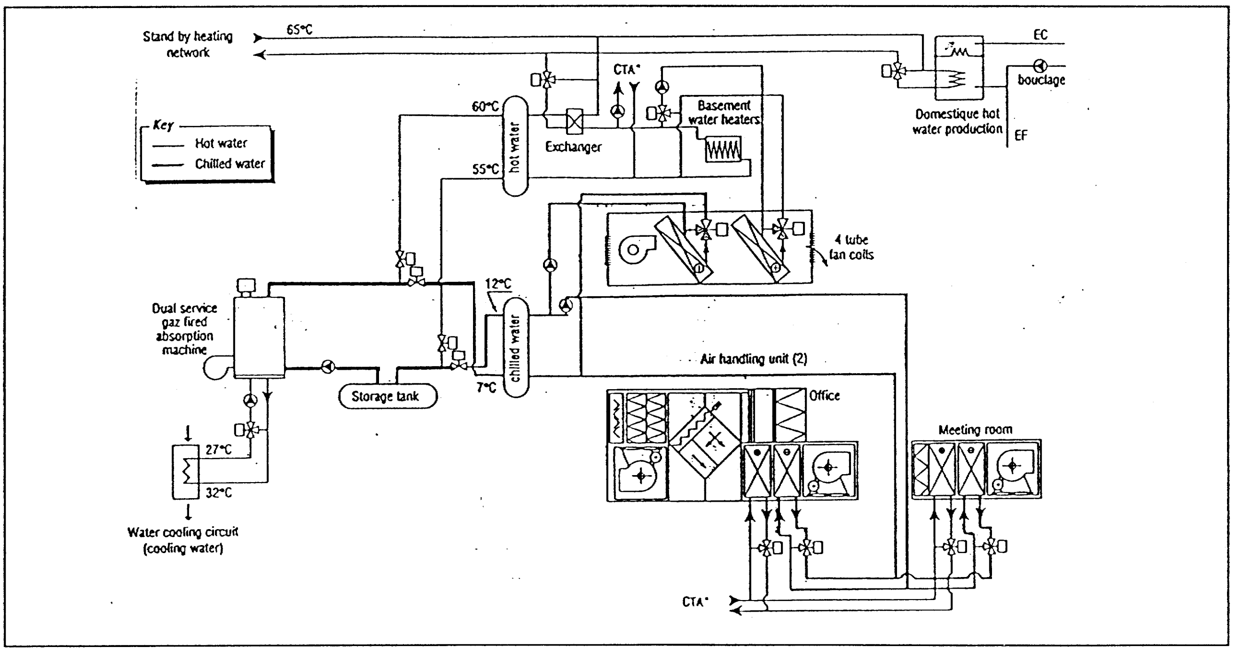
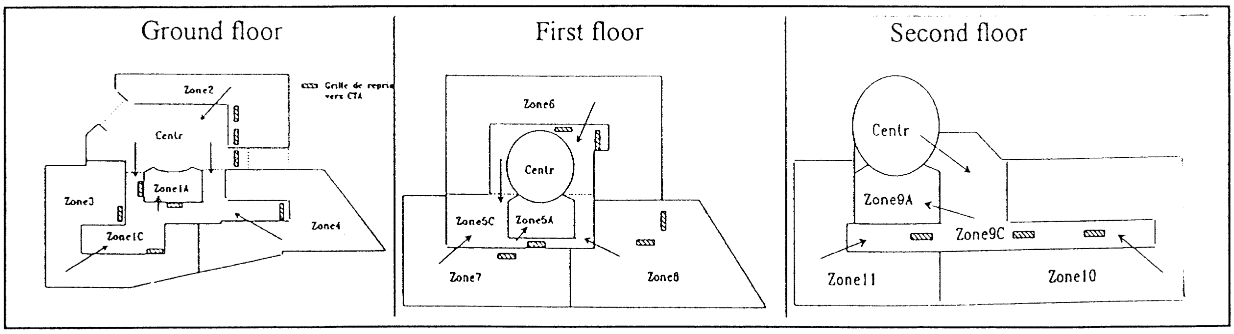


Figure 4: Diagram of the reference building zones



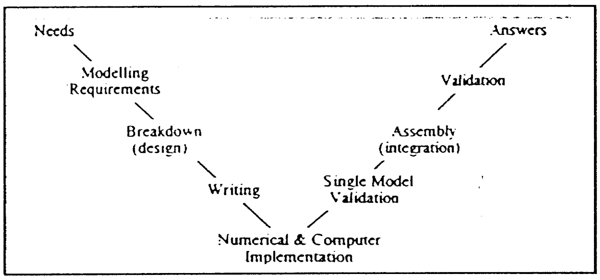
SOFTWARE

This study was performed using the ALLAN^{TM3} software [3], a pre- and post-processor belonging to a generation of modular tools enabling the symbolic description of systems. It is used in association with an NEPTUNIX algebraic/differential equation solver, either the NEPTUNIX solver or the DASSL solver. An interactive graphical control is provided over the following :

- description of basic component models, termed simpled models and defined by algebraic/differential equations, parts for discrete events description, procedural text if required, external a coupling variables on ports and graphical aspect,
- assembly of physical or technical system models termed compound models,
- simulation of system operation by calling of simulation softwares,
- free choice of observed variables during the simulation,
- interpretation and display of simulation results.

For compound models, ALLAN.^{TM} automatically controls and generates the coupling equations on the basis of the type associated with the coupling variables. A methodology was developed, ensuring the quality, reutilisability ans most profitable use of validated models. Figure 2 shows the V-cycle diagram giving an overview of the modelling approach used.

Figure 2. The modelling approach



In order to reuse all or part of the modelling studies, the systems in question must be carefully broken down into elementary parts.

This process divides the systems into a number of levels which form a tree comprising all the models used in the study. There are several types of level:

- functional level

- topological level

- technological level

- phenomenological level.

METHODOLOGY

The two objectives of the study do not require the same modelling level. The installation was therefore modelled in two different ways.

To analyse the thermal behaviour of the building, a simplified model of the installation can be used, coupled with the model of the real building.

To perform the sensitivity study of the nature of the air-conditioning system, the reference installation and its variants were modelled very accurately.

In the first stage, the various functions to be modelled were defined:

- main hot/chilled water production system; the various systems considered are: a chiller/heater absorption machine, a chiller absorption machine, an air-cooled compression heat pump, a heat pump with gas engine, an air-cooled compression refrigerating machine, a water-cooled compression refrigerating machine. When the production system is water-cooled, the hot/chilled water production function includes the heat discharge circuit and cooling tower or fluid cooler,

- makeup water heating system comprising a gas-fired boiler,

- water distribution; this comprises a 4-pipe distribution network when system is fitted with 4-pipe fan coils and a 2-pipe distribution network for a system of 2-pipe with electrip strip heat fan coils. When the production system is water-cooled, the hot/chilled water production function includes the control valves, the circulating pumps, the storage tank and the expansion vessel,

- cool/warm air production: the dual-duct air handling unit,

- air distribution, comprising an air intake and outlet network and 4-pipe fan coils or 2-pipe with electric strip heat fan coils,

- the building,

- the building management system.

In the second stage, each of these functions was modelled separately and then the various compound models were assembled to form an overall model. The breakdown of the reference simulator is presented in figure 3.

In the third stage, the reference simulator was validated.

The fourth stage constitutes the operational phase of the 10 simulators obtained.

INSTRUMENTATION

The building is equipped with a large number of meters and sensors, the readings from which are transmitted to the building management system. Two types of data are stored:

- data recorded over hourly periods (for metering) or shorter intervals (10 minutes for sensors and switches) to monitor the behaviour of certain components over standard time periods.

- data recorded over 24-hour periods (cumulated energy and cumulated electricity) which are stored continuously and used to draw up an energy balance of installation operation.

Without giving an exhaustive list of the values recorded, it is worth mentioning the principal data concerned to illustrate the scope of the experimental monitoring programme. The main data are:

- for the absorption machine: condenser and evaporator water inlet and outlet temperature, flue gas temperature, state of the burner, on-off indicators of the aborption machine and the primary pump, hot and cold energy meters, gas and electricity meters.

- for the air-conditioning unit: on-off indicators, air intake and outlet temperatures, bypass opening, opening of the two 3-way valves (one for the cold water circuit and one for the hot water circuit), relative humidity of recirculated air.

- for each of the 49 offices or corridors: air temperature, heating temperature setting, cooling temperature setting, representing 147 values for all offices.

- for weather conditions: external temperature, external relative humidity and total radiation on a horizontal surface.

- for the complete installation: the mains electricity meter.

All of this data has been stored since February 1995, which means that accurate experimental validation of the reference simulator can be performed.

This data is exploited firsthand by the personnel in charge of on-site operation. All values can be visualized via the building management system for immediate detection of any malfunctions and rapid pinpointing of their origin.

This experimental data also provides valuable information for analysis of temperature settings. For example, it has revealed that the annual average temperature setting for space heating is 21°C, a relatively high value compared to standard settings. Moreover, offices occupied by women are generally around 1°C warmer than those occupied by men ! For air conditioning, the annual average temperature setting is around 23°C.

This experimental data gives a clearer understanding of the influence of occupants on installation operation, notably through their choice of desired air temperature range. Indeed, the load on the heating and air-conditioning system varies considerably according to the temperature settings. In this building, for 1995, annual energy consumption for heating and air-conditioning totals respectively 27.1 MWh and 113.7 MWh for a comfort range of 20-24°C (temperature settings of 20°C for heating and 24°C for air-conditioning). We note the large difference in energy consumption between heating and air-conditioning. For a comfort range of 21-23°C, consumption totals 35.1 MWh and 125.6 MWh respectively (figures obtained by simulation), corresponding to a 29% increase for heating and a 10% increase for air-conditioning.

MODELLING/SIMULATION

The building

The building was divided into several zones. The breakdown of zones was decided mainly with respect to their geographical orientation, passageways and the ventilation system layout. The building was divided into 15 zones, including 12 ventilated zones: 8 office zones, 1 toilet zone and one corridor zone on each floor, 1 central zone common to all floors and corresponding to the entrance foyer and stairs. Figure 4 shows the breakdown of the building over the three floors.

The building is classified as discontinuously occupied premises with moderate inertia. The G1 coefficient of losses through the walls is equal to 0.48 W/m²°C.

The dual-service absorption machine

The dual-service absorption machine was modelled using a behaviour model. This model must reproduce, as faithfully as possible, real operating conditions, i.e., burner adjustment, heating and cooling performance, chilled/hot water outlet temperatures and gas and electricity consumptions.

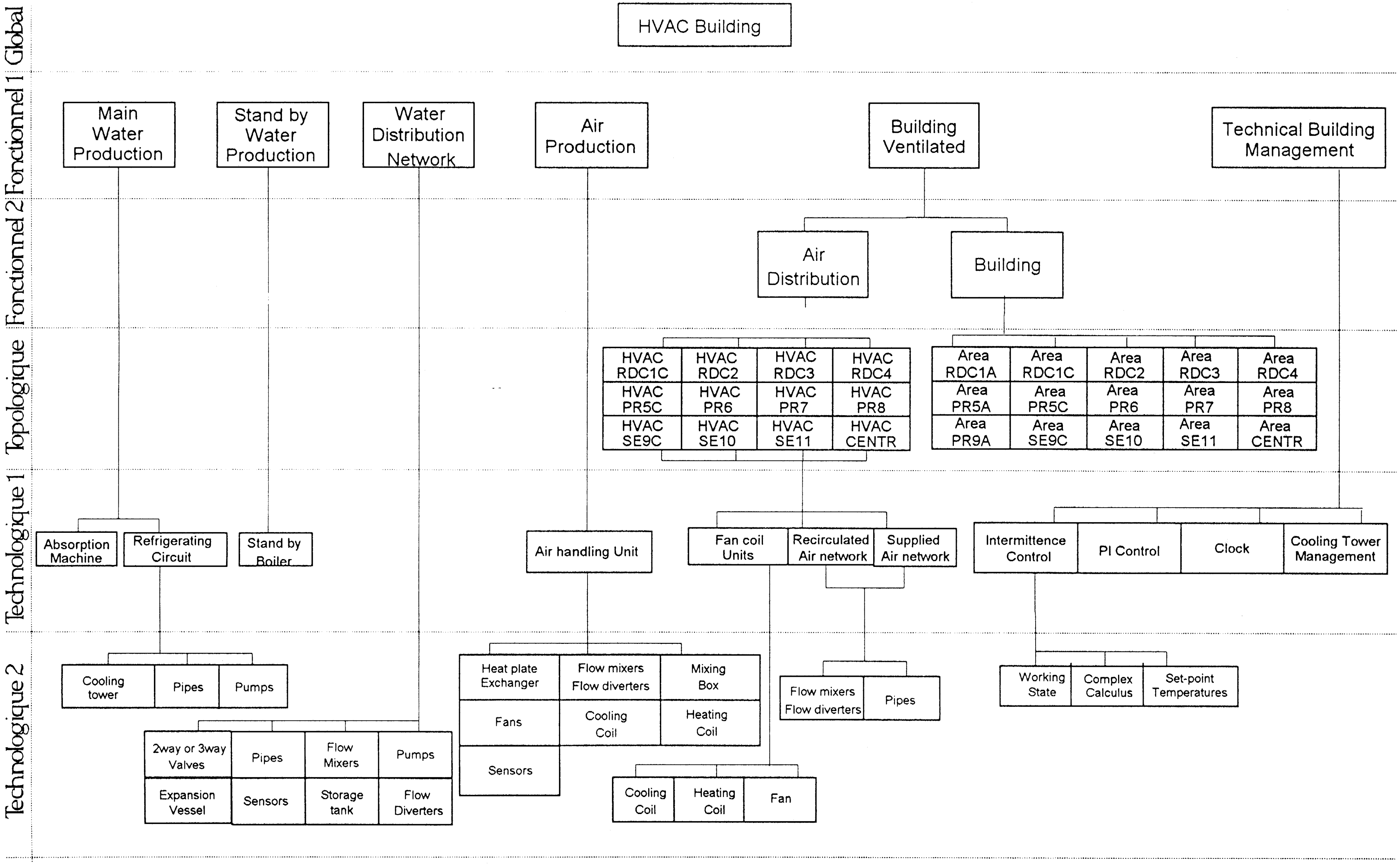
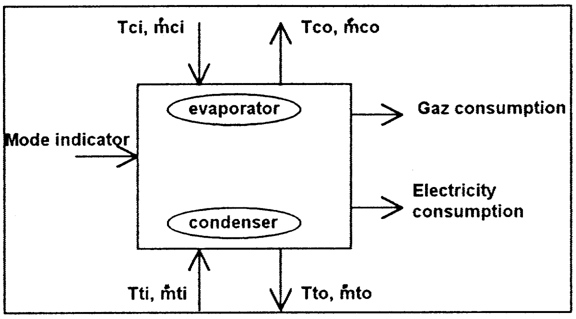


Figure 3 Breakdown Tree of the Reference Simulator

Figure 5: Diagram of the model of the dual service absorption machine

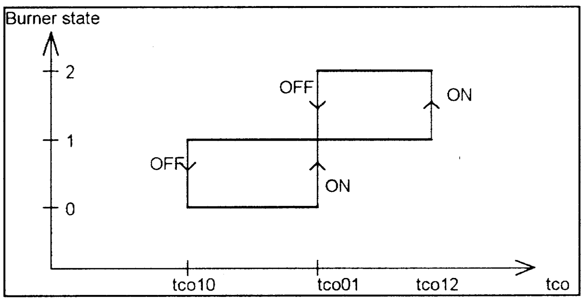


The 5 control variables are:
- mode: indicates whether the system is off or on, in heating or cooling mode
- tci: chilled/hot water temperature at the evaporator inlet
- tti: water temperature at the condenser inlet
- mci: water flow rate at the evaporator inlet
- mti: water flow rate at the condenser inlet

For each operating mode, the real technical system is controlled automatically by adjusting the hot or chilled water outlet temperature. Figure 6 presents burner adjustment in the air-conditioning mode. The burner has three settings in heating and air-conditioning mode:

- off
- setting 1 (50% of maximum output)
- setting 2 (100% of maximum output)

Figure 6: Burner adjustment in air-conditioning mode



For heat transfers, we assume that the absorption machine comprises two water circuits: a primary water circuit and a cooling water circuit. A heat balance is calculated for each circuit; at the evaporator the thermal power PO is positive or negative, depending on the operating mode (respectively heating or cooling mode)

$$M_e C p_{water} \frac{dT_{ev}}{dt} + \dot{m}_{ci} C p_{water} (T_{co} - T_{ci}) = \pm PO$$

At the condenser, the heat is discharged into the cooling circuit in cooling mode only.

$$M_c C p_{water} \cdot \frac{dT_{co}}{dt} + \dot{m}_{ti} C p_{water} \cdot (T_{to} - T_{ti}) =$$

$$\begin{cases} \dot{m}_{ci} \cdot C p_{water}(T_{cb} - T_{ci}) + PO & \text{(chiller mode)} \\ 0 & \text{(heater mode)} \end{cases}$$

The parameters (M_e Cp_{water}) and (M_c Cp_{water}) represent equivalent thermal capacities at the evaporator and the condenser respectively.

The machine's performance, i.e., the heating/cooling output and the coefficient of performance, are calculated by interpolation on the basis of real operating data. The model includes two tables of values (one for cooling mode and one for heating mode) indicating the heating and cooling output values as a function of discretized values of chilled water outlet temperature, and two other tables give heating and cooling efficiencies as a function of discretized load factor values. Gas consumption is then determined from the COP and the useful output.

The absorption machine model was validated experimentally with respect to actual heating and cooling mode operating data. Performance was modelled very successfully, since the values obtained by simulation are very close to experimental values, for the state of the burner and the evaporator water outlet temperature as well as for gas consumptions. Figures 7 and 8 illustrate this excellent match between experimental and simulation results.

Figure 7: Comparison of experimental/simulation results for evaporator outlet chilled water temperatures

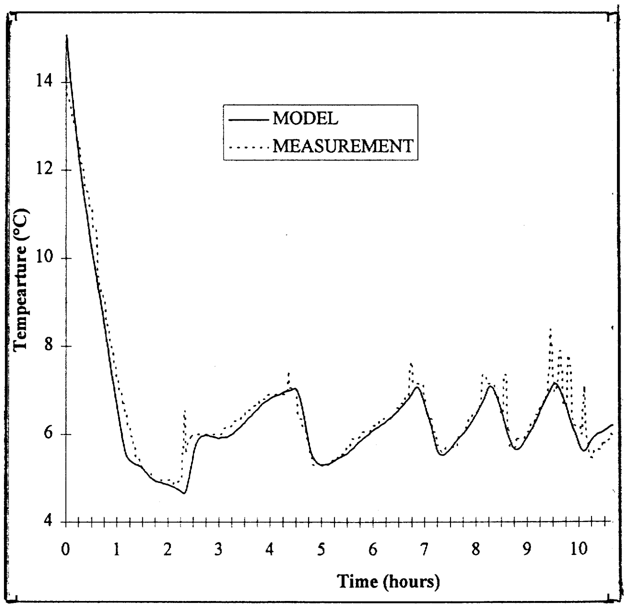
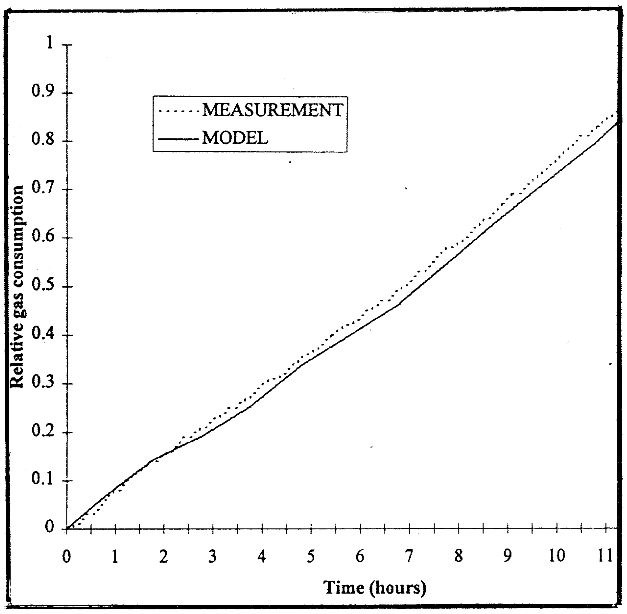


Figure 8: Comparison of experimental/simulation results for gas consumption



The other production systems were modelled along the same lines as for the dual-service absorption machine [4]. The experimental validations of these models also produced a very good match.

The simulators are now being validated. The complete validations will be presented at the conference.

CONCLUSION

The modelling/simulation study presented in this article is a large-scale project with a major experimental component.

The experimental studies provide a means not only to validate the models developed, but also to understand more fully the operating conditions of the installation and hence to perform simulations under conditions as close as possible to reality. In particular, this study has revealed the significant influence of building occupants.

The model of the complete installation was developed using Allan™.Simulation software. The identification model of the dual-service absorption machine gives very satisfactory results. Many other models, not presented in this article, have also been developed, notably models of the air handling unit, the water circuits and the building management system. Some of the models were taken from previous studies. The choice of modelling methodology favours the reuse of existing models. All the written models can be reused, opening wide-ranging opportunities for future research projects.

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NOMENCLATURE

Letters :

COP	Coefficient of Performance
Cp	Specific heat of fluid, $J.kg^{-1}.K^{-1}$
M	Mass, kg
$\dot{m}$	Mass flow rate, $kg.s^{-1}$
T	Temperature, K^{-1}

Subscripts :

ci	Fluid inlet from chilled (or hot) circuit
co	Fluid outlet from chilled (or hot) circuit
ti	Fluid inlet from tower
to	Fluid outlet from tower