Clemo p 202

MODELLING/SIMULATION STUDY OF A COMMERCIAL BUILDING IN COMBINATION WITH ITS AIR-CONDITIONING SYSTEM

Authors:
Frédéric MILCENT, Laurence LAPENU
GAZ DE FRANCE / Research and Development Division
361, aventie die Président Wilson - BP 33 - 93211 Saint Denis La Plaine - FRANCE

Introduction

In line with its work on the positioning of gas air-conditioning systems in the commercial sector, the Gaz de France Research and Development Division conducted both experimental and theoretical studies.

An air-conditioning system, known as **the** `reference solution", was installed and equipped in a building on Division premises. The purpose of the systern modelling and simulation study was above all to analyse the building's behavior regarding various criteria, while a technico-economic study compared the various (Generation systems. Only the first phase of the study is discussed in this article.

Description of the so-called "reference solution" system

The building studied (1400 sq. **m) is** representative of a category of **new** office buildings of the `company headquarters" type, having a complex three-storey configuration.

The premises are air-conditioned via 4-pipe fan coils which are fed by a dual-duct **air** handling unit.

Heating, and cooling are produced by a gas-fired absorption machine, with an auxiliary gas-fired boiler for rnid-season heating

Operating control and programming are handled by a Building Technical Management (GTB) systern.

In each office, one or rnore fan coils maintain a comfortable atmosphere within the temperature ranue desired by the user. The absorption rnachine produces heating or cooling respectively in winter and **in** surnrrier. However, for the two i-nid-season periods, the offices may be either heated by operating the boiler or cooled by operating the absorption machine. All year round, the users of the **meeting** rooms can switch on **the** ventilation (the single-effect air-conditioning plant) as desired.

The diagram below illustrates **the** operators of the systern for rnid-season periods.

1 G..

GAZ-FIRED AIR CONDITIONING SYSTEMS OF THE STUDIED BUILDING OF GI3F/D11 d.
Working diagram - Mid-season running

Stand by heatingWC
nemork

EC

boucfage

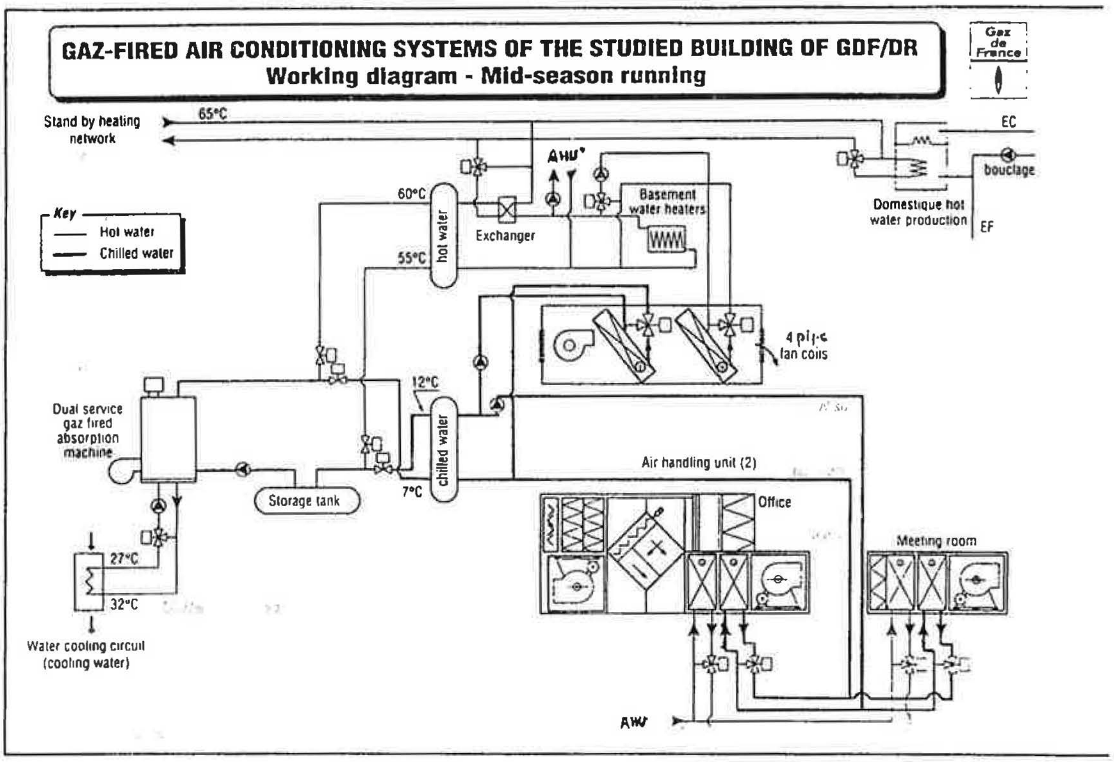
6

Wale, cl0109 C"C.,1

(cool ng ale')

AW

The modelling tool used: ALLAN. NEPTUNIX



The modelling tool used: ALLAN. NEPTUNIX

ALLAN.^{TM}[1] ("Software Access in Natural Language") is a pre- and post-proc associated to the NEPTUNIX algebraic/differential equation solver, organized around main stages, each of which is associated with a generic menu, as follows :

- DESCRIPTION : *formulating the models*

It is possible to describe simple or compound models, the behavior of which may both discontinuous and continuous aspects. Each model is described from the internal an external standpoints.

- Internal representation

- Simple model : text listing the model's coupling variables and describing the beh of the system modelled. This text has several blocks : DECLARATIONS, INIT, EQUATI(FORTRAN (procedural part), INTERFACE and AUTOMATE.

- Compound model : internal diagram grouping together all the occurrences of the si and/or compound models making up the model. The occurrences are connected to another via links between their bounds or "connectors". A link connects the variable o connector to the same-unit variable of the other connector by an equation:

extensive variable: balance equation
intensive variable: equation of equality

- External representation : external diagram, enabling the model to be used compound model. It is related to the internal representation via the list of coupling variabl

- CONSTRUCTION : *placing the models in situation*

To place the models in their situation, the main model (i.e. the model correspondir the technical system under study) must be brought together with the conditions to which

ALLAN. TNI, C'Software Access **in** Natural Lan(;Lia(,e") **is** a pre- and post-processor

W

associated to the NEPTUNIX al(@ebi-alc/d'ltTei-ential equation solver, organized around four **rnam** stages, each of **which** is associated **with** a ueneric rnenu, as follows

W,

- *DESCRIPTION:* ***llic*** models.

It is possible to describe **simple** or **compound** models, the behavlor of which may have both discontinuous and continuous aspects. Each model is described from the internal and the external standpoints.

Internal representation

Simple model : text listing the model's coupon(, variables and describing the behavior w

of the system modelled. Tlils text has several blocks ' DECLARATI0NS, INIT, EQ@JATIONS , FORTRAN (procedural pail), INTE-RFACL.' and Al JT0MATE. - Compound model : internal diagram grouping together all the occurrences of the simple w c

and/or compound models making up the model. The occurrences are connected to one another via links between their bounds or `connectors`. A link connects the variable of one connector to the sarne-unit variable of the other connector by an equation
extensive variable: balance equation

intensive variable: equation of equality

External representation @ external dlaurarn, enablin(the model to be used in a compound model. It is related to the internal representation via the list of coupling variables.

- CONSTRUCTION @ **placing,,** *117e* **@iio(lely** *iii.s.illicilioii*

To place the models in their situation, the main model (i.e. the model corresponding to

the technical system under study) must be brought together with the conditions to which it is

W

ALLAN.TM isi re-istered of'G@iz De **Fnince**

The CENTR zone describes the central zone of tile building, shared by all the floors and correspondiiiz,., to the stairwell

The dia,,,i-aiiis below describe the breakdown of the buildin. and the location of the

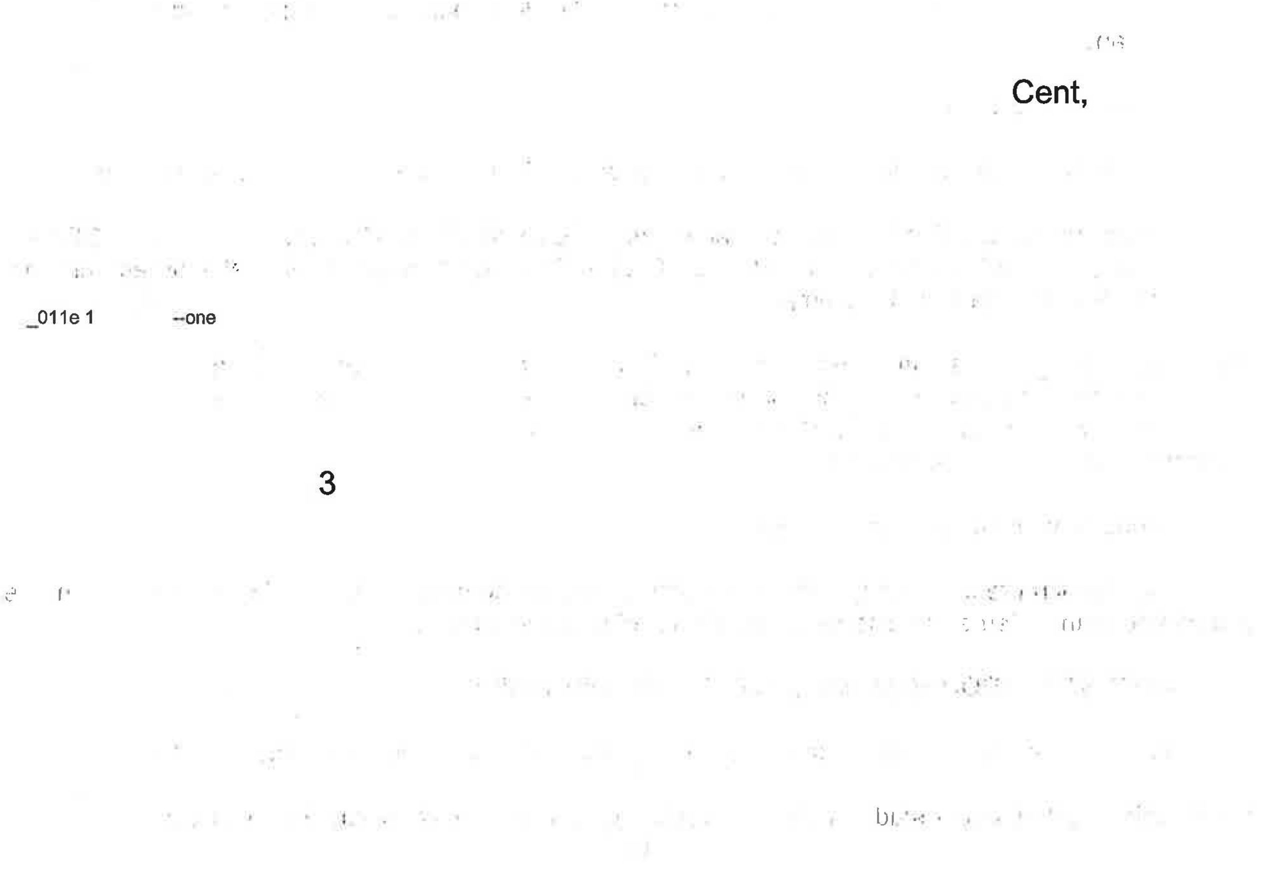
C@

return air re-isters feedin- the a'r-handllil,, unit for each of the floors.

C@

Diaurarns of tile breakdown of the building under study

Ground floor First floor Second floor



subjected (excitations). The simulator created can be used independently since it is written in Fortran and is thus portable.

- OPERATION . ***it,@itig*** 1he ***siiiiitlciloi.***

The simulation can be started as soon as the operating instructions are given (resolution, integration pitch, observations, re-assignments, etc.).

- POST-PROCESSING *:* **stiitiyiiig** *1he*

Graphs and additional calculations on results are obtained and new files are generated.

To be able to reuse all or part of the modelling studies, the systems under study have to be broken down carefully. This breakdown highlights a **number** of levels, resulting in a tree on which all the models used in the study can be visualized.

BREAKDOWN'
- functional level
- topological level

C)

- technological level

Z

- phenomenological level

Modelling a multizone

Determining how the building, should be broken down is based primarily on its geographical ostentation, the zones in which occupancy is assumed to be constant, the zones W Z:1
for circulation and the various ventilation pathways.

Accordingly, the building is broken down into 1 5 zones, including 12 blower zones. The total output is produced by 87 fan coils, but only 12 fan coils are taken into consideration, dimensioned according to the sources installed in each office and meeting room.

Z_

The air pathway is designed mainly in relation to the location of the return air registers w
feeding, into the air-handling unit, the ventilating rate via the registers is assumed constant for each floor and 'is computed on the basis of the return to the air-handling unit.

In addition, the zones for the restrooms (RDC 1 A, PR5A, PR9A), connected to a VMC (controlled mechanical ventilation) system], impose pathways of air drawn in from the surrounding zones.

c

In terms of inertia and heat loss, the building modelled and studied is a space occupied discontinuously with a medium inertia rating. The coefficient GI corresponding to heat losses is 0.48W/Km3.

Computing building requirements

Actual heating and cooling requirements are computed through simplified modelling, because, while the various gains - from the occupants, the office computer equipment and li(,htin(,, the sun and the ventilation - are shown, the real system itself is not modelled. Even the ventilation is simplified compared to that described in the building breakdown, because the zone-to-zone air transfers are not modelled. Moreover, a simplified form of control is set up, to resemble the requirements of the actual system as closely as possible.

=> **Control** and energy **production**

The heating period begins on 09/15 and ends on 05/15. The air-conditioning period be-ins on 03/15 and ends on 1 1/15. In the nild-season, both heatinu and air-conditioning are aval dable.

> Each zone is elther heated or cooled by adding a quantity of heat (for heating) or withdrawing it (for air-conditioning) directly from the air node for the corresponding zone. The production of heat or cooling is proportional and varies depending on the setting temperature. It is worth pointing out that the type of production (electricity, gas or other) is not important here. The maximurn air-conditj'onin(, input is different frorn the heating input. These two ratings vary from one zone to another.

For simulations of continuous operations, the set-point temperatures for heating and air conditioning are respectively equal to 20'C and 2CC.

For simulations with intermittent operations , a lower set-point temperature for heating of 1 2'C is used. The intermittent operation is achieved by a level 2 scheduler, which reactivates the systern 4 hours before occupancy on weekdays and 8 hours before occupancy on Monday mornings. In that way, the set-point temperature is reached from 8 a.in to 7 p.in., Monday throm,h Friday.

=> Ventilation

Requirements are comprised by, bulletin(, simplified models of the actual ventilation system. In partICUlar, an- circulation between zones Is riot taken into account. For each zone, an input of fresh air at the Outdoor temperature and an extraction of air (to the outdoors) at the temperature of the zone are considered, the rate is constant dui,In(y the ventilation time and varies frorn zone to zone (rate of Occupancy). The ventilation is started up 1 hour before Occupancy begins and is stopped at the end of occupancy. It operates year round, except on weekends.

subjected (excitations). The simulator created can be used independently since it is writ
Fortran and is thus portable.

- OPERATION : *using the simulator*

The simulation can be started as soon as the operating instructions are given (resol
integration pitch, observations, re-assignments, etc.).

- POST-PROCESSING : *studying the results*

Graphs and additional calculations on results are obtained and new files are generat

To be able to reuse all or part of the modelling studies, the systems under study ha
be broken down carefully. This breakdown highlights a number of levels, resulting in a tr
which all the models used in the study can be visualized.

BREAKDOWN :
- functional level
- topological level
- technological level
- phenomenological level

Modelling a multizone

Determining how the building should be broken down is based primarily on its geographical orientation, the zones in which occupancy is assumed to be constant, the zon
for circulation and the various ventilation pathways.

Accordingly, the building is broken down into 15 zones, including 12 blower zones.
total output is produced by 87 fan coils, but only 12 fan coils are taken into considera
dimensioned according to the sources installed in each office and meeting room.

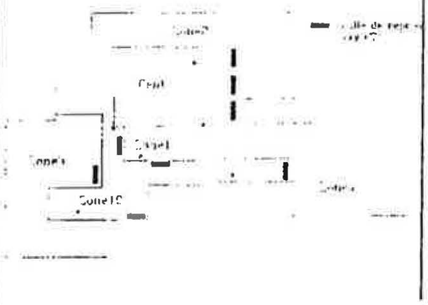
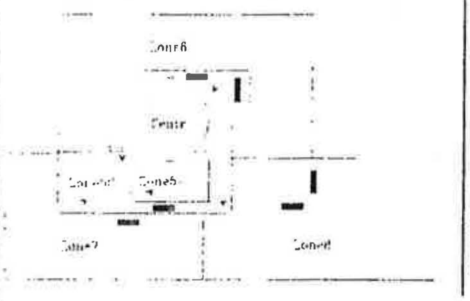
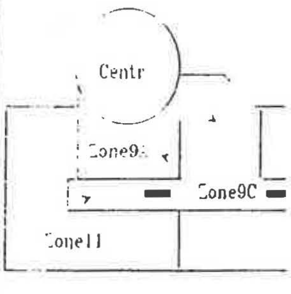
The air pathway is designed mainly in relation to the location of the return air regi
feeding into the air-handling unit: the ventilating rate via the registers is assumed constan
each floor and is computed on the basis of the return to the air-handling unit.

In addition, the zones for the restrooms (RDC1A, PR5A, PR9A), connected to a V
(controlled mechanical ventilation) system, impose pathways of air drawn in from
surrounding zones.

The CENTR zone describes the central zone of the building, shared by all the floors
corresponding to the stairwell

The diagrams below describe the breakdown of the building and the location of
return air registers feeding into the air-handling unit for each of the floors.

Diagrams of the breakdown of the building under study

Ground floor	First floor	Second floo
		

It should be noted that the fan coils operate both day and night, in order to avoid any
N1W
risk of the temperature falhil- below 5T. Over a year, these gains total 39.4 h.

Z@ In

Internal loads **due** to **the** occupants

These internal gains are proportional to the nurnber of occupants per zone. Each occupant releases a sefisitive heat estimated at 72W

A typical occupancy begins at 8 a.iii. and ends at 7 p.iii., Monday through Friday. The internal ,alns from the occupants, which are computed for each of the zones considered, total

C1
13.2MWh per year.

The table below shows the breakdown of the internal ---ains in the building studied.

Type of internal gain	Annual energy MWh-	Percent
Equipment	94.2	64%
Fan coils	39.4	27%
Occupants	1 -	9%

In computing requirements, no infiltrations are considered.

c@> Solar gains

The solar ,aitis are calculated iis'nc(x the "N/1@tdo France" file, which provides such d as the outdoor temperature and the total radiation on a horizontal surface.

Incident and transmitted solar radiation is computed as a function of the total radiation o horizontal plane, Radiation transmitted through the windows is calculated using a coefficient transmission, that varies dependim, on the an-le of incidence, into account.

c C1

Self-shadina are taken into consideration. For the wall facing south, the shadow cast the second floor on the ,round floor and the first floor was calculated. That shading has a lderable influence 1 1

cons as s shown 'n the table below, witch olves the annual energy values per surface area (in MWlVi-n2) for the different floors on the southern wall of the building.

Floor	Incident energy (MWli/iii'2	Transmitted energy (MWh/m2)
	955	506
1	79	170
0-ground	575	281

c:> **Internal** loads **due** to **the equipment** (lighting **and** **computers)**

These loads are evaluated experimentally by measuring power consumption. The internal gains per surface area are modelled at 1 6W/i-n2 durin. the daytime and at 2.9W/m2

z@ *in*

durinu the ni-lit. These 'Internal ---ains arnount to 94.2 MWh over a yearc::> **Internal** loads d

to the **fan** coils

These internal -ains are determined zone-by-zone on the basis of the average power consumed by the fan coils and the number of fan coils per zone. The average electric power, indicated on the rneter readings, equals 4.5 kW for all of the fan coils in the building.

Models used for computing requirements

The overall model is broken down into 5 main models : the model of the building, a model of the clock to convert the tirne variable (in seconds) into week, day and hour numbers, two models to compute both the heating and the cooling consurriptions, and a compound model called CALOR, which computes the various heat gains and takes control into account.

The specific modelling of the building is achieved using the tool m2m developed by GISE2. This modelling is based primarily on modal techniques.

W

,CALOR, the compound model, relies on 8 simple models. one describing the operating condition and the set-point temperatures desired for control put-poses, another which computes the output (occupants, light ing, fail coils, heat transfer by ventilation) corresponding to each

1-1 Z:1

type of internal gain, and the TREGUL model, which computes the heating and air-

conditioning powers needed to rneet the set points, taking the external and internal gains and tile losses due to ventilation into account.

Tile model of the level 2 intermittence scheduler computes three levels of operations the normal heatine or/and air-conditioning powers in occupancy's period depending on the outdoor temperature, the shutting down of heating or/and air-conditioning at tile end of tile W

occupancy's period and the restart with a i-naxiinLiiii power.

The control variables **in** the overall model are the air flow rate into each zone, the surroundin(r temperatures (outslde, **in** the basement and in the parkin(, area), as well as the 'dental and ti-aiisiii'tted rad'at'

various **incl** **1** i ions.

<u>External diagrarn of the overall model</u> <u>Internal dia,,rai-n of the overall i-nodel</u>

13A T 1 m

⇨ Solar gains

The solar gains are calculated using the "Météo France" file, which provides suc as the outdoor temperature and the total radiation on a horizontal surface.

Incident and transmitted solar radiation is computed as a function of the total ra on a horizontal plane. Radiation transmitted through the windows is calculated u coefficient of transmission, that varies depending on the angle of incidence, into account.

Self-shading are taken into consideration. For the wall facing south, the shadow c the second floor on the ground floor and the first floor was calculated. That shading considerable influence, as is shown in the table below, which gives the annual energy valu surface area (in MWh/m^2) for the different floors on the southern wall of the building.

Floor	Incident energy (MWh/m^2)	Transmitted energy (MWh/m^2)
2	955	506
1	379	170
0-ground	575	281

⇨ Internal loads due to the equipment (lighting and computers)

These loads are evaluated experimentally by measuring power consumption. internal gains per surface area are modelled at $16W/m^2$ during the daytime and at 2.9 during the night. These internal gains amount to 94.2 MWh over a year.

⇨ Internal loads due to the fan coils

These internal gains are determined zone-by-zone on the basis of the average p consumed by the fan coils and the number of fan coils per zone. The average electric p indicated on the meter readings, equals 4.5 kW for all of the fan coils in the building.

It should be noted that the fan coils operate both day and night, in order to avoi risk of the temperature falling below 5°C. Over a year, these gains total 39.4 MWh.

⇨ Internal loads due to the occupants

These internal gains are proportional to the number of occupants per zone. occupant releases a sensitive heat estimated at 72W.

A typical occupancy begins at 8 a.m. and ends at 7 p.m., Monday through Friday. internal gains from the occupants, which are computed for each of the zones considered, 13.2MWh per year.

The table below shows the breakdown of the internal gains in the building studied.

Type of internal gain	Annual energy MWh	Percent
Equipment	94.2	64 %
Fan coils	39.4	27 %
Occupants	13.2	9%

Models used for computing requirements

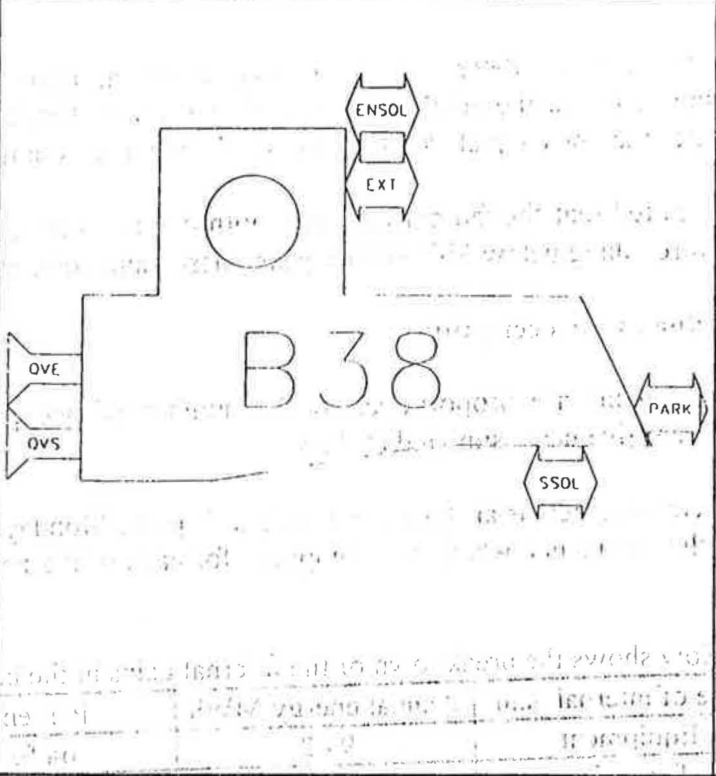
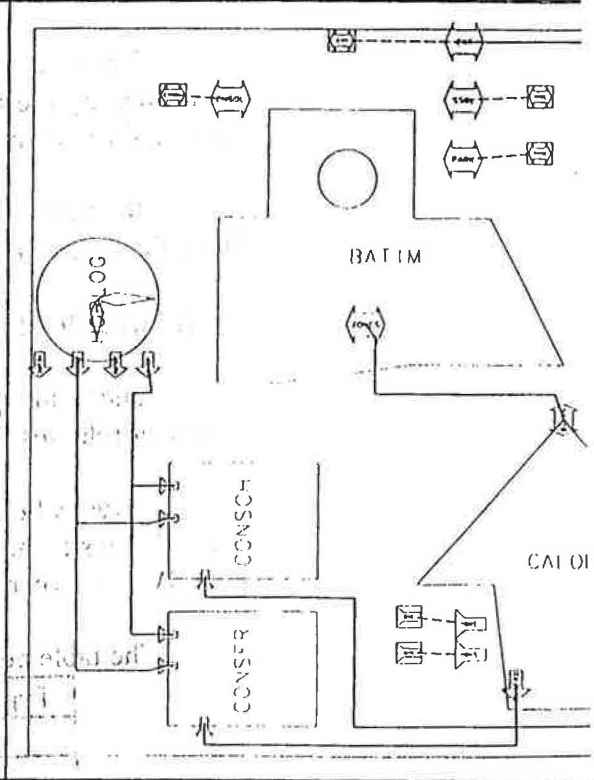
The overall model is broken down into 5 main models : the model of the buil model of the clock to convert the time variable (in seconds) into week, day and hour nu two models to compute both the heating and the cooling consumptions, and a com model called CALOR, which computes the various heat gains and takes control into acc

The specific modelling of the building is achieved using the tool m2m develo GISE[2]. This modelling is based primarily on modal techniques.

CALOR, the compound model, relies on 8 simple models: one describing the ope condition and the set-point temperatures desired for control purposes, another which con the output (occupants, lighting, fan coils, heat transfer by ventilation) corresponding t type of internal gain, and the TREGUL model, which computes the heating an conditioning powers needed to meet the set points, taking the external and internal gai the losses due to ventilation into account.

The model of the level 2 intermittence scheduler computes three levels of operat the normal heating or/and air-conditioning powers in occupancy's period depending c outdoor temperature, the shutting down of heating or/and air-conditioning at the end occupancy's period and the restart with a maximum power.

The control variables in the overall model are the air flow rate into each zon surrounding temperatures (outside, in the basement and in the parking area), as well various incidental and transmitted radiations.

External diagram of the overall model	Internal diagram of the overall model
	

---

[2] GISE (G

CM OR

jL_

2GISE (Grompe informatique et SY stenics Eiict-gdtiqtics) at the Ecole N@itioil@lle des Ponts et Chatissdes (EN-PC)
Gilles LEFEBVRE

6

To do so, the temperature charil-es In the building, - which this case is only affected by the outside ternperatUre, the solar radiation and the ---ains from the computers and fan coils are observed., the nUnierical and experimental values are compared zone-by-zone. The experimental values are avera(Tes of the temperatUre measurements in the offices comprising each zone.

As a -eneral rule, the simulation results fit the experimental measurements fairly closely

W

for all the office zones.

The following graph Illustrate the above statement.

W

affords a comparison between the air temperature obtained thrOLWII Simulation (TAIR _zone) and the temperature measured experimentally (TR_zone), for the office zone PR7 on the second floor.

External diagram of the CALOR model

HAFRO

OVE

Internal diagram of the CA-LOR model

TRECUL

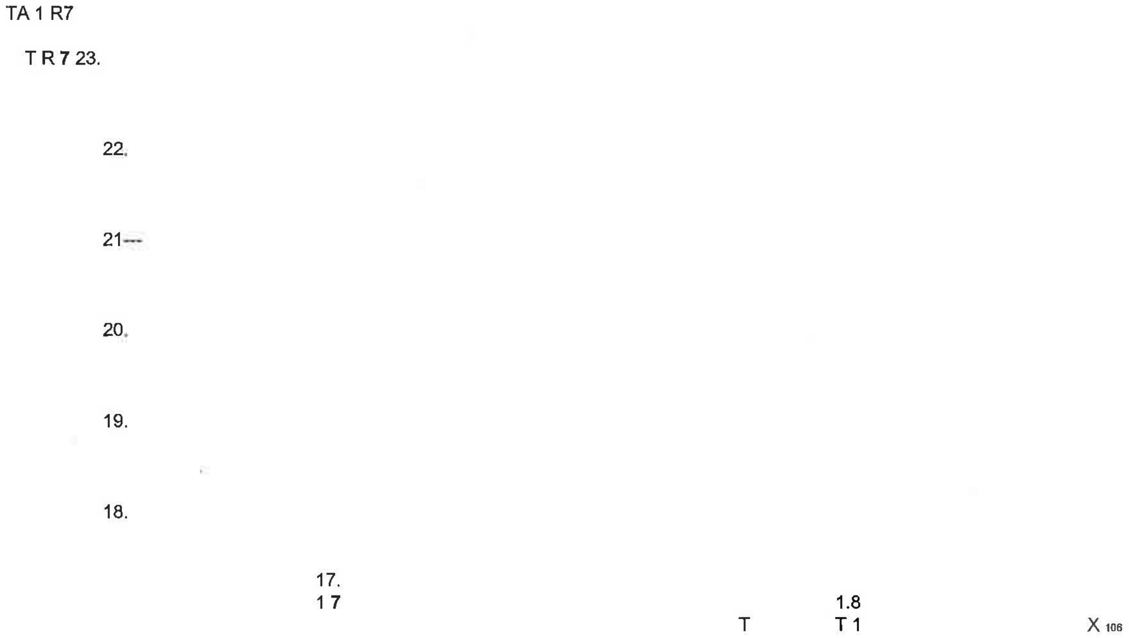
ECLAIR

Experimental validation **of** the building's dynamic

The objective is to validate the building's dynamics experimentally, without either heating or cooling, and without ventilation.

0

Comparison of simulated (TAIR7) and experimental (TR7) air temperatures for zone 7



Experimental validation of computations of heatinglair-conditioning requirements

The objective here Is to validate the computations of bullding, requirements experimentally. **Three** validation periods are considered, each lasting one week:

W

- a period in winter, when **heatim,** alone is required
- a period in rnid-season, when both heatim, and air-conditioning may be required

C@

- a period **in summer,** when air **conditionino** alone is required

A sinule set-point temperature is imposed in each room in the buildlng by means of the GTB (Building Technical N1anagernent) systeni. Experimental temperature measurements in

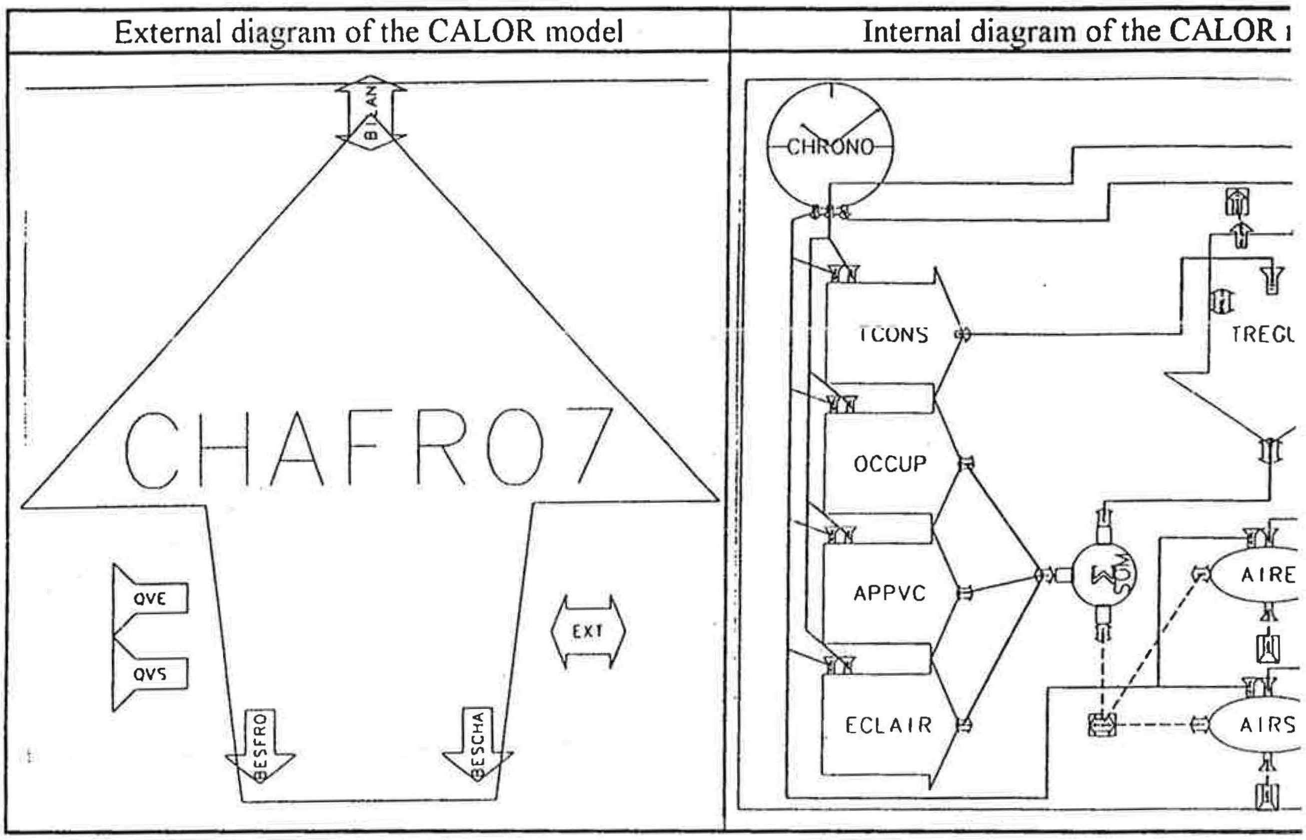
c c

each roorn are analyzed and compared with the set-point temperature. These measurements are then compared with the temperatures obtained through simulatioll.

The second phase consists in corriparin(I the values for the heatin- and/or air1-@ 0 conditioning requirements, which are obtained by experimentation and by simulation.

c

In this article, we will only describe the results of the validation in winter. The winter validation period began on February 19 and ended on February 24, 1996. The set-point c temperature was set at 20X' for each rooni.



External diagram of the CALOR model

Internal diagram of the CALOR

Experimental validation of the building's dynamics

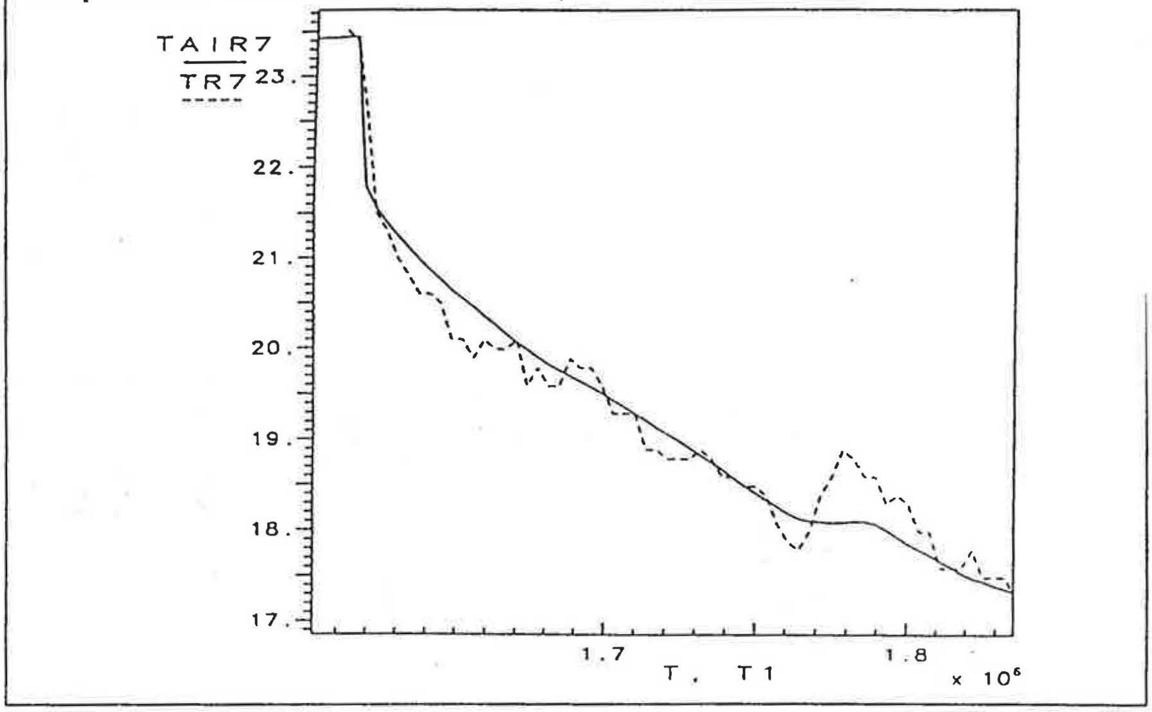
The objective is to validate the building's dynamics experimentally, without e heating or cooling, and without ventilation.

To do so, the temperature changes in the building - which in this case is only affe by the outside temperature, the solar radiation and the gains from the computers and fan c are observed; the numerical and experimental values are compared zone-by-zone. experimental values are averages of the temperature measurements in the offices compr each zone.

As a general rule, the simulation results fit the experimental measurements fairly cl for all the office zones.

The following graph illustrate the above statement; it affords a comparison betwee air temperature obtained through simulation (TAIR_zone) and the temperature meas experimentally (TR_zone), for the office zone PR7 on the second floor.

Comparison of simulated (TAIR7) and experimental (TR7) air temperatures for zone 7



Experimental validation of computations of heating/air-conditio requirements

The objective here is to validate the computations of building requirer experimentally. Three validation periods are considered, each lasting one week:

- a period in winter, when heating alone is required

- a period in mid-season, when both heating and air-conditioning may be required

- a period in summer, when air conditioning alone is required

A single set-point temperature is imposed in each room in the building by means o GTB (Building Technical Management) system. Experimental temperature measuremen each room are analyzed and compared with the set-point temperature. These measurement then compared with the temperatures obtained through simulation.

The second phase consists in comparing the values for the heating and/or conditioning requirements, which are obtained by experimentation and by simulation.

In this article, we will only describe the results of the validation in winter. The w validation period began on February 19 and ended on February 24, 1996. The set-ṛ temperature was set at 20°C for each room.

The graph below shows the temperature changes in zone 4 in the modelling (TA] and in the experimentation (TR4).

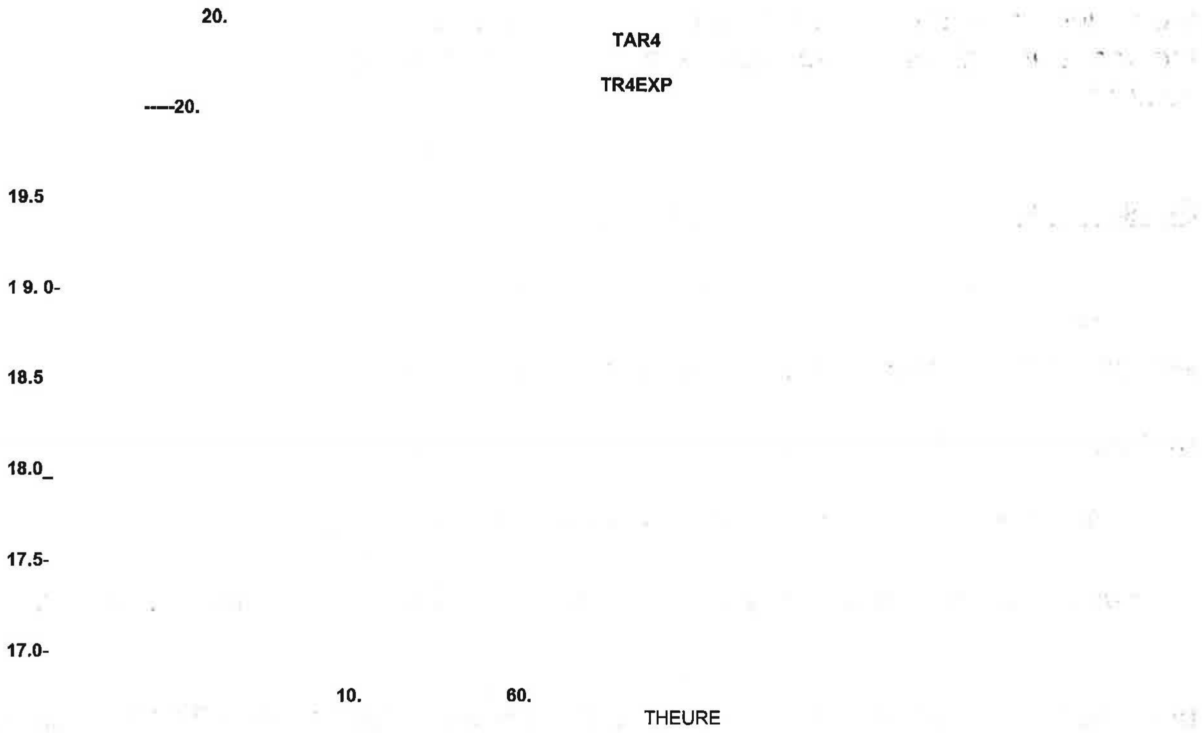
The graph below shows the temperature changes **in** zone 4 in the modelling (TAIR4)
W Zw)

and **in** the experimentation (TR4),

8

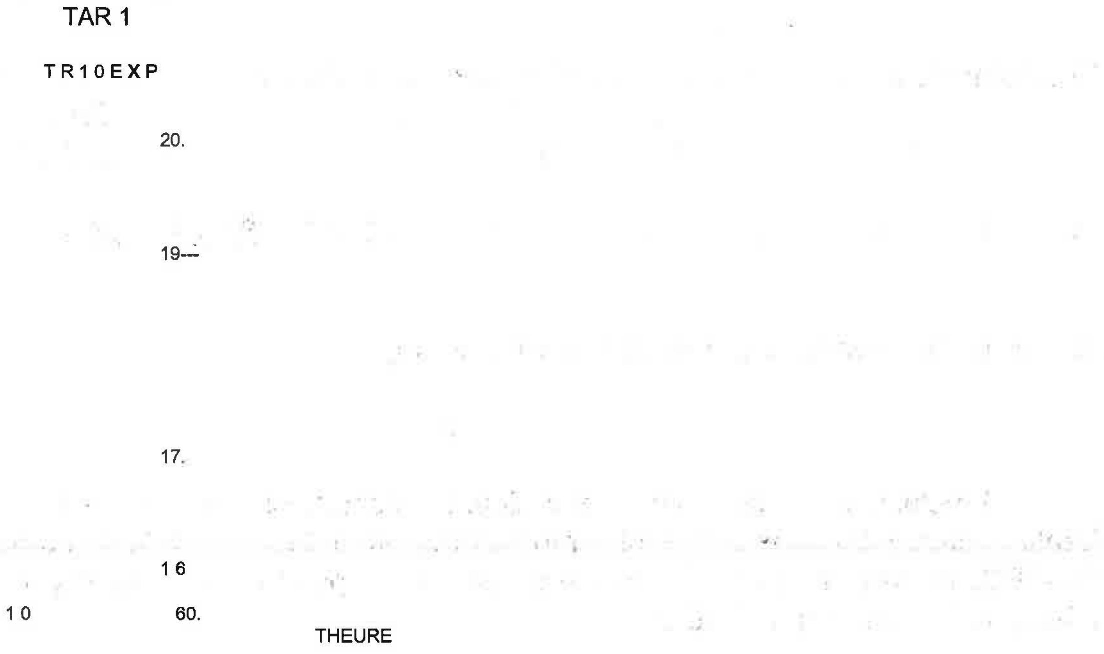
9

Comparison of stimulated (TAIR4) and experimental (TR4) **air** temperatures for zone 4



The graph below plots the temperature changes **in** zone 10 in the **modelling** (TAIRIO) and in **the** experimentation (TRIO). It clearly shows that the set-point temperature is not **maintained** in **this** zone.

Comparison of simulated (TAI RI 0) and experimental (TR 1 0) air temperatures for zone 10



As for the heating requirements, the experimentation indicates a value of 4.0 Mh
c
the period under consideration. The value obtained by simulation is equal to 4.1 N4Wh. He the modelling gives an accurate estimate of the heating requirements (on the scale of building).

<u>Sensitivity studies on annual requirements</u>

Several sirnulations were carried out in succession, each of thern highlighting the im of a different phenomenon (type of gain, intermittence, set-point temperatures, insulat windows areas , etc.), compared to that of the previous simulations.

n> **impact of** heat **gains with constant tenll)ei,,tttmi,e** set-points

The first series concerns the buildino shell, without an intermittent operation schedul
ls,
for heating/air-conditioniii(, set-poi res of 20'C/24'C, and shows the impact of the

1, int temperatu
beat gains. Simulation 1 shows the annual heating and a'r-cond't'on'ng requirements f buildinu with no (mins, which equal respectively 155 MWii and 0 N1Wh. This rneans that in **surnrrier,** the outdoor temperature does not rise **high** enough for the temperature in the

'n
different zones in the buildinu to exceed 24'C, for the weather conditions simulation In W sirritilation 2, all the ---ains are taken into account. The requirements then equal 33,4 Mh licatin(y and 123,4 MWIi for air-conditioning

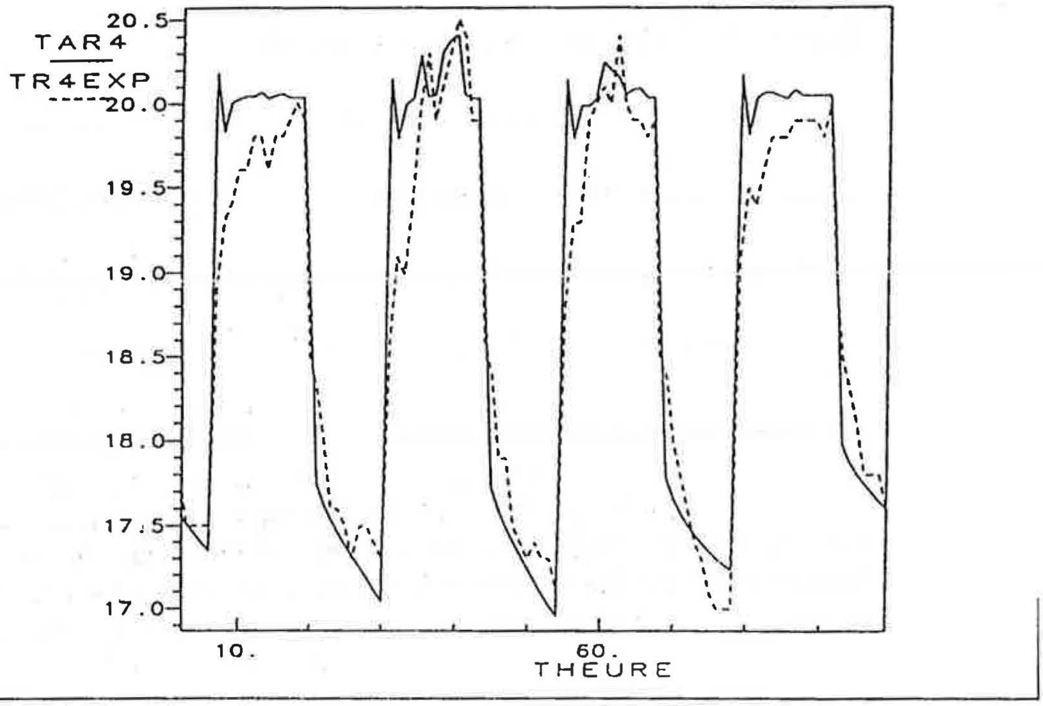
	Gains				Control		Requirements MWh	
No.	Solar	Occupants	Lighting	Fan-Coil	Intermittence	Setting	Heating	Cooling
		8-19	8-20	0-24		Ternp.		
1	0	0	0	0		200-24`	155	0
2	1	1	1	1	0	200-24`	33,4 @	123,4

11:, **Impact** of **intermittent operations with heat gains**

ty

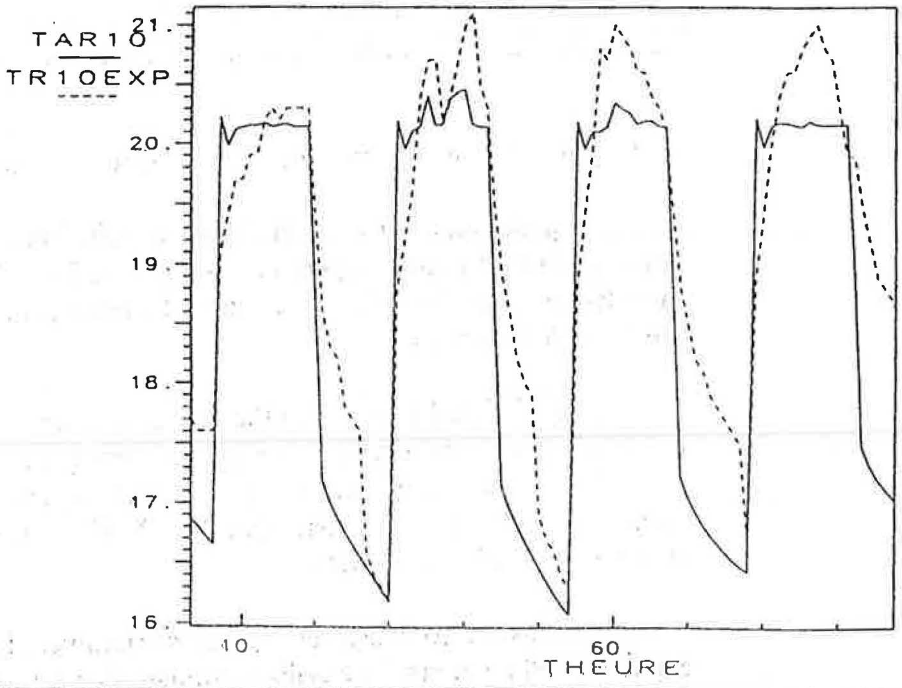
Simulations with an intermittent scheduler were also carried out, heating/airconditionmex set-point temperatures other than 20'C-24'C, namely 19'C-25'C an PC-2PC, in order to show the influence of the set point on the building requirements and Impact of intermittent operations.

Comparison of simulated (TAIR4) and experimental (TR4) air temperatures for zone 4



The graph below plots the temperature changes in zone 10 in the modelling (TAI and in the experimentation (TR10). It clearly shows that the set-point temperature i maintained in this zone.

Comparison of simulated (TAIR10) and experimental (TR10) air temperatures for zone 10



As for the heating requirements, the experimentation indicates a value of 4.0 M the period under consideration. The value obtained by simulation is equal to 4.1 MWh. the modelling gives an accurate estimate of the heating requirements (on the scale building).

Sensitivity studies on annual requirements

Several simulations were carried out in succession, each of them highlighting the of a different phenomenon (type of gain, intermittence, set-point temperatures, insul windows areas , etc.), compared to that of the previous simulations.

⇨ Impact of heat gains with constant temperature set-points

The first series concerns the building shell, without an intermittent operation schec for heating/air-conditioning set-point temperatures of 20°C/24°C, and shows the impact heat gains. Simulation 1 shows the annual heating and air-conditioning requirements building with no gains, which equal respectively 155 MWh and 0 MWh. This means that summer, the outdoor temperature does not rise high enough for the temperature i different zones in the building to exceed 24°C, for the weather conditions simulatior simulation 2, all the gains are taken into account. The requirements then equal 33,4 MW heating and 123,4 MWh for air-conditioning.

	Gains				Control		Requirements MWh	
No.	Solar	Occupants 8-19	Lighting 8-20	Fan-Coil 0-24	Intermittence	Setting Temp.	Heating	Cooling
1	0	0	0	0	0	20°-24°	155	0
2	1	1	1	1	0	20°-24°	33,4	123,4

⇨ Impact of intermittent operations with heat gains

Simulations with an intermittent scheduler were also carried out, for heatin conditioning set-point temperatures other than 20°C-24°C, namely 19°C-25°C and 21°C- in order to show the influence of the set point on the building requirements and the impa intermittent operations.

Simulation 4 constitutes the reference case : the conditions of the simulation repro the building's actual service conditions as closely as possible. This simulation may also be to estimate the influence of intermittent operations, which reduce both the he requirements (27,1 MWh instead of 33,4 MWh) and the air-conditioning requirements (1 MWh instead of 123,4 MWh).

The extent to which requirements are lowered as a result of intermittent operations expected. While control specialists estimate that installing a level 2 programmer saves rou 25% of the energy required for heating, in our case, a saving of 22% was achieved.

Simulation 4 constitutes the reference case : the conditions of the simulation reprod the buildin,,'s actual service conditions as closely as possible. This simulation may also be u to estimate the influence of' intermittent operations, which reduce both the heating requirem (27,1 MWIi instead of 33,4 N4Wii) and the air-conditioning reqU Irements (1 13,7 MWIi instea 123,4 MWIi).

The extent to which requirements are lowered as a result of intermittent operations is expected]. While control specialists estimate that Installing a level 2 programmer saves rou 25% of the energy required for heating, in our case, a saving of 22% was achieved.

For air conditionitw, a S'l/0 saving is achieved

Two additional ranoes are studied : 19'C - 25'C and 2 1 'C - 23'C. Tile results are logical : for heating, higher the temperature, tile greater tile heating requirements. And for cooling, the exact opposite is tr

			Gaills		Control		Requirements MWh	
No.	Solar	Occupants	Li(,lltlll(l	Fan-Coll	intermittence	Settinu	Heating	Cooling
			8-1 9	8-20	0-24	Ternp.		
4	1	1	1	1	1	200-240	27,1	113,7
8	1	1				190-250	2019	103,1
19 1	1	1	1			2 1 `-23) C,	35,1	125,6_

The table below uives the fi(,Lires reflecting the changes in requirements as the set-point

temperature is lowerec ot. ralsed by PC relative to the 2WC - 24'C range.

Interestingly, the implementation of intermittent operations on the weekend alone (simulation 3) lo the heating, requirements by 10% and the air-conditioning, requirements by 6%.

By comparing sirnulations 5 6 and 7 with the reference case, they highlight the impact of

c 1 0

the internal (,alns due to the fan coils and those due to the 11(1htina and the occupants. If the

Z:1 ID W

first type of internal (,arms are excluded, the heating requirements increase by 45% and airconditioning requirements drop by 16%. The influence of the second type of internal (lighting+occupants) is even <u>greater</u> : +146% for heating and -45% for all- conditioning. In the abse of internal oal'ns, the air-conditioning requirement is relatively low, only 48,6 MWh, despite the effe solar <u>gain</u>.

Gaills Control Requirements

No. Solar Occupants Li-litinu Fan-Coil Intermittence Setting

Heating

Cooling

8-1 9

20 0-24 Ternp.

2

1 1 1

1

0 200-24`

4 123,4

1 200-240

30,4

116,5

(weekend)

4

1 1 1

1

1 20'-24'27,1

113,7

5

1 0 0

1

1 200-240

62,0

6

1 1 1

0

1 20'-240

39,3

95,6

7

1 0 0

0

1 200-24`

83,5

148,6 1

Impact **of** the set-point temperatures

This series of simulations underlines the inipact of the set-point teMperatures.

For the reference sinlulation, the heatiti,,-coolin(y set-point temperature is 20T - 24T, 0 W

Chanue in set-point temperature	Chanue in annual lieatin(W requirements (reference set-point T-=20T)	Chan(le in annual air- W conditioning requirement (reference set-polilt T-=24-C)
- 1 "C	-23%	+ 1 0%
1 +111C	i+29%	-9%

Comparison between the 4-pipe system and the 2-pipe system

These sli-nulatlons analyze the advantages of a 4-pipe systern compared to a 2-pi system. WIth the 4-pipe systern, the building array have both heating and cooling duri the two

"-.> c

while the '-)-pipe systern cannot handle both s'i-nLl ltaneously. For a twoi-ni -season pert 1 1

pipe systeni, there 'Is a changeover date in the spring when the heating is turned otT a the C001111(7 systelli turned on The reverse occurs in the fall.

For the numerical computations, the two changeover dates were optinlized by , analyzill(l the power injected into the bulletin(,, for the reference simulation (4).

With a 2-pipe system (siviltdation 122), the heating requirements drop fi-orn 27,1 @V1WIi to 26,3) MWIi, those for air conditioning fi-om 1 1 3,7 MW]i to 1 1 3,4 MWIi. T decrease 'n both cases is sli-lit (--')% et -0,')%), because the changeover dates have b optirnized. To do so,

W W

the power requirements for <u>heating</u>, and air coiidltlotiln,(, were observed during the two nidseason perlods. It is found that the changeover date in tile spring corresponds to th tinie at which alr conditlonin- becomes inore prevalent the bu than heating. In realitv,

W

however-, these dates cannot be optlinized, fior the slniple reason that tile weekly, weat forecasts are riot sufflciently rellable

Interestingly, the implementation of intermittent operations on the weekend (simulation 3) lowers the heating requirements by 10% and the air-conditioning requir by 6%.

By comparing simulations 5, 6 and 7 with the reference case, they highlight the im the internal gains due to the fan coils and those due to the lighting and the occupants. first type of internal gains are excluded, the heating requirements increase by 45% and t conditioning requirements drop by 16%. The influence of the second type of interna (lighting+occupants) is even greater : +146% for heating and -45% for air conditioning. absence of internal gains, the air-conditioning requirement is relatively low, only 48,6 despite the effect of solar gain.

	Gains				Control		Requirements MWh	
No.	Solar	Occupants 8-19	Lighting 8-20	Fan-Coil 0-24	Intermittence	Setting Temp.	Heating	Cooling
2	1	1	1	1	0	20°-24°	33,4	123,4
3	1	1	1	1	1 (weekend)	20°-24°	30,4	116,5
4	**1**	**1**	**1**	**1**	**1**	**20°-24°**	**27,1**	**113,7**
5	1	0	0	1	1	20°-24°	66,8	62,0
6	1	1	1	0	1	20°-24°	39,3	95,6
7	1	0	0	0	1	20°-24°	83,5	48,6

⇨ Impact of the set-point temperatures

This series of simulations underlines the impact of the set-point temperatures.

For the reference simulation, the heating-cooling set-point temperature is 20°C - Two additional ranges are studied : 19°C - 25°C and 21°C - 23°C. The results are logical heating, the higher the temperature, the greater the heating requirements. And for coolin exact opposite is true.

	Gains				Control		Requirements MWh	
No.	Solar	Occupants 8-19	Lighting 8-20	Fan-Coil 0-24	Intermittence	Setting Temp.	Heating	Cooling
4	**1**	**1**	**1**	**1**	**1**	**20°-24°**	**27,1**	**113,7**
8	1	1	1	1	1	19°-25°	20,9	103,1
9	1	1	1	1	1	21°-23°	35,1	125,6

The table below gives the figures reflecting the changes in requirements as the set- temperature is lowered or raised by 1°C relative to the 20°C - 24°C range.

Change in set-point temperature	Change in annual heating requirements (reference set-point T°=20°C)	Change in annual air-conditioning requirements (reference set-point T°=24°C)
-1°C	-23%	+10%
+1°C	+29%	-9%

⇨ Comparison between the 4-pipe system and the 2-pipe system

These simulations analyze the advantages of a 4-pipe system compared to a system. With the 4-pipe system, the building may have both heating and cooling during t mid-season periods, while the 2-pipe system cannot handle both simultaneously. For pipe system, there is a changeover date in the spring when the heating is turned off a cooling system turned on. The reverse occurs in the fall.

For the numerical computations, the two changeover dates were optimized by an the power injected into the building for the reference simulation (4).

With a 2-pipe system (simulation 12), the heating requirements drop from 27,1 M 26,3 MWh; those for air conditioning from 113,7 MWh to 113,4 MWh. The decrease i cases is slight (-3% et -0,3%), because the changeover dates have been optimized. To the power requirements for heating and air conditioning were observed during the tw season periods. It is found that the changeover date in the spring corresponds to the t which air conditioning becomes more prevalent in the building than heating. In r however, these dates cannot be optimized, for the simple reason that the weekly w forecasts are not sufficiently reliable.

For the reference simulation, cooling and heating can be generated during two season periods, while simulation 11 involves a 4-pipe system assuming production of c and heating throughout the year. The requirements are almost the same as in the referenc : +0,7% for heating and +0,4% for air-conditioning.

	Gains				Control		Requirements MWh	
No.	Solar	Occupants 8-19	Lighting 8-20	Fan-Coil 0-24	Intermittence	Setting Temp.	Heating	Cooling
4	**1**	**1**	**1**	**1**	**1 (4 Pipes)**	**20°-24°**	**27,1**	**113,7**
11	1	1	1	1	1 (4 Pipes all the year)	20°-24°	27,3	114,2
12	1	1	1	1	1 (2 Pipes)	20°-24°	26,3	113,4

Variations from set-point temperatures may occur during mid-season periods, when heating and cooling cannot be produced. The bar graph below gives the number of hou occupancy over the year during which the temperature falls within each temperature range

For the reference simulation, cooling and heatim, can be -enerated durinu, t@@"O 111'd-
season periods, \,k,iille simulation 1 1 involves a 4~plipe s\@stciii assurning production cooliffil

W Z1

and licating throughout the year The requirements are alinost the sarne as **In** the reference case W

+0,7% for heatIn- and +0,4',1'0 for al'i--coiicl'Itloniti(i

	Gaills			Control			Requireme	
							MWII	
No.	Solar	Occupants	L'ILIItli]LI 8 -2 0	Fan-Coll 0-24	Intermittence	Settill(y Tenip.	Heatin-	Cooil
4	11	1	1	1	1 (4 Pipes)	20'-24027,1		113,7
11	1	1	1	1	1 (4 Pipes	20'-24'27,3)		114,2
			1	1	1 all the year)			
12	1	1	1 1	1 1	11 (2 Pipes)	20--24'26,3		1174

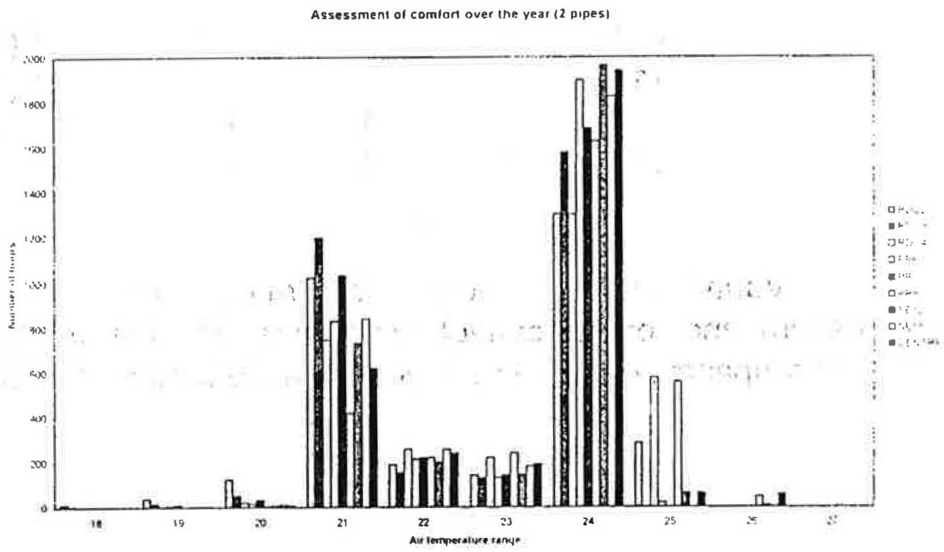
Variations fi-oni set-point temperatures IM1V Occur nild-season periods,, Mien both heatim, and cooliii,-, cannot be produced The bar graph below olves the number of hour of occupancy, over the year CILII-'iilL, which tile temperature falls \vithin each temperature ran

1

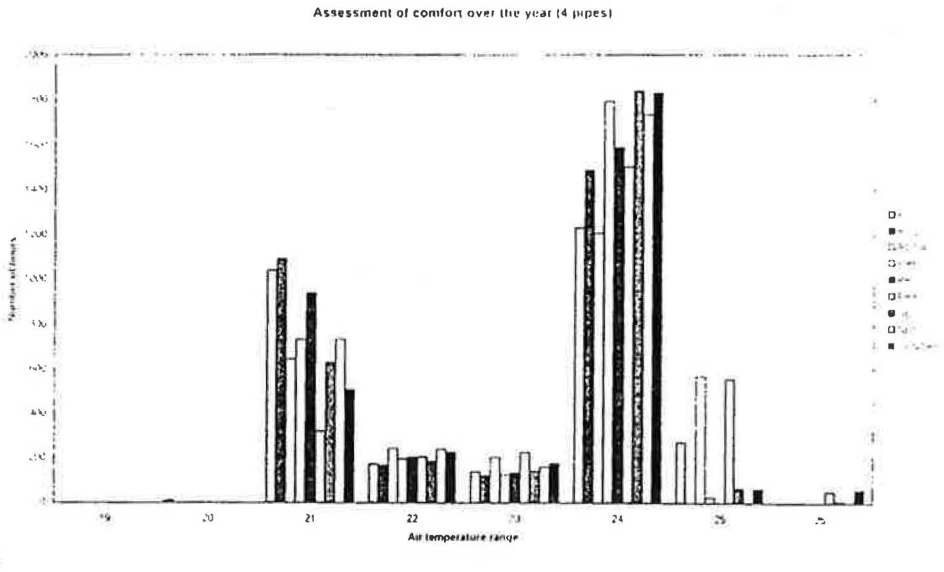
The resulting temperature discomfort in each zone can be analyzed by comparing th graph (2-pipe) and the 4-pipe (reference) bar graph. As can be seen, the 2-pipe s engenders almost no decrease in comfort due to less heating. It does, however, discomfort due to a lack of air conditioning, insofar as the temperature in certain zones 10, center) raises above 25°C with this system.

The 2-pipe system gives rise to relatively little discomfort. For all of the office zone temperature rises above 25°C for a total of 180 hours during the year (following the rul hour per zone); this corresponds to less than two days of discomfort per year in each office zones. That being said, it should be remembered that the two changeover dates been optimized in this case, but would not be in reality.

Bar graph (2-pipe fan coil)



Bar graph (4-pipe fan coil)



1 1 1

The resultin-g teiiil)ei,atL]l-Cd'scoinfoil **'n** each zone can be analyzed by comparing that bar ,,rapli (2-pipe) and the 4-pipe (reference) bar grapli. As can be seen, the 2-pipe system enuenders almost no decrease in comfort due to less heating. .It does, however, cause

discomfort **clue** to a lack *of* air coti(litlotilii(,, 'nsofar as the temperature **in** certain zones (6, 8 10, center) raises above 1~5'C with this systeril.

The 22-pipe systern (,-Fives rise to relatively little discomfort. For all of the office zones, the

teiiii)eratLil-C rises above 25'C for a total of 1 80 hours dU 1-1 11 {}the year (following the rule of 1

W 171

hour per zone), this corresponds to less than two clays of discomfort per year in each of the office zones. That bein- said, it should be remembered that the two chan-cover dates have

Z1

been optimized **in** this case, bUtwould not be **In** reality.

Bar graph (2-pilpe fan coil)

-f- Ih', v- (2 p,p-)

21 *2,*

Bar graph (4-pipe fan coil)

C

All-@..@t f m, @1 (4

AAA

21 2 1

M

c@ Influence of outer walls and roof insulation

1 1 1

These simulations show the influence of' the bii'lcl'n(=,"s outel. \veins and roof requirements.

For simulation 1 '), the thickness of the Insulation is increased so as to lower coefficient by 25% compared to the reference. This leads to a 45% drop in heating requirements and 10% rise in air conditioning requirements. When coefficient G1 is increased 25%, decreasing the thickness of the insulation, the thermal requirements rise by 50% and the

Z@

cooline requirem

carol) by 7%. In other words, while the heating requi irements are hilly W dependent on bulletin(, shell, those for air conditioning are riot This is because the

1

1S C1111 'ficant heat losses by conduction an(] coiivect'oti 'n the winter lia\e a strong et on heating. In the summer, the losses are sllght, so they have only a ininor afflect on conditional](,,

Gaills Control Requireillents

M@,@"ii Calculation of

No. Solar Occupants Lightin- Fan~Coll Intermil Setting Heatim, C001111 G1
8-19 8-20 0-24 -ttence Temp.

4 1 1 1 1 1 200-24.27,1 113,7
Reference

G 1

=0,48@@1/Ki-n'-

1 200-24015,0 124,5 G 1 -2

0,

Gl= -

)6@k'/Kiii-1

14 1 1 1 1 1 2W-24 0,7 105,4 Gl+25

1 2 G 1 =0

6OW/Kni_}

Influence of glazing areas

The followinu, simulations are used to study the sensitivity of requirements to the surf area in the bLill(liii,-, that Is fit with (-.base

For the reference case, the Olassed area is equal to -')00iii-, or -')5'0 of the total o surface area. Two other models of the bLiilcliii@-1 are created, one in which the glazin- are Cut roughly in half, and the other in which it is i-otiLlil@, doubled, In the first, the value of'coefrici

Z:1
G i is 0A0 W/Kn13 and in the second, 0, S7 W/Kni-1 (G 1 references 0,48

The simulation results show that the thernial requirements depend very little on the gla area (the buildim, 'Is fit with 6/10/4 cloLjl)ie-(,lazltiz(-,, the condLict'ori coefYic'eiit of witch

C@
is around)W/Kiii') The coolill(y requirements, on the contrary, carol) b\, 26/'O 'If the glas area Is cut In half while a SO',/o increase in the (flassed area results tit a 26% increas requiromcntsl

	Gaills			Control			Requirenlents IMWII		GlaziF
No.	Solar	Occupants 8-1 9	8-20	Fan-Coli 0-24	Internilt t ence	Settin, Y, Tenip. -	Heatim-,	cool' _@	Area 1110
-4	1	1	1	1	1	200-24	027,1	1 13,7	Ref 300n12
1 5	1	1	1	1	1	200-24`	12 1,7	8411	150
1 6	1			7	-I	20--24-	3 32,2	142,9	---F450 ni-

⇨ Influence of outer walls and roof insulation

These simulations show the influence of the building's outer walls and rc requirements.

For simulation 13, the thickness of the insulation is increased so as to lower coe G1 by 25% compared to the reference. This leads to a 45% drop in heating requiremer an 10% rise in air conditioning requirements. When coefficient G1 is increased 25 decreasing the thickness of the insulation, the thermal requirements rise by 50% ai cooling requirements drop by 7%. In other words, while the heating requirements are dependent on the building shell, those for air conditioning are not. This is becau significant heat losses by conduction and convection in the winter have a strong eff heating. In the summer, the losses are slight, so they have only a minor affect conditioning.

	Gains				Control		Requirements MWh		Calcu
No.	Solar	Occupants 8-19	Lighting 8-20	Fan-Coil 0-24	Intermi-ttence	Setting Temp.	Heating	Cooling	
4	**1**	**1**	**1**	**1**	**1**	**20°-24°**	**27,1**	**113,7**	Referer G1=0,4
13	1	1	1	1	1	20°-24°	15,0	124,5	G1-25 G1=0,3
14	1	1	1	1	1	20°-24°	40,7	105,4	G1+25 G1=0,6

⇨ Influence of glazing areas

The following simulations are used to study the sensitivity of requirements to the su area in the building that is fit with glass.

For the reference case, the glassed area is equal to 300m², or 35% of the total surface area. Two other models of the building are created, one in which the glazing area roughly in half, and the other in which it is roughly doubled. In the first, the value of coeffi G1 is 0.40 W/Km³ and in the second, 0.57 W/Km³ ($G1_{reference}$= 0.48 W/Km³).

The simulation results show that the thermal requirements depend very little o glazing area (the building is fit with 6/10/4 double-glazing, the conduction coefficient of v is around 3W/Km²). The cooling requirements, on the contrary, drop by 26% if the gla area is cut in half, while a 50% increase in the glassed area results in a 26% increa requirements!

	Gains				Control		Requirements MWh		Gla
No.	Solar	Occupants 8-19	Lighting 8-20	Fan-Coil 0-24	Intermit-tence	Setting Temp.	Heating	Cooling	A
4	**1**	**1**	**1**	**1**	**1**	**20°-24°**	**27,1**	**113,7**	Ref. 3
15	1	1	1	1	1	20°-24°	21,7	84,1	150 m2

CONCLUSION

Through this study, a comprehensive methodology foi- computing building requirements dynamically was developed. The modelling of the system was simplified, but all of the gains, both internal and external, were nevertheless taken into account.

The experimental validation of the building's dynamics showed a ,ood match betwe en the office temperatures calculated by simulation and those measured experimentally. As for the licatill(y re(ILlii-ciiieiits computed over a week, the experimental validation confirmed that tile 1-eqlii'i-ciiieiits for that period can be calculated accurately by simulation

A sensitivity study was conducted on hilding requirements over various parameters heat ,altis, intermittence, set-point temperature, type of emission system (4-pipe or '~-pipe **fan** coil), building insulations, glazing area. The study was useful not only in better understanding influences of those parameters, but also **in** quiantifying them.