International
Energy
Agency

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System Simulation Synthesis Report

Energy Conservation in Buildings and Community Systems Programme. Annex X.

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PREFACE

INTERNATIONAL ENERGY AGENCY

Effective cooperation amongst nations and development of new technologies to reduce dependence on fossil fuels are critically important elements of a sound energy future. Agreement by 21 countries to cooperate on energy policy is embodied in an International Energy Program, developed in the wake of the 1973/74 energy crisis and administered by the International Energy Agency, an autonomous body within the OECD.

ENERGY CONSERVATION IN BUILDINGS AND COMMUNITY SYSTEMS

As one element of the Energy Programme, the IEA sponsors research and development in a number of areas related to energy. In one of these areas, energy conservation in buildings, the IEA is sponsoring various exercises to predict more accurately the energy use of buildings, including comparison of existing computer programmes, building monitoring comparison of calculation methods, as well as air quality and inhabitant behavior studies.

16 countries have elected to participate in this area and have designated contracting parties to the Implementing Agreement covering collaborative research in this area. The designation by governments of a number of private organisations, as well as universities and government laboratories, as contracting parties has provided a broader range of expertise to tackle the projects in the different technology areas than would have been the case if participation was restricted to governments. The importance of associating industry with government sponsored energy R and D is recognised in the IEA, and every effort is made to encourage this trend.

THE EXECUTIVE COMMITTEE

Overall control of the program is maintained by an Executive Committee, which not only monitors existing projects but identifies new areas where collaborative effort may be beneficial. The Executive Committee ensures all projects fit into a predetermined strategy without unnecessary overlap or duplication but with effective liaison and communication.

FOREWORD

The final report of IEA Annex 10 is constituted by the present synthesis and 19 HVAC components specifications edited as separate booklets. Those may be obtained from the Operating Agent or directly from the authors of the specifications.

The annex has produced a tremendous amount of working documents. Their list is included here as Appendix 3. Among those are detailed synthesis reports concerning simulation exercises. Their conclusions are reproduced in Appendix 2 of the present document.

PARTICIPANTS

(Status at the end of the project)

1. Full participants

Belgium : University of Liège (ULg) (Operating Agent)
Finland : Technical Research Center of Finland (VTT)
Germany : University of Stuttgart (IKE)
Italy : Polytechnics of Torino (PT)
The Netherlands : Technisch Physische Dienst (TPD-TNO)
Sweden : Swedish Council for Buildind Research - Royal Institute of Technology (RIT)
United Kingdom : University of Technology - Loughborough (LUT)

2. Contributors

United Kingdom : University of Strathclyde (ABACUS)
Oscar Faber Partnership (OF)
Ove Arup and Partners (OA)
Amazon Energy (AE)
Switzerland : Swiss Federal Institute of Technology - Zürich (ETHZ)
Swiss Federal Laboratories for Materials Testing and Research (EMPA)
U.S.A. : University of Wisconsin, Madison (UW)

3. Observers

United Kingdom : Building Research Establishment (BRE)
Australia : C.S.I.R.O.
U.S.A. : ASHRAE 4.7 "Energy Calculation" committee
Germany : Fa. Siemens - Karlsruhe (SI)

The Belgian Contribution to the annex has been supported by the Belgian Science Policy Office and the Belgian Ministry of Economy.

LIST OF SYMBOLS

Symbol	Description of item	Units
A	area	m^2
a	thermal diffusivity	$m^2\ s^{-1}$
c	concentration	$kg\ m^{-3}$
c	massic heat	$J\ kg^{-1}\ K^{-1}$
c_p	massic heat at constant pressure	$J\ kg^{-1}\ K^{-1}$
c_v	massic heat at constant volume	$J\ kg^{-1}\ K^{-1}$
C	coefficient	(depends on the context)
C	(absolute) velocity	$m\ s^{-1}$
C	thermal capacitance	$J\ K^{-1}$
$\dot{C}$	fluid capacity rate	$W\ K^{-1}$
COP	coefficient of performance	-
d	prefix meaning differential	-
D	diameter	m
D_e	equivalent or hydraulic diameter	m
D_v	mass diffusivity	$m_2\ s_{-1}$
e	thickness	m
E	non thermal energy	J
E	electrical potential	V
f	frequency	Hz
f	friction factor	-
F	force	N
F_{ij}	angle factor (radiation)	-
g	gravitational acceleration	$m\ s^{-2}$
h	heat transfer coefficient	$W\ m^{-2}\ K^{-1}$
h_c	convective heat transfer coefficient	$W\ m^{-2}\ K^{-1}$
h_r	radiative heat transfer coefficient	$W\ m^{-2}\ K^{-1}$
h_D	mass transfer coefficient	$kg\ s^{-1}\ m^{-2}$
h	(massic) enthalpy	$J\ kg^{-1}$
h_a	enthalpy of dry air	$J\ kg^{-1}$
h_s	enthalpy of moist air at saturation	$J\ kg^{-1}$
H	absolute enthalpy	J
$H_{fuel,net}$	net caloric value of fuel	$J\ kg^{-1}$
I	electric current	A
I	intensity of solar radiation	$W\ m^{-2}$
I_b	beam intensity of solar radiation	$W\ m^{-2}$
I_d	diffuse intensity of solar radiation	$W\ m^{-2}$
I_{gl}	global intensity of solar radiation	$W\ m^{-2}$
k	thermal conductivity	$W\ m^{-1}\ K^{-1}$
K	global permeance (AU + C)	$W\ K^{-1}$
L	length	m
M	mass	kg
$\dot{M}$	mass flow rate	$k\ s^{-1}$
M	molecular weight	$kg\ mol^{-1}$
n	exponent	-
N or n	number in general	-

N	rotating speed	s^{-1}
NTU	number of transfer units (AU/C)	-
p	pressure	Pa
p_a	partial pressure of dry air	Pa
p_w	partial pressure of water vapor in moist air	Pa
p_s	partial pressure of water in saturated moist air	Pa
Q	heat transfer	J
$\dot{Q}$	time rate of heat transfer (thermal power)	W
r	radius	m
r	gas constant	$J\ kg^{-1}\ K^{-1}$
R	thermal resistance	$m^2\ KW^{-1}$
s	massic entropy	$J\ kg^{-1}\ K^{-1}$
S	absolute entropy	$J\ K^{-1}$
t	temperature	°C
T	absolute temperature	K
u	massic internal energy	$J\ kg^{-1}$
U	absolute internal energy	J
U	overall heat transfer coefficient	$W\ m^{-2}\ K^{-1}$
v	massic volume	$m^3\ kg^{-1}$
V	absolute volume	m^3
$\dot{V}$	volumetric flow rate	$m^3\ s^{-1}$
w	humidity ratio of moist air	$kg(water).kg^{-1}(dry\ air)$
w_s	humidity ratio of moist air at saturation	$kg(water).kg^{-1}(dry\ air)$
W	work	J
$\dot{W}$	non thermal power	W
X	vapor quality	-
x, y, z	coordinates	m
α	absortivity, absorptance (radiation)	-
α	linear coefficient of thermal expansion	K^{-1}
β	volume coefficient of thermal expansion	K^{-1}
γ	control function	-
Δ	difference between values	-
ε	error	-
ε	emissivity, emittance (radiation)	-
ε	effectiveness	-
η	efficiency	-
λ	wavelength	m
λ	excess of air	-
ν	kinematic viscosity (diffusivity)	$m^2\ s^{-1}$
φ	relative humidity (p/p_s)	-
$\rho = 1/v$	volumetric mass	$kg\ m^{-3}$
ρ	reflectivity, reflectance (radiation)	-
σ	Stefan-Boltzmann constant	$W\ m^{-2}\ K^{-4}$
τ	time	s

τ	transmissivity, transmittance (radiation)	-
ω	rotating speed	rad s^{-1}

SUBSCRIPTS

a	air
a	available
cd	conduction
cv	convection
co	combustion
ch	chimney
cons	consumed
db	dry bulb
dp	dew point
em	emission
en	environmental
ex	exhaust or exit (leaving)
f	saturated liquid state
fg	state g minus state f
F	frontal
g	saturated vapor state
gl	global
gr	ground
h	isenthalpic process
in	internal, inside
j	element number
L	loss
m or $\overline{x}$	mean value
m	molar basis
max	maximum
min	minimum
N	in nominal conditions
out	outside
o	referring to initial or standard states or conditions
p	constant pressure process
r	refrigerant
r	radiant or radiation
r	required
re	return
s	at saturation
s	isentropic process
s	surface
set	set point
su	supply (entering)
st	stored
t	total
T	isothermal process
u	useful (power, energy)
v	constant volume process
w	wall
w	water
wb	wet-bulb

DIMENSIONLESS NUMBERS

Ar	Archimède	Gr / Re^2
Fo	Fourier	$\alpha . \tau / L^2$
Gr	Grashof	$L^3 . \beta . g . (\Delta T) / \nu^2$
j_D	Colburn (mass transfer)	$Sh / Re . Sc^{1/3}$
j_H	Colbrun (heat transfer)	$Nu / Re . Sc^{1/3}$
Le	Lewis	a / D_v
Nu	Nusselt	$h . L / k$
Pe	Peclet	$Re . Pr$
Pr	Prandtl	ν / a
Ra	Raleigh	$Gr . Pr$
Re	Reynolds	$C . L / \nu$
Sc	Schmidt	ν / Dv
Sh	Sherwood	$h_D . L / D_v$
St	Stanton	$h / G . c_p$

1. INTRODUCTION

Nowadays, system simulation becomes part of the regular activities of the HVAC engineer. In the near future, the diffusion of expert systems should enable automatic control of large installations, including forecasting and decision making leading towards optimal comfort and energy consumption. Maintenance should also become a computerized task for such systems.

In any circumstance, the performance of such software will rely essentially on the quality of the mathematical models so that they will represent the thermal -and sometimes mechanical- behavior of the systems components.

The correct choice of models constitutes a difficult task. Indeed, for complex system simulations, these models should result from a delicate compromise between :

- accuracy of prediction;
- simplicity of use and easy availability of data;
- coherence between models coupled by the simulation.

Work performed by Annex 10 was twofold. First, models were gathered to implement a data bank. Second, simulation exercises were defined and performed to demonstrate the feasibility of thermal simulations on realistic configurations.

The collection of models became with time a very first priority because of the scarcity of information available in the literature. Simulation exercises proved also of great interest for many reasons, among which :

- maybe for the first time, different research teams compared systematically their simulation procedures and results;
- those comparisons, involving models of various levels of sophistication and sometimes drastically different approaches, provided valuable information on the optimal level of complexity each model should present;
- the use of the models documented in the data bank constituted a systematic verification of their correctness and understandability;
- the exercises demonstrated the possibility to simulate complete systems, including interactions as between building and HVAC equipment.

The data bank and simulation exercises constitute now the basis for another I.E.A. cooperative effort (Annex 17) which is devoted to the evaluation of Energy Management Systems.

2. OVERVIEW OF ANNEX 10 ACTIVITIES

2.1. Practical organization

Annex 10 was a task-sharing project. It started officially in January 1983 and ended in December 1987.

Each Annex 10 participant contributed continuously to the implementation of the data bank. The specifications to be produced were selected and shared by mutual agreement, according to their possible use in the simulation exercises.

Most ot the participants were involved at least in some of these exercises.

Initially HVAC component specifications and simulation exercises were selected in the field of residential heating, starting from the generators and progressively extending the analysis to the distribution networks, emitters and control devices.

Further work was developed in the field of air conditioning.

The Annex 10 participants met twice a year during working meetings where the results of the simulation exercises and the contributions of component specifications to the data bank were reported and compared.

A total of about 500 working documents were circulated among the participants in the course of the Annex. A list as well as individual copies of the documents may be obtained from the Operating Agent.

A set of 27 reports (HVAC specifications and synthesis reports on simulation exercises) were selected and reviewed as official reports of this project. These reports are listed and very briefly summarized hereafter.

2.2. Participations

Different levels of participation were offered in the course of this project. The following institutions are responsible for at least one of the final specifications and/or one of the simulation exercises :

Belgium :	University of Liège	(ULg)
Finland :	Technical Research Center	(VTT)
Germany :	University of Stuttgart	(IKE)
Italy :	Politecnico di Torino	(PT)
Sweden :	Royal Institute of Technology	(RIT)
Switzerland :	Federal Laboratories for Materials Testing and Research	(EMPA)
	Federal Institute of Technology	(ETHZ)
The Netherlands :	Technisch Physische Dienst	(TPD-TNO)
United Kingdom :	Loughborough University of Technology	(LUT)
	Ove Arup and Partners	(OA)

Contributions were also offered by :

United Kingdom:	Amazon Energy Ltd University of Strathclyde Oscar Faber Partnership
United States of America :	University of Wisconsin

2.3. History

The main activities are described in 10 semi-annual progress reports submitted to the executive committee and (with more details) in the minutes of a dozen working meetings organized in the course of the annex. Only a very brief summary of the activities will be given here :

1980-81 : Preparation of the Annex.
The project was officially approved by the executive committee in June 1981.

1982 : Initial phase of the project
(Most of official commitments were only confirmed in the course of 1982 or even later).

4 meetings :
Liège (February)
Amsterdam (June)
Zürich (October)
Liège (December) in connection with the first International Conference on System Simulation in Buildings.

Preliminary work on HVAC specifications and on simulation exercises.

1983 : official start with
Belgium (Operating Agent)
Germany
Italy
Sweden
Switzerland
United Kingdom, as official participants

2 working meetings :
Lausanne (April)
Stuttgart (October)

Development of first HVAC specifications (heating components) and organization of heating simulation exercises ("La Chaumière").

1984 : Finland becomes official participant.

2 working meetings :
London (April)
Stockholm (October)

Development of HVAC specifications (priority still given to heating components), continuation of exercises on "classical" heating, preparation of air conditioning exercises.

1985 : ASHRAE-IEA symposium (Chicago, January 1985)

2 working meetings :
Torino (April)
Helsinki (October)

Development of HVAC specifications (heating and air conditioning).

1986 : the Netherlands become official participant.

2 working meetings :
Delft (April)
Roma (October)

Second International Conference on System Simulation in Buildings, Liège (December 1986).

Development of HVAC specifications.
Heat pump simulation and hydraulic calculation exercises.
Continuation of air conditioning simulation exercises.

1987 : 2 working meetings

Stuttgart (April)
Loughborough (October)

Final review and correction of existing HVAC specifications.
Hydraulic and air conditioning simulation exercises are brought to completion.

1988 : closing meeting

Liège (February)
Preparation of final reports.

3. CONTENTS OF THE DATA BANK

3.1. Main characteristics of the models

Upon completion, the IEA Annex 10 databank provides mathematical models for most of the equipment found in usual hydronic heating systems (figure 1) or air-conditioning installations (figure 2).

Priority was given to the physical and mathematical descriptions. Actually, computer codes are only provided when available and some are only applicable in a specific computational environment (as TRNSYS types for example).

Models essentially describe the thermal behavior of equipments. In other words, most of them apply both mass and energy conservation but do not consider momentum conservation equations. In that frame, for instance, valves will operate with prescribed authority, which is not deduced from calculations. However, devices presenting typical flow resistance are sometimes documented for the pressure drop they induce in networks, enabling aeraulic or hydraulic calculations.

Emphasis has been put on static models. Experience from simulation exercises and experiments often proved that such models are sufficient for accurate energy consumption predictions and the evaluation of comfort requirements. As an example, a cycling fuel-oil boiler may be represented by a linear relationship between consumed and actually produced powers, even if ON-OFF cycles of the burner do create high frequency dynamic fluxes. The presence of an aquastat maintaining the water exhaust temperature within strict boundaries and the further existence of a three-way valve downstream from the boiler, smooth out unsteady variations of the water temperature as this information is transmitted to the distribution network.

A main exception is constituted by the building model, which presents evidently much larger time constants than do the other pieces of equipment . Heating panels also require a dynamic treatment. As they are often part of the building construction (i.e. floor heating panels), their simulation should be coupled with that of the building. It is easily done in this annex as both use a resistance - capacitance approach.

Even if steady state behaviors are usually described, most of the components are also dynamically modelled. In particular, attention is brought to the split of radiating panels into subcapacities as well as to the dynamics of thermostatic valves.

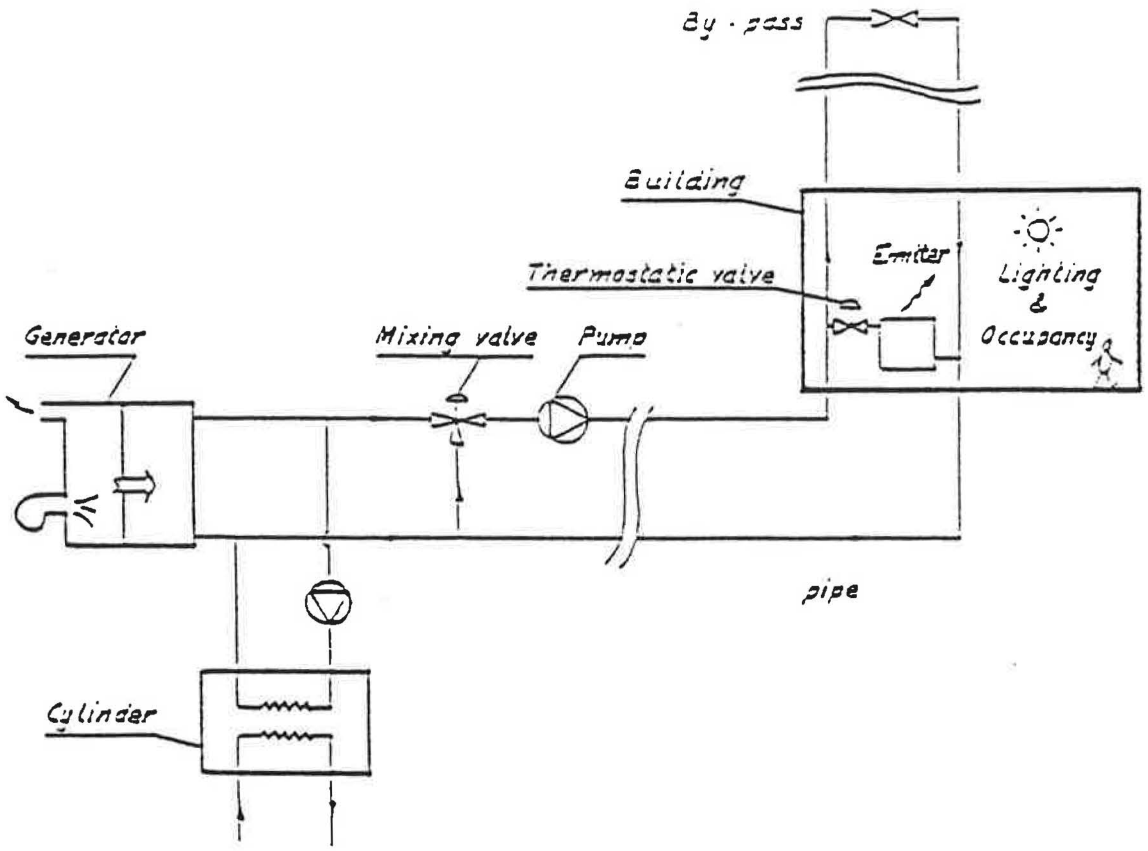


Figure 1 : Heating system

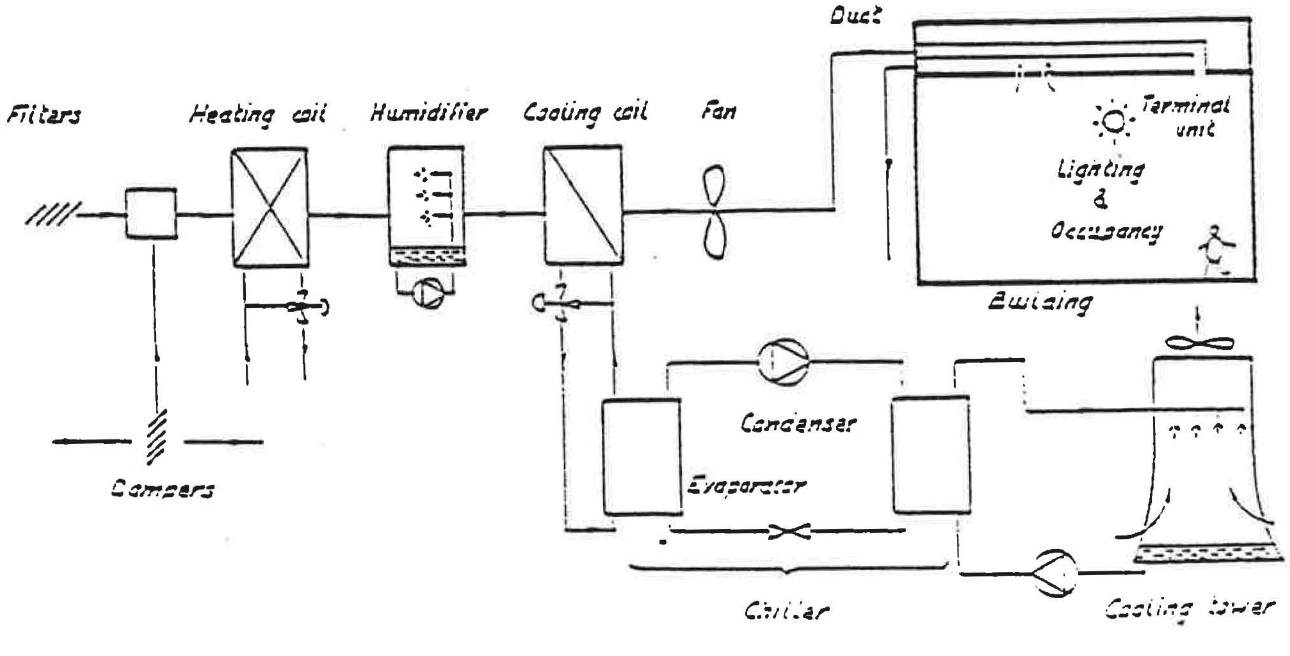


Figure 2 : Air conditioning system

As already mentioned, all models result from a careful compromise between accuracy and simplicity. So-called "reference" models, those trying to represent all physical phenomena, have not been considered. Most pieces of equipment involving heat exchanges are simulated on the basis of mass and energy conservation laws. Within those models, correlation laws allow the use of a limited amount of parameters and variables, essentially those necessary for the transfer of information from one component to another of a system. Pumps and fans , however, and sophisticated components (the heat pump for instance) are represented by curve fitting polynomials. Consequently, all models possess very strict domains of validity, depending on the range of fits and the limits of definition of their various parameters.

Complexity of the models is often limited by the availability of data. The more a model tends to represent physical reality, the more information is needed to determine its parameters. There exists a limit where information is not available anymore and where the use of the model becomes questionable. Data from the literature is sometimes scattered and often contradictory. IEA Annex 10 documents try to produce coherent values for the definition of parameters and suggest default values with possible ranges of errors.

However, for some equipment, the minimum level of complexity requested from the mathematical model for sufficiently accurate predictions becomes incompatible with catalogue data. In those conditions, results of standard laboratory tests are to be used and hints are given when only partial information exists.

3.2. Structure of the databank

Each component of the databank is described by a separate specification, following a somewhat standardized format.

First, the device is described and its use briefly commented on. A principle graph, highlighting input and output variables as well as parameter definitions is always present. Both are clearly defined. The basic assumptions upon which the model will rely are stated. Eventually, general variables and internal parameters used by the model are defined.

A second part of the specification covers function laws used by the model. This part constitutes the real kernel of the specification. It aims at an easy use by readers and as such is more a description of step by step procedures to apply the various equations of the model than a textbook demonstration of their validity. Errors introduced by assumptions on one side, by the usual accuracy of data on the other, are here clearly specified. Also, ranges of application are mentioned.

The specification is completed by information on direct energy consumption, that is resulting from the component itself, and indirect consumption by secondary appliances such as pumps needed to produce flow through the component. A list of references is also provided, notably including many documents produced during the construction of the databank. Finally, some specifications provide technical and economic data related to the maintenance and purchase of the component.

As such, the specification constitutes already a valuable set of information. However, to enter the IEA Annex 10 databank, it must be guaranteed by at least two participants other than the author. Their reviewing includes the application of the step by step procedure on numerical examples. Therefore each specification provides one or more short documented applications which notably help in the understanding of the model.

Care has been given to a certain coherence between models and to the correct transfer of information between different models. This has been ensured by the use of the documented models in sets of simulation exercises.

3.3. Review of specifications

A general classification of the various components covered by the databank is :

- generators producing necessary heating and/or cooling power;
- heat (and mass) exchangers;
- fluid "flow devices" (fans and pumps);
- fluid "distributors" (pipes and ducts);
- controllers;
- building subsystem.

All specifications are edited as separate booklets. Summaries are given in appendix 1 of this report. Some very short comments are also given hereafter.

3.3.1. Generators

In this category, a fuel-oil boiler, an air to water heat pump and a liquid chilling system are documented.

3.3.1.1. *The boiler model* is restricted to hot water units fired by fuel-oil burners.It presents a static representation of the boiler's thermal behavior, applying the empirical law of Dittrich stating a linear correlation between the burner power and the useful power actually delivered to the water. The burner operation may consist of ON/OFF cycles or may perform at various power levels. The model separates the combustion process from the heat exchange and considers successively a heat exchanger between water and flue gases, then a second one between water and the environment.

This model was developed on the basis of the results of simulation exercises, where many different approaches were tested.

3.3.1.2. *The heat pump model* is based on simple polynomial fits. The "reference" data may be taken from catalogues of manufacturers; they may also be generated from a much more detailed model. Detailed models of various cooling components were documented in the course of the Annex 10 project. But this information was not included in the final specifications.

Independent variables are the air and water temperatures. Biquadratic laws involving them are applied in order to define the heat flow at the condenser and the mechanical power consumed by the compressor. Frost formation is considered by using a special "mass transfer parameter".

3.3.1.3. ***In the water chiller model***, both condenser and evaporator are regarded as counterflow heat exchangers. The compressor is modelled by considering a Carnot efficiency, i.e. the ratio between the full load COP and the theoretical Carnot COP.

Part load operation is represented by the definition of a correction factor relating the full load COP to its part load equivalent.

3.3.2. Heat and mass exchangers

This is the most important set of components to be modelled in HVAC application.

They are classified hereafter by considering successively the components involving transfers of

- only heat
- heat and/or mass
- only mass (filters).

The modelling of the components is based on :

1) energy and/or mass conservation;
2) Newton's law in heat and/or mass transfer (this transfer flow rate is assumed proportional to a certain difference of "potential") : $\dot{Q} = AU\Delta t$;
3) some semi-empirical laws for heat and mass transfer coefficients.

3.3.2.1. ***The heating radiator*** is a heat exchanger whose characteristics are the following :

1) one "fluid" (the internal environment) has an infinite capacity flow rate;
2) the global heat transfer coefficient is affected by the temperature difference between the two fluids ("free convection" effect).

Static as well as dynamic models are proposed. In the current practice, the static model is sufficiently accurate for most energy simulations. It relies on many experimental results and was also checked through the simulation exercises.

3.3.2.2. ***Floor heating panels*** are also heat exchangers. Their thermal mass may generally not be neglected in the simulations. The model selected is based on very simple first order representation. Various methods to determine the parameters are proposed.

3.3.2.3. *Air conditioning coils* behave as pure heat exchangers or as heat and mass exchangers, according to the "regime" considered.

Very classical heat exchanger modelling is used in "dry" regime, with reference to an "effectiveness". This term is defined as a semi-empirical function of the flow rates of the two fluids.

For cooling coils, when condensation occurs, the model assumes that a certain amount of air by-passes the coil, while the remainder transits through it and exits saturated. The total heat transfer is computed, assuming the air side heat transfer coefficient is enhanced by the sensible heat ratio, so that only dry bulb temperatures are involved.

The specification devotes much room to the determination of all thermal resistances. The model may be used from catalogue data or with theoretical heat transfer characteristics.

This specification is strongly supported by an important international bibliography, as well as by many simulation exercises.

3.3.2.4. *Ventilation heat recovery devices* may involve coils or other sorts of heat exchangers. A special specification is devoted to the modelling of these devices ; practical indications are given on the way to define their thermal effectiveness. Condensation and frosting risks are taken into account. Some of this information is validated by laboratory experiments. Limited simulation exercises were also performed.

3.3.2.5. A *Cooling tower* is also classified as a type of heat and mass exchanger; its characteristic is the direct contact between the two fluids.

Two models are proposed :

- the first one applies the merkel theory and requires a numerical integration of temperatures and enthalpies all along the paths of both fluids;
- the second model is very simplified : it defines the tower effectiveness in the same way as for a "classical" heat exchanger with one infinite capacity flow rate (water side).

International bibliography and experimental results enable good validations of these models. Some simulation exercises also evaluated the applicability of the simplified model.

3.3.2.6. *The adiabatic humidifier* appears as a particular case of a cooling tower. It is, by definition, a pure mass exchanger. Its effectiveness may again be defined by comparison with a "classical" heat exchanger with an infinite capacity flow rate on the water side. Therefore, the influence of the air flow rate is modeled. Pressure drop estimates are also given in the specification.

3.3.2.7. The last type of mass heat exchanger considered here is the *air filter*. Its filtering effectiveness does not interfere directly with the behavior of other HVAC components. More important is the definition of its air flow resistance. The specification indicates how to predict the time increase of this resistance.

3.3.3. Fluid "flow devices"

3.3.3.1. Real characteristics of *pumps* are too often forgotten in system modelling. The specification presents the characteristics in detail. Not only the relationship between pressure drop and the corresponding flow rate has to be modelled : pump consumption may not always be neglected in the whole system energy balance.

3.3.3.2. *Fans* are treated in a similar way. Their consumption is never negligible. Also the heating-up of the air through the fan has to be correctly estimated.

Polynomial approaches are proposed in order to represent the pump and fan characteristics. Examples of pump and fan characteristics were used in some of the simulation exercises.

3.3.4. Fluid "distributors"

These components may be considered as "parasitic" heat and momentum exchangers. They have to be described according to both effects.

3.3.4.1. In first approach, the *pipes* thermal behaviour may be represented by static models. But indications about dynamic modelling are also given in the specification. Pressure drop calculations are also documented.

This information was developed in parallel with the hydraulic simulation exercises.

3.3.4.2. *Ducts* are modelled in the same way as pipes. But they could deserve more attention due to the importance of "parasitic" heat transfer and "auxiliary" energy consumption they may cause in the installation. Also, leakages must sometimes be taken into account.

The specification contains the practical information required for realistic thermal and aeraulic modelling. This information is supported by a large international bibliography; it was also checked through some limited simulation exercises.

3.3.5. Controllers

3.3.5.1. A model of *thermostatic valve* was proposed and extensively used in several simulation exercises. This model intends to represent the thermal <u>and</u> the hydraulic behavior of the valve.

The thermal model proposed is dynamic and considers specifically the heat exchange between the valve sensor and the environment on one side, the water circuit and the radiator surface on the other. The actuator may be affected by some hysteresis.

3.3.5.2. Three other water *flow control devices* are modelled in a separate specification : the 3-way mixing valve, the by-pass valve and the differential pressure control valve.

Different controller characteristics (P, PI and PID) are considered in the specification. Time delays and time constants of actuators may also be taken into account.

This specification was checked through several hydraulic simulation exercises.

3.3.5.3. *Air dampers* are also modelled. The specification gives typical relationships between pressure drop factor and angular position of the blades.

This specification has been checked through some very simple simulation exercises.

3.3.6. The building subsystem

This subsystem includes the building itself, the lighting devices and the occupants.

3.3.6.1. When most emphasis is to be given to equipment in system simulation, large reference models for *buildings* become somewhat cumbersome,even if they allow strong coupling between system and occupancy zones. Therefore,it was decided to propose a multi-zone, dynamic second order lumped parameters model for the representation of buildings behaviors.

The model operates with linearized and globalized surface exchanges, thus it predicts resultant temperatures. Internal loads are brought at the zone nodes, while solar loads are treated by means of equivalent sol-air temperatures.

The model was used in most of the simulation exercises. It was also validated through several comparisons with more detailed models.

3.3.6.2. *Lighting devices and occupancy loads* are also described in a specification. Reference data are given on these terms; they concern mainly :

- the loads due to <u>artificial</u> lighting and occupancy metabolism;
- the possible contribution of <u>natural</u> lighting and the real use of solar protections;
- the domestic hot water consumptions;
- the calculation of PMV and PPD according to Fanger model.

4. OVERVIEW OF THE SIMULATION EXERCISES

Simulation exercises constituted an important part of Annex 10 activities. Their objective was to demonstrate the feasability of complete system simulations on realistic situations. They provided regular validations of component models documented in the data bank. Notably, they proved that significant results concerning energy consumption and peak power search could be obtained with the use of simple static models of components.

Each exercise was the responsability of a specific participant, who was in charge of documenting it, leading comparisons between participants and drawing conclusions. Every participant took part in at least some of those exercises.

The main conclusions drawn from the various exercises are presented in Appendix 2 of this report. Hereunder, a sketchy description of the simulations is given :

4.1. During the initial phase of the annex, Belgium led preliminary simulations on the heating system of a single low cost family house, located in Seneffe (Belgium).

4.2. At the official start of the annex, another example of application was selected : the heating system of a multistorey apartment building, called "La Chaumière", and located in Lausanne (Switzerland). The system had been extensively monitored and sufficiently documented for simulations to be carried out on realistic grounds. They were led by EMPA (Switzerland). They started with modelizations of the boiler to progressively extend to the exercises on the coupling between the system and the building itself, considering various control strategies.

All those simulation exercises were performed while HVAC components specifications began to appear in the data bank. Conclusions of the simulations greatly contributed to the improvement of the models and notably decided of the level of complexity the various models had to represent for satisfactory accuracy. However, they were obtained too early to enable systematic validations of the information selected in the data bank, and many specifications experienced strong improvements thereafter.

Further simulation exercises on "La Chaumière" included the retrofit of its heating plant by addition of an air-water heat pump (figure 5). These exercises were conducted by ETHZ (Switzerland). They verified the heat pump model selected for the data bank.

Finally, some participants got involved in a very refined simulation of the hydronic system, including hydraulic balances and the consideration of the interactions between thermostatic valves and the building indoor temperatures (figure 6). This set of exercises, led by VTT (Finland), illustrated how detailed simulations may become and showed the efficiency of by-pass valves in complex networks. They also constituted validity checks for many devices documented in the data bank.

4.3. At about halfway through the annex, still another example was selected in order to study air-conditioning applications. It was constituted by a realistic adaptation of the Collins Publishers Administrative Office in Glasgow (UK) and its VAV air-conditioning system (figures 7 and 8). Here again, simulation exercises were gradually defined : first, a study of the air loop alone, including fan, coils, humidifier, filters and dampers. Then, the coupling of the system to the building was considered and various control strategies analysed. Finally, water circuits were introduced, notably with the simulation of a water chiller associated to a cooling tower.

Simulation exercises were defined and led by LUT (UK). Early results are very much dependent upon the level of knowledge obtained by participants on the building and its equipments. While work progressed, specifications about the system to model were modified. Therefore, results should not all be used as references in the future. Only the results of the very last and most ambitious global exercise are reported in the synthesis report.

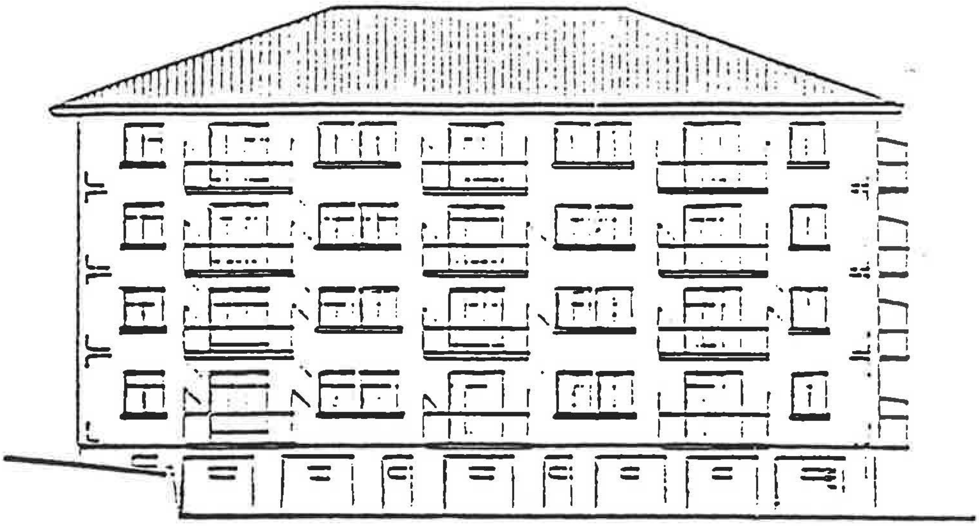
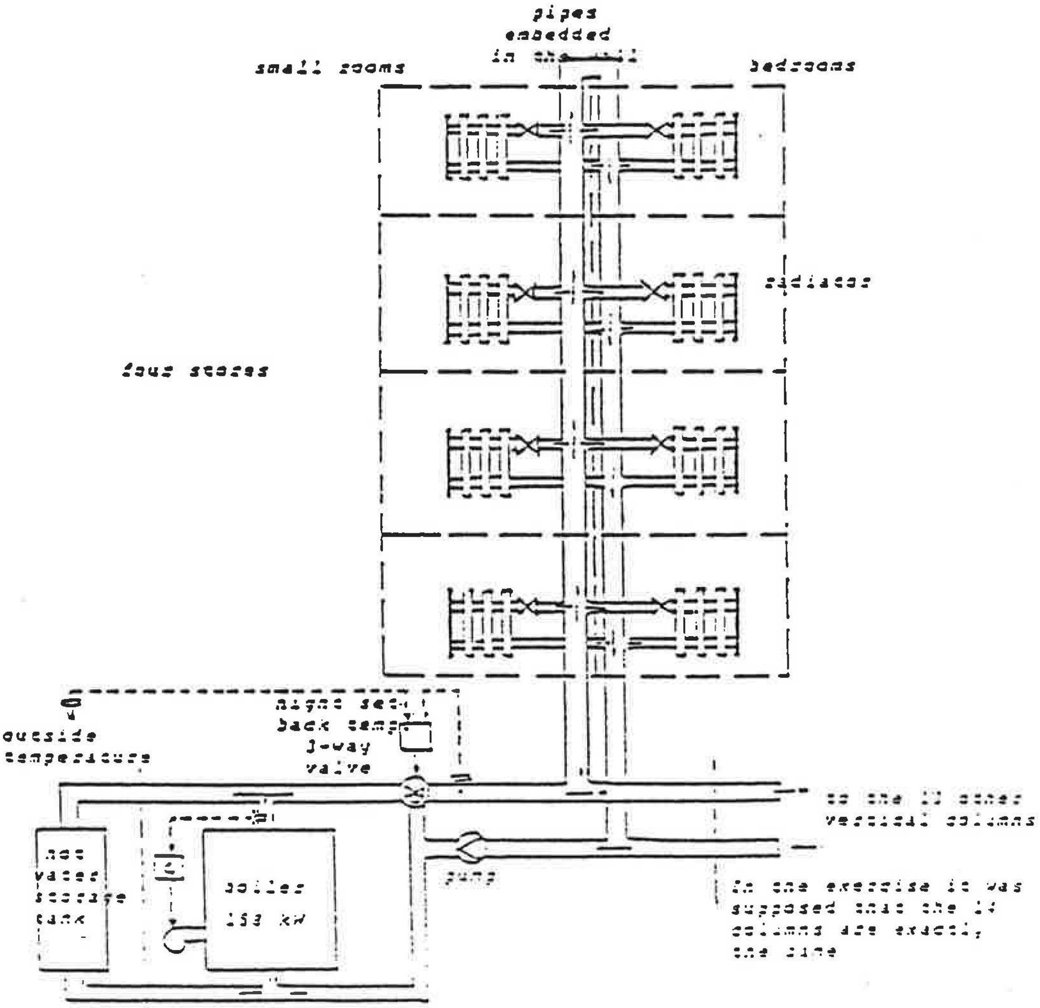


Figure 3 : Residential building "La Chaumière"



In the exercise it was supposed that the 14 columns are exactly the same

Figure 4 : "La Chaumière" : heating system

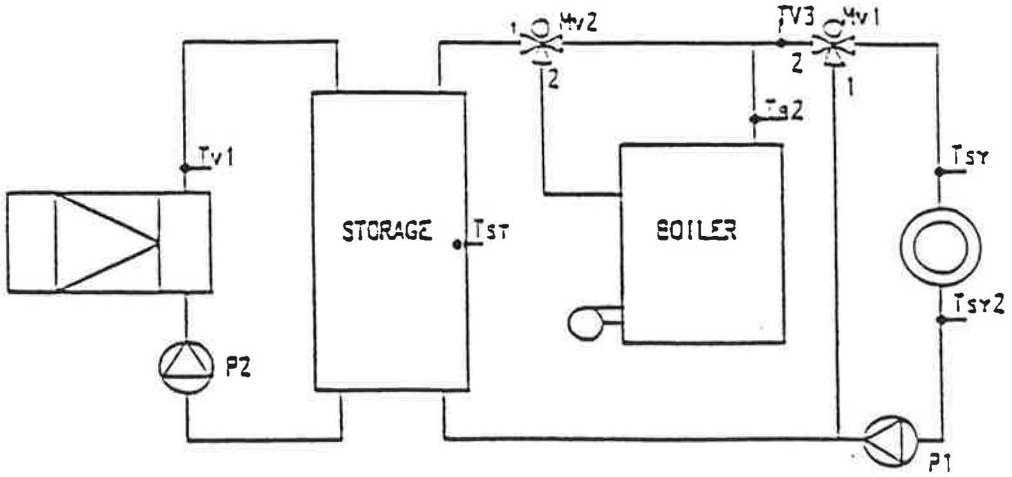


Figure 5 : Heating plant - configuration B

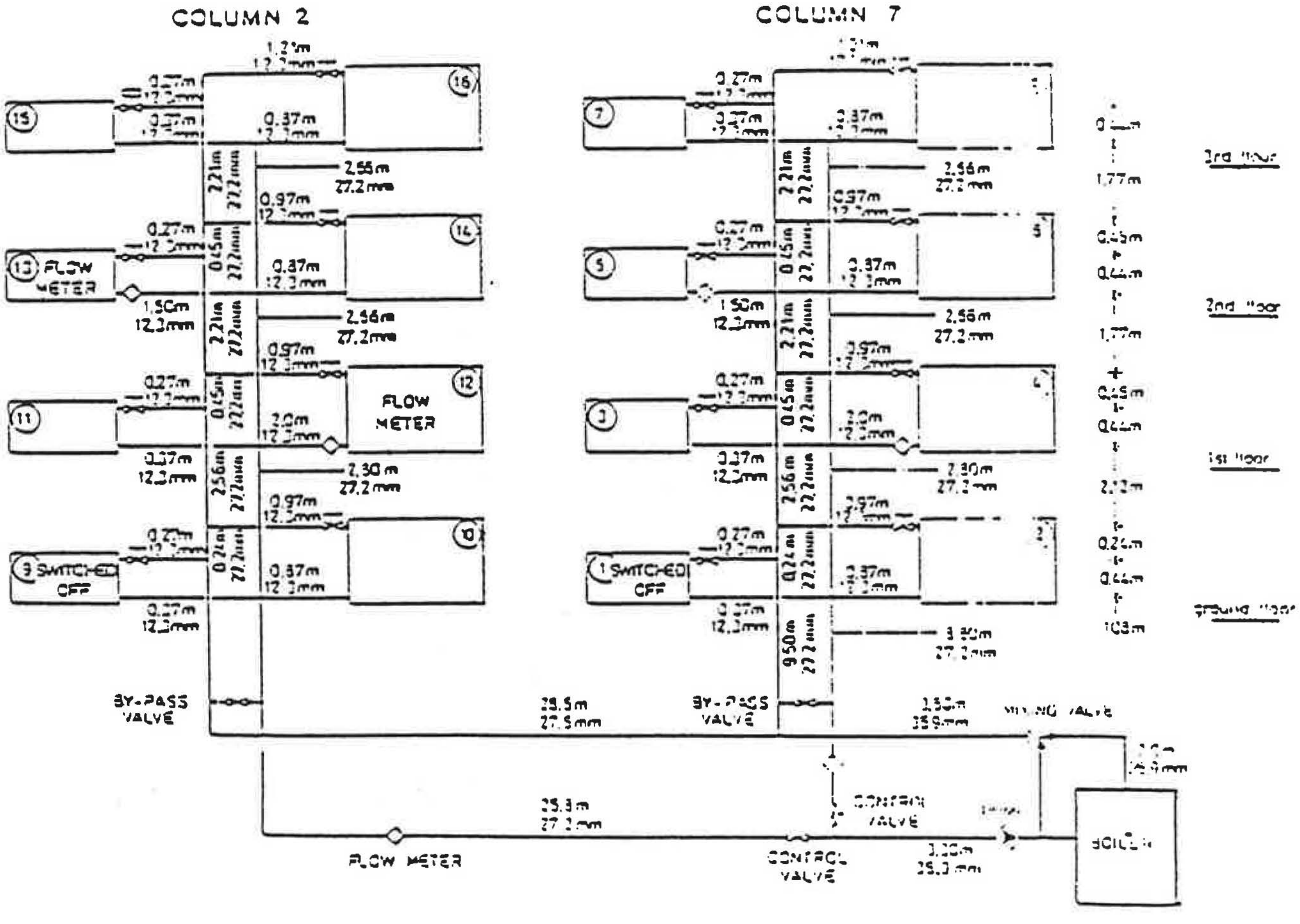


Figure 6 : Heating network configuration for dynamic simulations

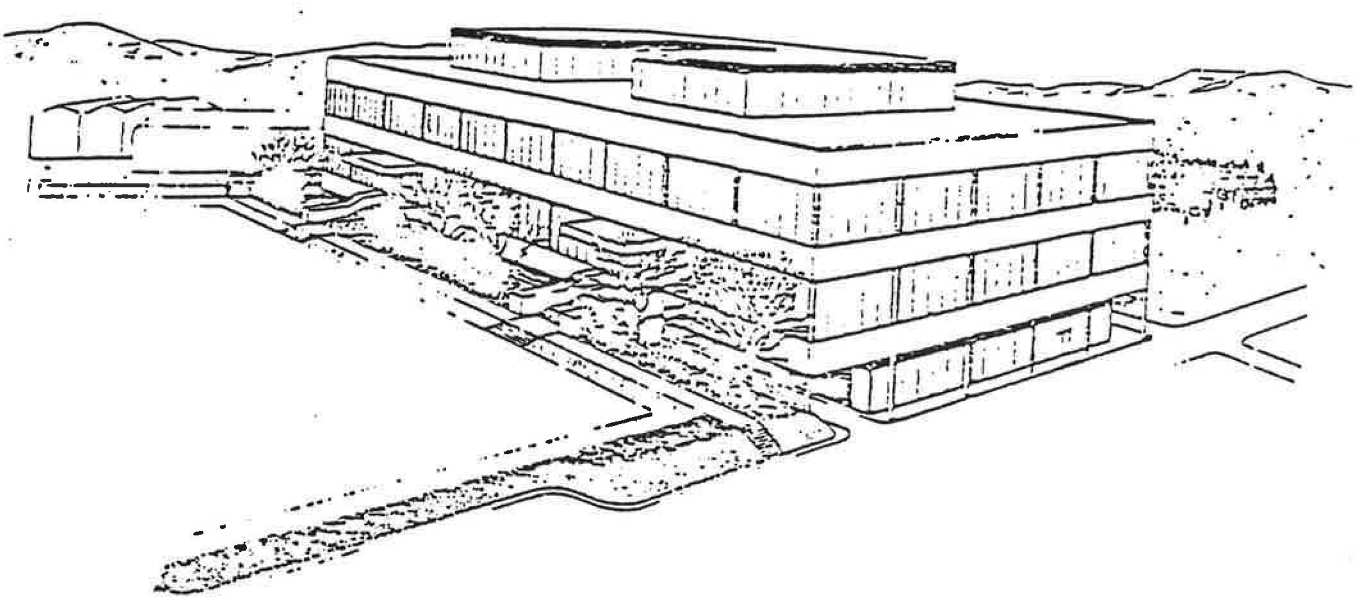


Figure 7 : Collins office building

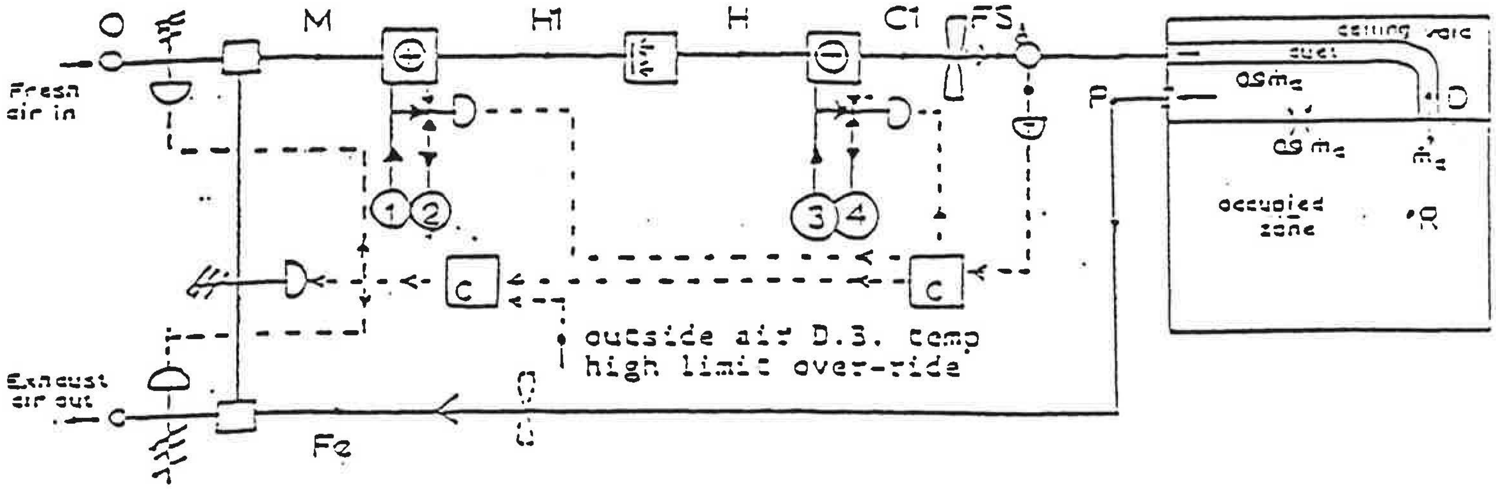


Figure 8 : HVAC system of the Collins building

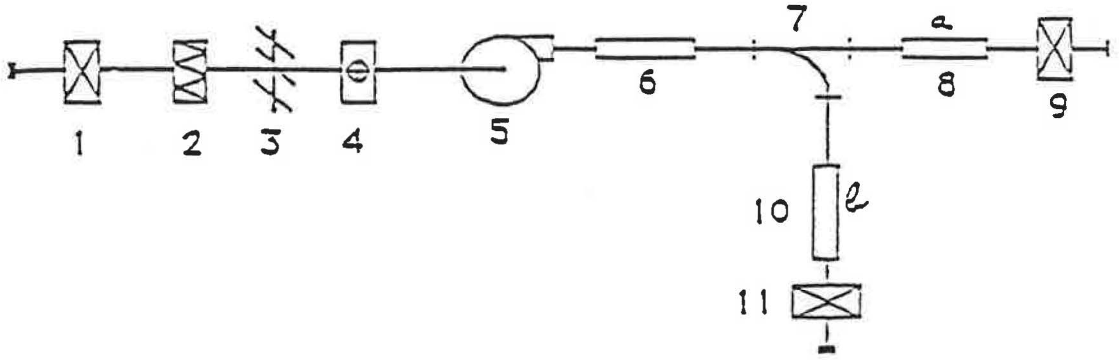


Figure 9 : Test configuration for airflow calculations in ductworks

APPENDIX 1

SUMMARIES OF THE HVAC COMPONENTS SPECIFICATIONS

Generators

S1 Fuel oil boilers
S2 Heat pumps
S3 Chillers

Heat and mass exchangers

S4 Radiators
S5 Floor heating panels
S6 Coils
S7 Heat recovery devices
S8 Cooling towers
S9 Humidifiers
S10 Filters

Fluid propellers

S11 Pumps
S12 Fans

Fluid distributors

S13 Pipes
S14 Ducts

Controllers

S15 Thermostatic valves
S16 Flow control devices
S17 Air dampers

Building subsystem

S18 Buildings
S19 Lighting devices and occupancy

SPECIFICATION S1 : Fuel oil boiler

AUTHORS : M. Dachelet, J.P. Eppe, J. Hannay, L. Laret,
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REVIEWERS : Univ. Stuttgart-IKE (Germany)
VTT (Finland)

SUMMARY

Function

Transfer of chemical energy released by fuel oil combustion to a working fluid (water).

Model proposed

Steady-state representation (possible extension to take some dynamic effects into account).

The boiler is supposed to be controlled by cycling the burner power ($\dot{Q}_b$) between two levels :

$$\overline{\dot{Q}_b} = \theta\,(\dot{Q}_b)_{max} + (1 - \theta)(\dot{Q}_b)_{min}$$

$$\text{with } 0 \leq \theta \leq 1$$

It is assumed that the same linear relationship can be used in order to define the boiler in useful power ($\dot{Q}_u$) :

$$\overline{\dot{Q}_u} = \theta\,(\dot{Q}_u)_{max} + (1 - \theta)(\dot{Q}_u)_{min}$$

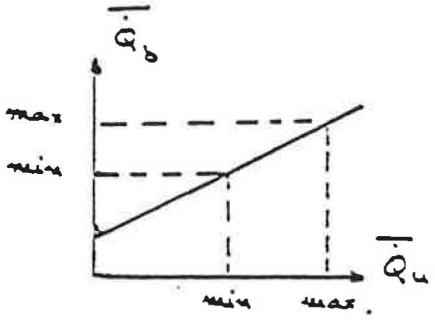
Experimental data has to be used in order to define the couples of values ($\dot{Q}_u$, $\dot{Q}_b$) at the different burner power rates obtained.

At each power rate, the loss ($\dot{Q}_b - \dot{Q}_u$) has to be identified as a function of the operating conditions : water and gas flow rates, water and environmental losses.

This is done by imagining the separation of heat exchanges in two points in series on the water circuit : the first one refers to the "useful" gas-water heat transfer; the second one (much smaller) takes into account the environmental losses. Global heat exchange coefficients (AU) of these heat exchanges are identified from boiler tests results.

General relationships

The most important outcome of this model is to give a linear relationship between $\dot{Q}_b$ and $\dot{Q}_u$ in the same control domain ($\dot{Q}_{min}$, $\dot{Q}_{max}$) and at constant running conditions (water temperature and flow rate) :



$$\overline{\dot{Q}_b} = C_0 + C_1 \overline{\dot{Q}_u}$$

Experimental validation

The model was validated at various occasions, by testing boilers in a large range of control modes and running conditions.

Identification of parameters

Manufacturers data and current laboratory tests do not always allow an accurate identification of all the parameters of the simulation model. Typical default values are given in the specification.

Subroutine

A "TRNSYS-type" subroutine is given in appendix with a sample of simulation results.

SPECIFICATION S2 : Air-to-water heat pump

AUTHOR : Manuel R. Conde

INSTITUTION : Eidgenössische Technische Hochschule Zürich
Institut für Energietechnik
Laboratorium für Energiesysteme
Zürich , Switzerland.

REVIEWERS :

SUMMARY

Function

Increase the exergy content of a thermodynamic sink by consuming exergy and anergy from thermodynamic sources.

Model proposed

The model is a set of relationships for steady state operation, with a quasi steady approach to the simulation of operation under frosting conditions.

The general form of the model's laws is :

$$\dot{L}_i\,(T_e{*},\ T_c{*}) = A_i + B_i\,T_e{*} + C_i\,T_c{*} + D_i\,T_e{*}\,T_c{*} + E_i\,T_e{*}^2 + F_i\,T_c{*}^2$$

Three laws are usually necessary for use in the model :

$$\dot{W}(T_e{*},T_c{*}) = K_w \quad \dot{L}_w(T_e{*},T_c{*})$$

$$\dot{Q}(T_e{*},T_c{*}) = K_q \quad \dot{L}_q(T_e{*},T_c{*})$$

$$\dot{R}(T_e{*},T_c{*}) = K_r \quad \dot{L}_r(T_e{*},T_c{*})$$

A correction to the air volumetric flow rate across the evaporator under frosting operation is necessary :

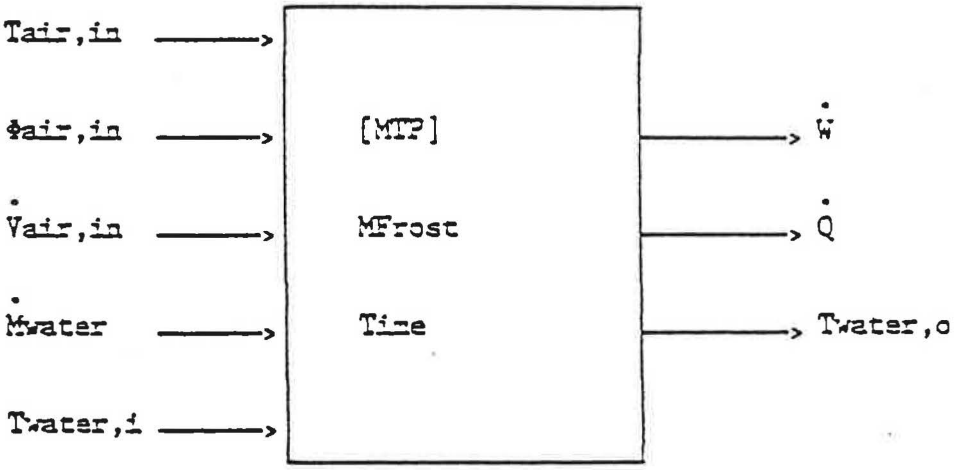
$$\dot{V}_{actual} = K_v \quad \dot{V}_{cat}$$

Where the K_w, K_q, K_r and K_v are factors accounting for the performance losses due to frost accumulation onto the evaporator surface.

The K's are calculated as polynomial functions of the (MTP) variable defined as

$$(MTP) = \int_0^{\tau} \frac{X_{air,in} - X_{air,sat,surf}}{X_{air,sat,surf}} \sqrt{\frac{\dot{V}_{da,actual}}{\dot{V}_{da,cat}}} \, dt$$

A block diagram of the model is depicted in the following :



showing the information flow as input and output variables, and the status variables.

Validation

The model has been used throughout the heat pump exercises in Annex 10.

Comparison with field data have shown an agreement within ± 10% of the measurements.

Identification of parameters

Data from manufacturers is used to derive the coefficients A_w... F_w, A_q... F_q, and A_r...F_r of the function laws. Default values are proposed in the model for the coefficients functions in the functions K_w, K_q, K_r, and K_v.

SPECIFICATION S3 : Liquid chilling system

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REVIEWERS : Université de Liège (Belgium)
Politecnico di Torino (Italy)

SUMMARY

Function

Heat transfer from warmup water to the outside air

Model proposed

The steady-state model is based on a practical approach of the chilling system of conventional machinery.

Only one compressor is simulated without revolution control. The components which have been modelled are : compressor, condenser, evaporator and cooling tower.

The performance of a cooling machine is characterised by its COP. At full load, this COP is a function of the temperature of evaporator and condensor.

At partial load, this COP decreases. This decrease in COP is given by the partial factor.

The standard relations which have been derived for three types of compressors (piston, screw, centrifugal) are : Carnot efficiency, minimum cooling capacity and partial load factor.

There is no variation of the Carnot efficiency dependent of the temperatures of evaporation and condensation. The Carnot efficiency is assumed to be constant.

The partial load curve is derived for :

- piston compressors,	GRASSO AC80-series design capacity range 95 to 379 kW
- screw compressor,	GRASSO MS1024 design capacity 537 kW

- centrifugal compressors, CARRIER series 19
  design capacity 352-7034 kW
  YORK, turbopack series OT.GT.C2
  design capacity 1200 kW

The evaporator, condenser and cooling tower are described as counter-flow heat exchangers with a constant heat transfer of the exchanger (AU). The simulation of the cooling tower is based on Merkel's theory.

The model is based on these starting points. This model can be used as part in a dynamic program for hourly calculations of the heating and cooling demand of a building.

Validation

The accuracy of the steady state model is checked against manufacturers catalogue data.

Identification and parameters

All parameters used in the model can be obtained from catalogue data, given by manufacturers. Meteorological data is necessary.

Subroutines

Subroutines are given in appendix with an example of simulation results.

SIMULATION S4 : Radiator

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CONTRIBUTORS : VTT (Finland)

REVIEWERS : University of Liège (Belgium)
Politecnico di Torino (Italy)

SUMMARY

Function

Heat transfer from hot water to a room by convection and radiation.

Model proposed

A simulation model for all kinds of radiators and convectors is presented.

The steady state heat emission of the radiator is calculated using an empirical exponential relationship between performance and logarithmic temperature difference between the radiator and its environment :

$$\dot{m}_w \cdot c_w \cdot (t_{su} - t_{ex}) = \dot{Q}_N \, (\Delta t_{log} / \Delta t_{log,N})^n$$

The dynamic behaviour is simulated using a first order model. The radiator thermal mass is concentrated in one mass point, located at the exhaust of each radiator element.

$$\dot{m}_w \cdot c_w \cdot (t_{su} - t_{ex}) = c_{rad} \cdot \frac{dt_{ex}}{d\tau} + \dot{Q}_N \cdot (\Delta t_{log} / \Delta t_{log,N})^n$$

If several radiator elements are used, these elements are connected in series.

Validation

The accuracy of the steady-state and dynamic model is checked against measurements. The simulation time step and the number of elements has a considerable influence on the accuracy of the dynamic model.

Identification and parameters

All parameters used in the model can be taken out of catalogue data, given by manufacturers.

Subroutines

A subroutine is given in appendix with an example of simulation results.

SPECIFICATION S5 : Floor heating panels

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Italy

REVIEWERS : University of Liège (Belgium)
Technical Research Center of Finland,
Espoo (Finland)

SUMMARY

Function

The component described in this specification is constituted by pipes embedded in floors. Hot water flowing in the pipes supplies the heat that is then transferred to the upper (and lower) room through the structure of the floor.

Model

The model is based on an electric equivalent circuit. It gives the value of the floor surface temperature and the value of the heat flux towards the heated room by solving one differential and two arithmetic equations. An iterative process is required if the indoor temperatures of the heated rooms are unknown.

Validation

The model has been validated against experimental results of tests performed in the climatic chamber of the Polytechnic of Turin. It has not been validated in a common Annex 10 exercise.

Identification of parameters

The parameters required by the model are mainly the thermophysical properties of the materials : they can be taken from manufacturer or literature data.

Subroutines

No subroutine is proposed for this component. The model only requires a subroutine for solving differential equations : one of the many subroutines reported by the common numerical literature can be used.

SPECIFICATION S6 : Coils

AUTHOR : M.J. Holmes

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U.K.

CONTRIBUTORS : LUT, ULg

REVIEWERS : IKE, VTT, PT, ULg

SUMMARY

Function

Heating and cooling coils are passive devices. In the context of this specification they transfer heat from a primary fluid, which can be water, steam or a refrigerant, to a secondary fluid, air. The heat transferred may be both sensible and latent. The amount transferred depends upon the design of the coil and the thermodynamic states of the two fluids. This specification gives methods that can be used to calculate the appropriate surface heat transfer coefficients and thus the coil performance.

Models

While the bulk of the specification is concerned with steady state sensible and latent duties, dynamic performance is not ignored. In particular a simple method by which time constants can be assessed is included along with a description of what is needed for a more thorough analysis.

Validation

The recommended methods are based on established theories, proven by the author's experience in the laboratory. Data on surface heat transfer coefficients are taken from recognized sources and include the effects of twisted tape turbulators within water tubes. In addition, it is shown how suitable data can be extracted from manufacturers catalogue data.

Subroutines

The specification describes how various control methods can be modelled and gives algorithms that might be incorporated in a computer program. FORTRAN listings of some of the calculation techniques are also included.

SPECIFICATION S7 : Heat recovery device (HRD)

AUTHORS : R. Kohonen, M. Nyman

INSTITUTION : TECHNICAL RESEARCH CENTER OF FINLAND
Laboratory of Heating and Ventilation

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SF-02150 ESPOO, Finland

REVIEWERS : University of Wisconsin (UW)
University of Liège (ULg)
Ove Arup and Partners (OA)

SUMMARY

Function

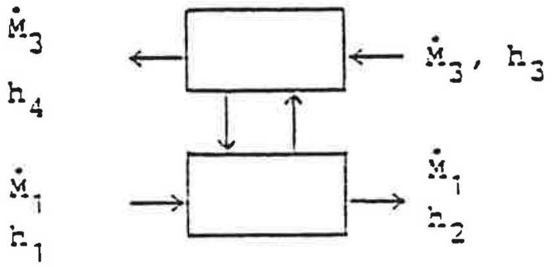
Transfer of the heat of the extact air to the supply air directly or indirectly.

Model

The function law of a HRD is described by thermal efficiency $_{su}$ related to the supply air.

$$\dot{Q}_{HRD} = \varepsilon_{su} \dot{M}_{su} c_p (T_3 - T_1).$$

Steady-state and dynamic models for calculation of the thermal efficiency of flat plate cross flow, indirect liquid run around and solid matrix regenerator heat recovery devices are introduced. Models are based on the local heat and mass transfer balances of fluid flows.



Validation

Some of the models are validated against laboratory tests, but only separate "mini" exercises are worked within Annex 10.

Identification of parameters

For energy calculations, parameters (thermal efficiency) can be taken directly from manufacturer data. For models to calculating thermal efficiencies, heat transfer coefficients,fluid regenerator matrix properties, coil/regenator matrix configurations, pipe diameters, plate/fin thickness etc. should be known.

Subroutines

Not included in the specification.

SPECIFICATION S8 : Cooling tower

AUTHORS : P. Arneodo, V. Giaretto, A. Mazza

INSTITUTION : Dipartimento di Energetica
Politecnico di Torino
Corso Duca degli Abruzzi, 24
10129 TORINO - ITALY

CONTRIBUTORS : University of Liège
Laboratory of Thermodynamics, Belgium

TNO-TPD, Delft, The Netherlands

REVIEWERS : University of Liège
Laboratory of Thermodynamics, Belgium

University of Wisconsin
Solar Energy Laboratory
Madison, U.S.A.

Ove Arup and Partners
London, U.K.

EMPA, Abteilung Bauphysik
Duebendorf, Switzerland

SUMMARY

Function

Cooling towers are used to reject heat from a water circuit to the atmosphere. Normally, in HVAC applications, the water comes from the condenser of a refrigerating system, where it is used as a cooling fluid.

Model

Two steady state models are proposed for counterflow cooling towers. A very simple model considers the cooling tower as a heat exchanger with a constant heat transfer area and a constant heat transfer coefficient; the performance of the cooling tower is computed by means of its water side effectiveness, for which a simple direct expression is given. The more complex model follows the classical Merkel theory, where the heat transfer is driven by the enthalpy difference between the air stream and the saturated air at the air-water interface.

Validation

The models proposed are very well known since a long time. They have been tested by several authors and they have been used satisfactorily in common Annex 10 exercises. However, comparison with experimental results is very limited. A comparison of the results of both models and catalogue data is reported in Appendix C of the specification.

Identification of parameters

Parameters required for the simulation have to be indirectly taken from manufacturers' catalogues; identification of such parameters is easily accomplished, starting from two generic operating conditions taken from catalogues. A fully worked out example is given in Appendix D of the specification.

Subroutines

Routines for computer simulation of cooling towers are given in appendices to the specification. Both models are implemented. The code is written in FORTRAN 77 and the data input and output routines have been kept separate from the main solution procedure, so that they can be easily eliminated or modified in order to incorporate the main routine into existing programs.

SPECIFICATION S9 : Humidifiers

AUTHORS : 1) P. Arneodo, A. Mazza

2) V.I. Hanby

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10129 Torino
Italy

2) Department of Civil Engineering
University of Technology
Loughborough
Leicestershire LE11 3TU
UK

REVIEWERS : University of Liège (Belgium)
Amazon Energy (UK)

SUMMARY

Function

To increase the moisture content of air in HVAC plant.

Model proposed

Two types of humidifier are considered; steam humidifiers, in which the process is considered to take place at constant dry bulb temperature and adiabatic humidifiers, which are considered to operate at constant wet bulb temperature. Adiabatic humidifiers are characterised by their effectiveness, which varies with the flow rate of air through the device. The air pressure loss of humidifiers is also considered.

Validation

The predicted performance of humidifiers is compared with manufacturers data.

Identification and parameters

A single set of operating conditions (usually available from the manufacturer) is required for the calculation of model parameters. An example of parameter calculation is given in the specification.

Subroutines

None supplied.

SPECIFICATION S10 : Air filters

AUTHORS : P. Arneodo, A. Mazza

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Corso Duca degli Abruzzi 24
10129 TORINO
Italy

REVIEWERS : Loughborough University of Technology,
Dept. of Civil Engineering, U.K.

VTT - Technical Research Centre of Finland,
Lab. of Heating and Ventilation.

SUMMARY

Function

The air filters described in the component specification are those used in air conditioning systems for cleaning supply air with relatively low dust concentrations, normally not higher than 3 mg per m^3 of air.

Model

The presence of an air filter in an air conditioning system represents a pressure drop increasing with time. The air filter model, based on two possible experimental equations, evaluates the change of pressure drop due to filter clogging.

Validation

The filter model can easily be introduced in air conditioning system simulations that take into account the influence of pressure drops on energy consumptions. The model has been tested in a common Annex 10 exercise. An example of application is reported in par. 4.

Identification of parameters

Parameters can be taken by fitting the manufacturers data or can be, in some cases, evaluated as a function of air filter characteristics and of dust concentration. Typical values for one of these parameters are proposed in the specification as a function of air filter quality and of dust concentration.

Subroutine

No subroutine is proposed for this component as the model equations can very easily be introduced into every simulation program.

SPECIFICATION S11 : Pump

AUTHORS : M. Brossa, A. Mazza

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Italy

REVIEWERS : Loughborough University of Technology
Dept. of Civil Engineering, U.K.

Royal Institute of Technology
Division of Building Services Engineering
STOCKHOLM, Sweden

SUMMARY

Function

A pump is a device used to supply energy or pressure head to a fluid (liquid), so that the fluid can flow in a piping system and connected devices with the required flow rate, overcoming the pressure losses encountered along the circuit.

Model

Only centrifugal pumps are considered, in steady state conditions. They are modelled by their pressure and power versus flow rate characteristics. A detailed description of all kinds of losses in the pump and associated electric motor is given.

Validation

The model is very simple and traditionally used to simulate pump behaviour. A common Annex 10 exercise has shown that it is adequate for HVAC system simulation.

Identification of parameters

Parameters can be obtained directly from, or by fitting the manufacturers' data. Efficiency values required to evaluate the actual energy consumption of the component are not always given by manufacturers.

Subroutines

No subroutine is proposed for this component, as the model equations are very simple. A short computer program is given to obtain the characteristic curves of a pump by interpolation of manufacturers data.

SPECIFICATION S12 : Fans

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2) V.I. Hanby

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2) Department of Civil Engineering
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UK

REVIEWERS : TNO (Holland), Ove Arup & Partners (UK)

SUMMARY

Function

To produce a continuous flow of air against moderate pressures.

Model

A steady state model is proposed covering axial and centrifugal type fans. The model is based on curve fitting manufacturers data : in the case of centrifugal fans, fan speed is considered as the operational parameter, for axial flow fans blade angle is used. In each case data is required of pressure against volume flow rate and also absorbed power against volume flow rate. Compressibility effects are not accounted for in the model although the necessary corrections are given.

Dimensionless fan characteristics are used to reduce the quantity of data required.

Validation

The model reproduces the manufacturers source data.

Identification and parameters

Catalogue data is required for the model : an example is given of the recommended method of transforming these data into the model format.

Subroutines

None supplied.

SPECIFICATION S13 : Piping

AUTHOR : T.G. Malmström

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Drottning Kristinas väg 37A
S-100 44 Stockholm, Sweden

REVIEWERS : University of Stuttgart
IKE Abt HLK, FRG

Technical Research Center (VTT)
Espoo, Finland

SUMMARY

Function

Transport of hot or cold water for climate installations in buildings.

Model

Pipe installations in buildings mostly form large networks. The present models are restricted to a segment of such a system. Both thermodynamic and hydraulic models are discussed in the steady-state approximation :

- the thermodynamic modelling results in a simple algebraic relation. For dynamic models we refer to the specification on ducts,
- the pressure drop calculation involves pipes, bends, t-pieces etc. according to

$$\Delta P = \zeta \cdot \rho \cdot V^2/2$$

when the friction coefficient ζ is discussed.

Validation

The proposed steady-state models are based on well established results available in special literature on this topic.

Identification

All the parameters used in the models can be evaluated by given empirical expressions. In the case of hydraulics additional information (flow resistances for various components) may also be obtained from catalogues of the manufacturers.

Subroutines

No subroutines are included because the application of the models is strongly dependent on the equation solvers used in the synthesis of the system. Such computer programmes may vary considerably due to the requirements as to generality, system layout, transient and/or stationary models, computer capacity etc.

SPECIFICATION S14 : Ducts

AUTHORS : T.G. Malmström, L.G. Olsson

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Drottning Kristinas väg 37A
S-100 44 Stockholm, Sweden

REVIEWERS : Technical Research Center (VTT), Espoo, Finland

University of Technology (LUT), Loughborough, U.K.

SUMMARY

Function

Transport of air for ventilation or air-conditioning of occupied zones in buildings.

Model

Ducts in buildings generally form elaborate networks. The present models are restricted to a duct fragment of such a system. Both thermodynamic and hydraulic analyses are discussed :

- pressure drop calculations (involving ducts, bends, t-pieces, etc.) are performed in the steady-state approximation,
- thermodynamics is evaluated both with stationary and transient models, resulting in a simple algebraic relation and 2 coupled differential equations, respectively. In the latter case further simplifications must be introduced.

Validation

The proposed steady-state models are based on well established results available in the special literature. The dynamical model (thermodynamics) is a first order extension of the former ones.

Identification

All the parameters used in the models can be evaluated by given empirical expressions. In the case of hydraulics additional information (flow resistances for various components) may also be obtained from catalogues of the manufacturers.

Subroutines

No subroutines are included because the application of the models is too strongly dependent on the equation solvers used in the synthesis of the system. Such computer programmes may vary considerably due to the requirements as to generality, system layout, transient and/or stationary models, computer capacity, etc.

SPECIFICATION S15 : Thermostatic valve

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GERMANY

CONTRIBUTOR : VTT (Finland)

REVIEWER : EMPA (Switzerland)

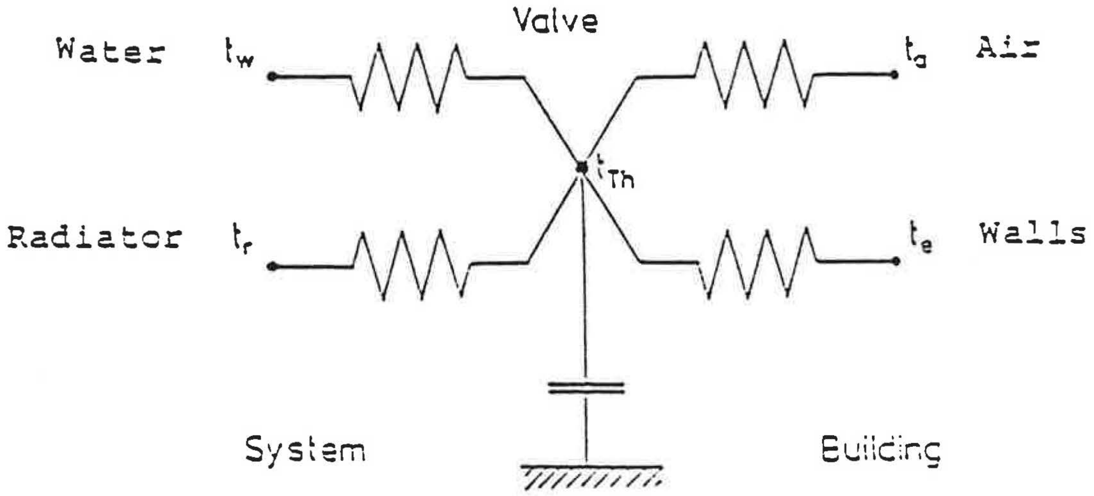
SUMMARY

Function

The function of a thermostatic valve is to control the room temperature by varying the waterflow through the radiator.

Model

The thermostat (sensor and casing) is concentrated to a joint mass point, which reacts on varying temperatures of supply water, radiator, air and walls. The dynamic thermal behaviour is described using a first order model :



The relationship between waterflow through the valve and temperature of the thermostat, when the pressure drop over the valve is constant, is linearized. To calculate the mass flows and pressure drops in the whole network, it is suggested to replace the valve by a single hydraulic resistance with varying resistance factor.

Validation

A comparison of measurements and calculations shows a good accuracy of the model.

Identification of parameters

All input parameters are available, if the valve is tested according to DIN 3841.

SPECIFICATION S16 : Flow control devices

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REVIEWERS : Politecnico di Torino (Italy)

SUMMARY

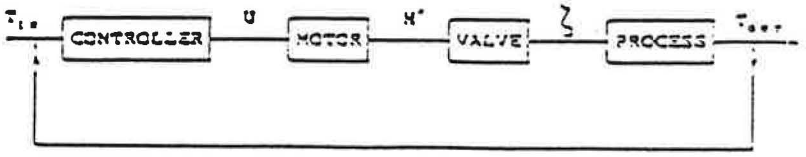
Function

3-way mixing valves (including controllers and actuators) are used for controlling the supply water temperature of heat distribution networks. Bypass valves and differential pressure control valves improve the hydraulic stability of networks by controlling a constant differential pressure.

Models

Models for DDC-type controller and actuator are dynamic, while models for 3-way mixing valve, bypass valve and differential pressure control valve are static.

The deviation between the set temperature of supply water and the actual supply water temperature is an input signal of the 3-way mixing valve controller. The controller outputs a voltage signal U to the actuator, which gives a relative valve position H_x.



The 3-way valve is handled as two separate 2-way valves, one for the pipe of boiler circuit and another for the bypass pipe. The hydraulic characteristics of valves ($k_v(H_x)$ - curves) are either linear or logarithmic :

$$k_v = k_{vo} + (1 - k_{vo}/k_{vs})k_{vs}H_x \qquad \text{(linear)}$$

$$k_v = k_{vo}e(\ln(k_{vs}/k_{vo})H_x \qquad \text{(logarithmic)}$$

The single resistance factors (H_z) corresponding to k_v-values are calculated on the bases of the determination of the k_v-value of valves.

The bypass valve and differential pressure control valve are also handled as single resistance factors, which are functions of the controlled pressure difference ((p)). The hydraulic characteristics of valves are assumed linear.

Validation

Models of 3-way mixing valve (including DDC-type controller and actuator) and bypass valve have been validated in Exercise 5.

Identification of parameters

Most of the parameters are to be taken from manufacturers data. The control parameters of DDC-type controllers should be determined by measurements (step response test). The required default parameters of models are given in the specification.

SPECIFICATION S17 : Dampers

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REVIEWERS : VTT (Finland), RIT (Sweden)

SUMMARY

Function

To produce controllable total pressure loss in a duct.

Model proposed

A simple empirical model is proposed, based on the velocity pressure of the air approaching the damper. The model considers single blade dampers, together with opposed and parallel blade control dampers. The damper is characterised by a single resistance factor, which is a function of the angle of the blade to the air stream, and also by the configuration of the damper.

Validation

The accuracy of the model is checked against the source data.

Identification and parameters

Data required for the model can be taken from manufacturers catalogues, the CIBSE (UK) and ASHRAE (USA) Guides.

Subroutines

None supplied.

SPECIFICATION S18 : Building

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Ove Arup & Partners (United Kingdom)
TPD-TNO (The Netherlands)

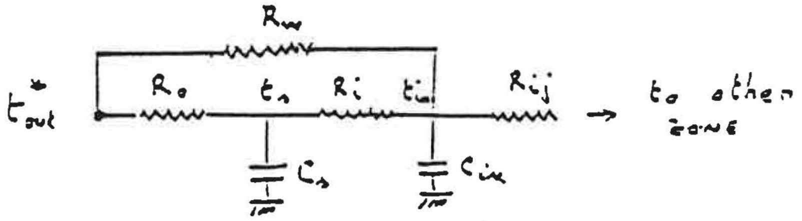
SUMMARY

Function

A building hosts occupants. Thermally speaking, its volume constitutes a zone of space where comfort requirements are to be met.

Model

Dynamic and multizone. Zones represented by lumped parameters models (figure 1), interconnected by resistive connections. Convective and linearized radiative heat exchanges at surfaces are globalized. Therefore, computed temperatures are resultant.



Internal gains and loads from the HVAC system are brought to the zone nodes (t_{in}), while solar gains and IR losses are considered by the use of equivalent "sol-air" temperatures.

Validation

The model has been successfully compared with reference building loads programs in various applications. No direct validation with experimental data was performed, except for laboratory climate rooms.

Identification of parameters

Parameters are obtained from the description of the walls structures and from the building blueprints. Information on the occupants number, schedules and use of internal loads should also be given. Hourly values are generally required.

Meteorological data is also necessary.

SPECIFICATION S19 : Lighting devices and occupancy loads

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CONTRIBUTORS : EMPA (Switzerland)

REVIEWERS : Ove Arup & Partners (UK)

SUMMARY

Function

Relations for internal loads and time schedules of lighting and occupancy are given as well as profiles of the use of hot water consumption in dwellings.

Model proposed

The proposed models are sets of relationships for :

- lighting power which depends on illuminance, specific luminance flux, area of the room and utilisation factor, lightloss factors, ventilation factors values are given for manufactured data.
- available daylighting in a room geometry, reflectances and glass area in the room. The relations are based on measured and validated data.
- use of blinds depending incident solar radiation based on measured data.
- cooling load due to the occupancy depending metabolism of persons based on measured and validated data.
- domestic hot water consumption depending on the hour based on measured data in a number of European countries.

Validation

The different relations are compared with or are a result of measured data.

Identification and parameters

The parameters used in the relationships can be taken out of catalogue data, given by manufacturers.

Subroutines

A subroutine is given in the appendix with the calculation of the PMV and PPD values based on the Fanger theory.

APPENDIX 2

SUMMARIES OF THE SYNTHESIS REPORTS ON SIMULATION EXERCISES

Heating systems

E1 Synthesis report for three years of activities 1983-85)
E2 Analysis of boiler simulations
E3 Simulation of a section of heat distribution system and simulation of the whole system.
E4 Simulation of the heating system coupled with the building, using different control hypotheses
E5 Heat pump exercises
E6 Hydraulic network simulation

Ventilating and Air-conditioning systems

E7 Global energy simulation. Plant and Building
E8 Ductwork system exercise

E1-AN10-860429-01

Synthesis report for three years of activities (1983-1985)

The simulation exercises

April 1986

Marie-Anne Morant
University of Liège
Belgium

This report presents the synthesis of the exercises performed during the last three years of activities.

Since the beginning, two different typical systems have been chosen. One building is a multi-family residential house with central boiler and hot water heat distribution. The realistic reference data came from the "La Chaumière" building in LAUSANNE (Switzerland) for which experimental information has been collected. The other building is a three storey commercial building with an air-conditioning system. The existing reference is the Collins building in GLASGOW, previously analyzed by IEA Annex 4.

In the field of residential heating, the simulation exercises were selected starting from the generators and progressively extending the analysis to the distribution networks, emitters and control devices. The purpose of this method was to check the accuracy of the models and the main parameters concerned with the component behaviour, before starting with parametric studies and control strategies analyses. The air conditioning exercises have also been produced following progressive steps.

At the end of these three years, the most interesting examples analyzed in the field of residential heating have been :

- a parametric study of the boiler;
- the simulation of a global heating system;
- a parametric study of the thermostatic valve;
- the simulation of various configurations of a heat production system including a heat pump;
- the analysis of the distribution network hydraulic effects.

For commercial buildings, different strategies of air control units have been approached and will be developed. The production plant is also progressively introduced.

This report gives all details on the different exercises especially on their main objectives and their main results concerning energy performances.

Conclusions about the exercises on the "La Chaumiere" building

The main objectives of the exercises have been achieved :

- the exercises have demonstrated the possibilities of simulation programs;
- different models of classical heating system components have been compared;
- the importance of dynamic behavior has been estimated and simple correlations have been extrapolated;
- important parameters have been defined for an accurate simulation on the one hand and for energy consumption on the other hand;
- parametric studies have been performed and some energy conservation possibilities have been obtained;
- advanced systems as the heat pump have been included into the exercises;
- through the hydraulic network simulations, the hygrothermal behaviour of heating systems will be better understood.

E2-AN10-880104-03

Analysis of the boiler simulations

(Exercise 2 on the La Chaumière building)

Jürg Gass
Nicole Hopkirk
EMPA
Switzerland

Introduction

The analysis of boiler simulation models presented below is part of the IEA-Annex 10 research project. It consists in simulating an existing boiler in the building "La Chaumière" in Lausanne, using measurements as input data (ref. 1). Five of the countries involved used dynamic models, whereas EMPA used a stationary model based on the DOE program. The aims were to :

- investigate the capabilities of simulation methods for boilers,
- compare the different models,
- establish which parameters are important for an accurate simulation on the one hand and which are important for energy consumption on the other hand,
- estimate the importance of dynamic behaviour and determine to what extent stationary models are adequate.

The countries presented here are Germany (IKE), Italy (PT), Sweden (RIT), Belgium (ULg), Scotland (ABACUS) and Switzerland (EMPA).

Overview of the exercises

The six exercises in the project were : the existing boiler (ex. 2.0), the same boiler with a higher burner power adjusted to the maximum rated boiler power (ex. 2.1), the same boiler with a better insulation (ex.2.2), a modern boiler (ex. 2.3) and the new boiler with a higher heat capacity (ex. 2.4). For these exercises (2.0 - 2.4) the boiler water temperature varied between 60°C and 70°C. Only the feed-in water temperature to the distribution system after the mixing valve was a function of the outside temperature. In the last exercise (2.5), the boiler thermostat setting itself varied according to the outside temperature, including a night set back. In each case the same load and input data were used and the energy consumed and production efficiency were calculated.

Conclusion

1. It is clear that the existing models presented are quite capable of simulating a boiler.

2. The simpler models do not give a physically accurate representation of the variations of the flue gas, ventilation and surface losses with load, although the total losses are accurate enough to predict the energy consumptions. Omitting the outside temperature does not play a large role at high loads but could become more important at low loads.
   The difference between the models seem to be mainly due to different "static" values used and not to dynamic effects. The actual scatter about the regression lines is small.

3.a) The important parameters for dynamic simulation are :

- the flue gas temperatures (which practically never reach steady state even at high loads) as a function of time,
- the air temperature during burner-off periods in the combustion chamber (which remains higher than expected for high loads),
- the length of the cycle,
- the necessity of dividing the boiler into two parts.

For stationary models the following parameters are important :

- the relationship between the flue gas and ventilation losses to obtain the correct chimney losses,
- the correct splitting of the boiler into two parts,
- the correct choice of steady state values.

3.b) At high loads the total losses are 15 % of the fuel consumption. 2/3 of the losses are due to flue gas losses, 1/4 are due to surface losses , where the ventilation losses are practically negligible. So it is important for energy conservation to construct boilers with low flue gas temperatures.
At low loads (domestic hot water only) the total losses go up to 60 % of the fuel consumption, more than 1/2 of which are caused by surface losses. Good insulation of the boiler is therefore of importance.

4.a) For short periods, when the dynamic model is economically acceptable, it gives very important detailed information as to what is happening physically. It can then either validate a steady model or be used to determine a simple relationship, as has been done for this exercise.

4.b) If one uses a steady state model, it is important when choosing the steady state temperatures, that the errors introduced in the calculations of the flue gas and ventilation losses cancel out, giving correct chimney losses. We see that in exercise 2.0 the differences do cancel out over a long period.

5. One can say that for yearly energy calculations the linear regression model is adequate.

6.a) The analysis of the various boilers indicates that good economies can be obtained either by reducing the burner power of the old boiler, if that is possible, which gives an economy of about 6 % of the consumed energy or by insulating the boiler, with reduced burner power, more adequately (3.3% economy). If both improvements can be applied one can reach economies of about 9 % of the consumed energy.

6.b) Replacing the old common boiler by a new good quality one can give economies of about 13 % of the consumed energy.

6.c) However, improving new boilers by either introducing a higher capacity or allowing the boiler water temperature to fall below 60°C only gives small economies of about 1 % of the consumed energy. One must remember that all the previous boilers had their boiler temperatures limited to 65°C.

7. Finally, one can say that generally good economies can easily be achieved in old installations. Possibilities of further improvements of the new boiler are limited but could be reached by the condensation of the flue gas.

E3-AN10-850308-01

Exercises on the building "La Chaumière"

Simulation of the heating system

Exercises 1-b and 1-c : simulation of a section of the heat distribution system and simulation of the whole system

Analysis of the results

March 1985

Anne-Marie Morant
University of Liège
Belgium

Description of the simulation exercises

The exercises discussed here are two of several simulation exercises performed on the heating system of the two multi-storey building "La Chaumière" in Lausanne.

The distribution network is formed by fourteen similar vertical columns. Each vertical pipe supplies eight radiators placed in parallel which heat eight different rooms (two per floor) (see figure 1). Most of the pipes are embedded in the external walls. The boiler is connected to the system through a three-way valve which controls the distribution feed water temperature as a function of the outside temperature. A night set back in the regulation law decreases the emission during a night period of seven hours. The production system for hot water consumption is not simulated, but the energy delivered by the boiler for the hot water production is taken into account.

Exercise 1-a, which will not be discussed here, is the simulation of the boiler alone. For this exercise, the energy delivered by the boiler was given hour per hour. Exercise 1-b is the connection of the two previous exercises. It bears on the simulation of the whole heating system. This report will discuss the results obtained by the Annex 10 participants related to exercises 1-b and 1-c. For these two exercises, no parametric study and no optimization of the system was performed.

Conclusion

Simulation exercises have been performed starting with the boiler, and progressively extending the analysis to the distribution networks, emitters and control devices. The two exercises discussed here are among the first exercises made on the building "La Chaumière". Thus, all the problems in the exact definition of the input data were not really solved before getting to the following exercises. A consequence of this is that comparisons of the exercises 1-b, 1-c participants results are very poor. In fact, the difference between the models used are "drowned" by the differences in the input data. However, some comparisons between the ULg and IKE radiator models have been made and it appears that the difference between the two models is not very significant above all when the heat output is considered on a long period (more than an hour).

What appears from these results is that dynamics are not of a great interest when the room response is not considered and when the distribution supply water temperature is a linear function of the outside temperature. The energies delivered by the boiler, injected into the distribution system, and emitted to the rooms are indeed nearly linear functions of the outside temperature.

E4-AN10-851023-02

Analysis of the results of exercise 3

"La Chaumière" building

"Simulation of the heating system coupled with the building, using different control hypothesis"

Helmut Ast
Wolfram Stephan
IKE
University of Stuttgart
Germany

Introduction

The aim of this exercise was to give an overview of the possibilities of programs which simulate the thermal dynamic behaviour of the complete heating system and the building together.

Several parametric studies were done. First the control behaviour of thermostatic valves was examined.

The second part of this exercise deals mainly with control strategies of the boiler and the three-way mixing valve, also using thermostatic valves for the control of emitters.

The exercises were done by ULg, RIT and IKE.

Conclusions

The investigation of the control behaviour of thermostatic valves shows that the thermostatic valves performs quite well. The control efficency was at least 95 % and the degree of heat gain utilisation 78 %.

Additional simulations done by IKE showed that the hysteresis of a thermostatic valve had only little influence on efficiencies. If the mean set points of the thermostatic valves are kept constant, a little lower efficiency for lower hysteresis occurs. The hysteresis influences mainly the changes in the room temperature. Results show greater changes in the room temperatures for greater hysteresis.

As heat emissions from the pipes and heat gains are not controlled, an ideal emission (ideal control) had a control efficiency of 98.8 % and a degree of heat gain utilisation of 95 %.

A hand valve control had a control efficiency of 91.3 % and a degree of energy utilisation of 9.3 %.

These results show again that the thermostatic valve control is quite good, if the set points are very well adjusted.

The heat production of the heating system of "La Chaumière", which consists in an old boiler and a three-way mixing valve was changed and a new boiler, without mixing valve, was installed. The renewing of the heating plant did not influence the heat emission of the radiators and pipes, although there was a higher variation of the supply temperature. Only the better boiler efficiency reduces the heat consumption of the boiler.

Additionally the cylinder for hot water was changed and a priority control for hot water was introduced. No change in the heat consumption and heat emission of the pipes and radiators were calculated.

The heating system of "La Chaumière" was considered in continuous operation, with night set back and night cut off. Between continuous operation and night cut off the distribution losses decrease by about 20 %. The control efficiency increases by approximately 1 %.

The main energy saving by night set back and night cut off was caused by lower room temperatures. Especially in the case of the night cut off the room temperatures were lower than expected, even during the day period. This lack of comfort produces an energy saving of 5 to 6 % if the night set back and night cut off are compared.

Finally, it should be noticed that the results are only valid for the heating system of the "La Chaumière" building.

The comparison of the programs of RIT, ULg and IKE shows that the programs of ULg and IKE work very well and most of the results agree. The reason for the differences can always be found in different input data.

The program of RIT can hardly be compared, as the results differ too much.

E5-AN10-880113-01

Heat pump exercises
on
"La Chaumière"

Analysis of the results

October 1986
Revised December 1987

Manuel R. Conde, ETHZ
Gerhard Zweifel, EMPA
Switzerland

Objectives of the heat pump exercises

The objectives of the heat pump simulation exercises were defined as follows :

- Find new polynomials, or due corrections to the catalogue-fitted polynomials, to describe a "black box" type model for air-to-water heat pumps. Losses due to frost/defrost should be accounted for by means of a global correction factor.

- Investigate the potential for electric power peak generation by air-source heat pumps.

- Compare several configurations of bivalent heating plants using air-to-water heat pumps.

- Study the influence of the heat pump size on the total installation running costs.

- Analyse the possibility of economic optimization of bivalent heating plants.

E6-AN10-880506-02

Synthesis report

Hydraulic network simulation
La Chaumière building

April 1988

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Ari Laitinen
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Finland

Summary

The thermohydraulic analysis of a water radiator heating system is a part of the IEA-Annex 10 : Building System Simulation Work. The analysis consisted in simulating a water radiator heating system coupled with the building using design data as input.

The aim of the exercise was to get a better understanding on the thermo-hydraulic behaviour of a water radiator heating system as a whole. It was also of interest to find out the influences of low control devices on thermal control of the system. The exercise was also a test for the component models developed within the IEA-Annex 10.

Altogether three participants carried out the exercises, which had three stages : hydraulic balance, thermal balance, and plant simulation coupled with the building.

Within the hydraulic balance analysis the network was first adjusted to have the measured flow rates.

It was also found that a water radiator heating system can be dimensioned with a "quick" method with reasonable accuracy, i.e. the wanted flow rates are obtained without precise pressure drop calculation. The quick dimensioning method requires loose pipe-dimensioning (friction losses less than 50 Pa/m) and high pressure loss at radiator valves (higher than 4 kPa). The corresponding figures for the reversed return system are 100 Pa/m and 2 kPa.

High initial pressure level at radiator valves may, however, cause unintended noise problems, when a part of radiator valves close, because pressure drop in closing valves may exceed 10-15 kPa.

Pressure condition can be kept relatively constant by using by-pass or pressure differential control valves, which means that the distribution network can be omitted in a hydraulic sense and that the so called system characteristics (authority model) for radiator valves can be applied.

The system mass flow rate can be kept constant, if the 3-way mixing valve is relatively loose (big k_v-value) and if it has linear-linear valve characteristics.

Thermal balance analysis showed that only half or less than hald of the total heat emission of the network is by radiators and thus controllable by thermostator valves.

Response of the network to a room air transient was studied first with an inert building, i.e. an artificial room air transient was assumed. This simulation showed the importance of flow control devices in stabilizing the network hydraulically.

Although the radiator valves in one column were nearly closed the pressure conditions could be kept nearly original (designed). Heat emission of the network was also influenced by the flow control devices : the narrower the proportional band of by-pass valves the smaller the deviation of heat emission and flow rates of the radiators from the wanted values.

The influence was rather marginal, absolutely approximately 44 %. As the return water temperature is increased (decreased) if by-pass (pressure differential) valves are used, it is advantageous to use by-pass (pressure differential) valves in boiler-heated (district) heating systems.

The plant simulation coupled with the simulation of building is perhaps the most comprehensive task that has been carried out within the IEA-Annex 10 work. Here two complete columns with eight radiators in each were studied.

Dynamic models for boilers, pipes, radiators, thermostatic valves, as well as for the building were used. Also the mixing valve having an actuator with PI-controller was modelled. The models used by the participants were introduced within the IEA-Annex 10 project. The heating system and the building were described by hydraulic and thermal modes, respectively. A typical simulation time with a VAX 11/780 computer was 1200 CPU-secs per day (5 min time step).

The dynamic behaviour of the network was studied for a two-week period. It was found that if by-pass valves are used, the energy consumption of the distribution network can be reduced by 1 - 4 %. Therefore, we may conclude that the use of by-pass or pressure differential valves has not a great energy saving potential, but they should be used to stabilize the network hydraulically.

Dynamic considerations showed that dynamics of the network does not play any important role in the thermohydraulics of the distribution network, not even during the morning start period. A well-tuned PI-controller can supply a constant water temperature although the outlet temperature of the boiler was oscileating considerably.

Finally, we can conclude on the models developed within IEA: Building System Simulation for simulating the hydronic heating system coupled with the building was found to be reasonable and accurate enough to analyse the energy saving potential and influences of the components on the thermohydraulic performance of the water radiator heating system.

E7-AN10-880208-02

Collins Building Exercise 5

Global energy simulation - plant and building

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General

The primary objective of exercise 5 was to establish the feasability of carrying out a global energy simulation of HVAC plant coupled with a building, using component models derived from the specifications in the data bank. The system chosen was the VAV air conditioning system modelled in previous Collins building exercises coupled with a simplified building model. The specification for the exercise is contained in AN10-871011-01 with additional information from AN10-850921-01 (Exercise 4).

Weather data for a summer period of two weeks and a winter period of the same time were supplied by ULg. The results reported here cover only the summer period as all contributors had completed the simulation for this period and also because the control system as specified was unsuitable for winter operation.

The results are reported in two sections : a period of one complete week (the second of the two available) the first weed being used to "run up" the models and a more detailable analysis of one day, August 29th, when results are reported for the running of the plant between 8.00 and 17.00 hours (the hours of occupation of the building).

Results were contributed by PT, ULg and TNO, and are presented in the form of sketch graphs prepared by the author.

Conclusions

The results of this exercise have shown that component models constructed from the specifications in the Annex 10 data bank can be used to simulate the global energy consumption of an air conditioning system coupled with a building. The results discussed in this report have concerned only the summer period as the control system modelled was not suitable for the winter case. It is normal for a VAV system to serve an internal zone only which would always (when occupied) be subject to heat gain.

It would be expected that there would be some numerical differences in the reported results but what is important is that all the simulations reproduced the main characteristics of the building/plant combination; an example of this is the way that all the simulations predicted quite accurately the conditions under which the plant was unable to meet the imposed load. During this time, when the plant was working at its maximum capacity, the results were generally close and the complete system behaviour was determined mostly by the dynamics of the building model.

E8-AN10-880208-03

Ductwork System Exercise
Results

January 1988

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General

The objective of the exercise was to test the operation of component models written from the specifications for ducts (RIT), filters (PT) and dampers (LUT). Results were received from LUT, VTT, ULg and RIT. Full results included pressure drops and flow rates for each component in the example system for the operating conditions specified. Selected results only are reported here.

Conclusion

The exercise has provided a simple means of testing component models derived from the ductwork component specifications. All the results support the expected behaviour of the components; numerical differences have been shown to be a consequence of :

i) variation in operating conditions (VTT)
ii) different ways of implementing the same model (all)
iii) different interpretation of the specification (LUT).

APPENDIX 3

LIST OF IEA-ANNEX 10 DOCUMENTS

File : AIEDBANK

I.E.A. - Annex 10

DATA BANK

List of documents available

(Update : October 1988)

AN10-820210-04	General presentation of the technical form (ULg)
AN10-820210-05	HVAC rotating regenerator (ULg)
AN10-820210-06	Heat emitters (ULg)
AN10-820210-07	Distribution network (ULg)
AN10-820210-11	List of terminology symbols (ULg)
AN10-821008-01	Water boiler (ULg)
AN10-830127-05	Section 0 : general description of building system (ABACUS)
AN10-830127-06	Section 1 : VAV terminal unit (ABACUS)
AN10-830127-07	Section 2 : ductwork (ABACUS)
AN10-830127-08	Section 3a : heating coils (ABACUS)
AN10-830127-09	Section 3b : cooling coils (ABACUS)
AN10-830127-10	Section 4 : fans (ABACUS)
AN10-830127-11	Section 5 : humidifiers (ABACUS)
AN10-830127-12	Section 8 : pumps (ABACUS)
AN10-830701-03	Section 6 : mixing section of air handling unit (ABACUS)
AN10-830701-04	Section 9a : centrifugal chiller, general description (ABACUS)
AN10-830701-05	Section 11 : cooling tower (ABACUS)
AN10-830509-01	Water heating analysis (FABER)
AN10-830808-01	Radiator (IKE)
AN10-831020-02	Simulation of centrifugal water chiller plant (OA)
bis	Simulation of heating and cooling coils for performance analysis (OA) - paper presented at the 1st ICSSB in Liege
AN10-840220-01	Pipes and ducts (RIT)
AN10-840222-03	Building simplified model (ULg)
AN10-840227-01	Steady-state model of reciprocating compressors (ETHZ)
AN10-840313-01	Thermostatic valves (IKE)
AN10-840411-11	Steady-state models for liquid-cooled condensers (ETHZ)
AN10-840411-12	Pumps (PT)
AN10-840412-02	Equipment specifications for system simulation (ARUP)
AN10-840412-03	Fortran routines to determine psychrometric properties and processes.
AN10-840709-02	Research of a good boiler model for HVAC energy simulation : Draft (ULg)
AN10-840712-01	Dynamic energy simulation : the domestic central heating system (ABACUS). AMSE conference, 28th June, 1984, Athens.
AN10-840906-02	Fans (LUT)
AN10-840907-02	A general computer simulation model for furnaces and boilers : Draft (IKE)
AN10-841010-03	Steady state model of finned-coil direct expansion

	evaporators (ETHZ)
AN10-841010-02	Steady state model for thermostatic expansion valves (ETHZ)
AN10-841010-01	Heat pump (ETHZ)
AN10-841108-14	Heat pump : errata (ETHZ)
AN10-841025-01	Fortran routines to determine psychrometric properties and processes
AN10-841108-15	Cooling tower (PT)
AN10-841108-16	Humidifier (LUT)
AN10-841108-17	Humidifier (PT)
AN10-841108-18	Psychrometric subroutine uses ASHRAE algorithms
AN10-841108-19	Draft of a component "pro-forma"
AN10-841218-01	A general computer simulation model for furnaces and boilers (IKE) - paper presented at the ASHRAE meeting, January 1985, Chicago
AN10-841218-02	A simple boiler model (RIT) - paper presented at the ASHRAE meeting, January 1985, Chicago
AN10-841218-03	Research of a good boiler model for HVAC energy simulation (ULg) - paper presented at the ASHRAE meeting, January 1985, Chicago
AN10-850308-00	TRNSYS 12.1: a Transient System Simulation Program
AN10-850308-02	Extract of TRNSYS - thermal storage
AN10-850326-02	Steady state heat losses from pipes embedded in walls or mounted in slots
AN10-850410-17	Piping for heat distribution (water) (RIT)
-18	An overview of existing methods for floor heating panel simulation (PT)
-19	Air-to-water heat pump simple simulation model (ETHZ)
-20	A simulation model for cooling coils (PT)
-21	Cooling and dehumidying coils (Ulg)(slides copies)
-22	Results on the simulation of cooling towers (PT)
-23	Development of cooling tower model (ULg)
-24	Comparison of IKE psychrometric routines with ASHRAE routines (IKE)
-25	Thermodynamic properties of humid air (ETHZ)
-26	Vapor-compression-system analysis (14th chapter of "refrigeration and air conditioning" STOECKER)
AN10-850610-02	Air-to-water heat pump - simple simulation model (ETHZ)
AN10-850627-01	Specification for the routines to calculate the thermodynamic properties of moist air (IKE)
AN10-850720-01	Radiator (IKE)
AN10-850720-14	Radiator : Addendum (IKE)
AN10-851023-15	A steady state mathematical simulation model for air-to-water heat pumps (ETHZ)
AN10-851023-16	Panel heating and cooling systems (AE)
-17	Hydraulic model for 3-way mixing valves (VTT)
-18	Hydraulic model for bypass valves and differential pressure control valves (VTT)
-19	Hydraulic model of thermostatic valves (VTT)
-20	Boiler specifications (ULg)
-21	A model for an oil boiler with domestic hot water heat exchanger (VTT)
-22	Determination of the properties of humied air (TNO)
-23	CATS subroutines computer subprogrms for calculation of thermodynamic properties of moist air (ASHRAE)

-24	Air-to-air heat recovery systems (VTT)
-25	Comments on HVAC rotation regenerator (TNO)
-26	Models for variable speed centrifugal chillers-abstract (ULg)
AN10-851212-01	Comments on the IKE's radiator specifications (ULg)
AN10-860326-01	Radiator : steady-state model (IKE)
AN10-860409-13	Response to the comment concerning the model of an oil boiler with domestic hot water heat exchanger (VTT)
-14	Design of low energy HVAC-systems with a computerized psychrometric chart. A.H.C. VAN PAASSEN. Delft University of Technology.
-15	Description-heat pump model (water to water) (TNO)
-16	Survey of existing mathematical models of the compression heat pumps (TNO)
-17	Computer-aided calculation of the thermodynamic properties of commonly used refrigerants (ETHZ)
-18	Panel heating and cooling systems (draft) (AE)
-19	Lighting devices and occupancy loads (TNO)
AN10-860409-20	Air ducts (RIT)
-21	Introduction to terminal unit modelling in a duct work (Sweden)
-22	A model for an indirect heat recovery device (VTT)
-23	Cooling towers (PT)
-24	Cooling tower (TNO)
AN10-860623-01	Air Ducts (RIT)
AN10-860701-01	Boiler (ULg)
AN10-860704-01	Description of a compression heat pump system (TNO)
AN10-860704-02	Description of a liquid chilling system (TNO)
AN10-860704-03	Description of the cooling tower + 4 appendices (TNO)
AN10-860707-01	Comments on the RIT's air ducts specifications (ULg)
AN10-860731-02	Building specifications (ULg)
AN10-861006-01	Thermostatic valve (IKE)
AN10-861014-02	Component specification : radiator (IKE)
AN10-861022-04	Fans : specification (LUT)
AN10-861022-06	Air-to-water heat pump : technical form (ETHZ)
AN10-861022-07	Comments and questions on the TNO-TPD heat pump model (ETHZ)
AN10-861022-09	Comments on the radiator technical form by IKE (ULg)
AN10-861022-10	Comments on the radiator technical form by IKE (VTT).
AN10-861022-11	Comments on the AE's panel heating and cooling systems specification (ULg)0
AN10-861022-12	Humidifiers : specification (LUT-PT)
AN10-870326-02	Air ducts (RIT)
AN10-870326-04	Heating and cooling coils (OA)
AN10-870326-05	Building (ULg)
AN10-870406-01	Dampers (LUT)
02	Heat recovery devices (VTT)
AN10-870407-01	Humidifiers (LUT)
AN10-870408-01	Air filters (PT)
02	Floor heating panels (PT)
03	Cooling towers (PT)

04	Lighting devices and occupancy (TNO)
05	Heating and cooling coils (OA)
06	Radiator (IKE)
07	Boiler (Ulg)
12	Description of a liquid chilling system (TNO)
13	Models for 3-way mixing valves, by-pass valves and differential pressure control valves (VTT)
AN10-870615-01	Heat transfer and pressure drop characteristics of heating, cooling and dehumidifying coils (ULg)
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02	Comments on the boiler specification from Ulg (IKE)
05	Panel heating and cooling systems (Amazon)
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03	Psychrometrics calculations (TNO)
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AN10-871014-01	Hydraulic networks calculation techniques (VTT)
02	Heat recovery devices (VTT)
AN10-871021-01	Ducts (RIT)
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04	Boiler (ULg)
05	2 pages correction to chiller specification (AN10-870911-01) (TNO)
06	Results of the mini-exercise "pressure drop calculation in a simple duct work" (RIT)
AN10-871023-01	Correction to chiller program (AN10-870911-01) (TNO)
AN10-871103-01	Review of Amazon panel heating by UWM
AN10-871112-01	Review of heat recovery devices by UWM
AN10-871117-01	Flow control devices (VTT)
AN10-871117-02	Heat recovery devices (VTT)
AN10-871124-01	Air to water heat pump (ETHZ)
AN10-871124-02	PSYCHLES. Thermodynamic properties of moist air (ETHZ)
AN10-871127-01	Correction to lighting and occupancy loads (TNO)
AN10-871127-02	Liquid chilling system (TNO)
AN10-871211-01	Fuel oil boiler (ULg)
AN10-871211-02	Building (ULg)
AN10-871214-01	Review of hydraulic networks by UWM
AN10-871214-02	Review of cooling tower by UWM
AN10-871215-01	Fuel oil boiler (ULg)
AN10-871216-01	Building (ULg)
AN10-871217-02	Flow control devices (VTT)
AN10-871222-01	Review of liquid chiling system (ULg)
AN10-871222-02	Review of flow control devices (ULg)
AN10-871223-02	Review of PSYCHLES (ULg)
AN10-880104-01	Floor heating panels (PT)
AN10-880105-01	Review of PT "Air filters" (ULg)
AN10-880108-01	Review of "Liquid Chilling System" (UWM)
AN10-880117-01	Review of "Hydraulic Network" by (ULg)
AN10-880117-02	Review of "Cooling Towers" by (ULg)
AN10-880117-03	Review of "Coils" by (ULG)
AN10-880117-04	Review of PT "Panel Heating" by (ULg)
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AN10-880118-02	Radiator (IKE)
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AN10-880120-02	Review of "Analysis of the Boiler Simulation"	(ULg)
AN10-880120-04	Review of "Floor Heating Panels"	(VTT)
AN10-880122-02	Heat recovery devices	(VTT)
AN10-880126-01	Lighting devices and occupancy loads	
AN10-880126-02	Liquid chilling system	
AN10-880126-03	Liquid chilling system	(TNO)
AN10-880126-04	Liquid chilling system-appendices	(TNO)
AN10-880201-01	Air filters	(PT)
AN10-880201-02	Floor heating panels	(PT)
AN10-880202-01	Thermostatic valve	
AN10-880202-02	Thermostatic valve	(VTT)
AN10-880202-03	Dampers	(LUT)
AN10-880202-04	Humidifiers	(PT, LUT)
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AN10-880204-01	Fuel oil boiler - erratum	(ULg)
AN10-880204-02	Building - erratum	(ULg)
AN10-880204-03	Review of "Heat Recovery Devices"	(ULg)
AN10-880205-02	Summary of Ducts	(RIT)
AN10-880205-04	Summary of Piping	(RIT)
AN10-880212-01	Coils	(OA)
AN10-880208-05	Flow control devices	(VTT)
AN10-880208-06	Review of "Network Simulation and Building Specification" L. LARET	(CSTB)

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LA CHAUMIERE EXERCISES

SPECIFICATIONS.

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AN10-820210-02	"La Chaumière" (EMPA)
AN10-821015-01	Reporting format "La Chaumière" (EMPA)
AN10-830511-01	Specifications of the data for the exercise 1a on "La Chaumière" building (IKE)
AN10-830615-01	Revised specifications for the exercise 1 a : Simulation of the heating plant (EMPA)
AN10-830615-02	Revised specifications for the magnetic tape data for "La Chaumière" for exercises 1.4. (EMPA)
AN10-830701-02	Extract from " La Chaumière " final report (N°82-05-01)(Ecole Polytechnique Fédérale de Lausanne). Chapter V, Heating Plant
AN10-830701-01	Comments on exercise 1 b (IKE)
AN10-830901-01	Specifications for the exercise 1 b :simulation of a section of the heat distribution system (EMPA)
AN10-831115-01	Problem concerning Exercices 1a and 1c (EMPA)
AN10-831129-02	Remarks and comments on the specifications for the exercises on La Chaumière (ULg)
AN10-831220-01	Answers to remarks and comments on the specifications (EMPA)
AN10-840117-01	Correction to the answer of the questions sent in December 83 (EMPA)
AN10-840117-02	Measurements (EMPA)
AN10-840209-01	Letter from ULg : concerns present simulation exercises
AN10-840220-01	Additional information to the exercise 1 b (linear heat loss coefficients) (EMPA)
AN10-840220-02	Recapitulations of Ex. 1a, 1b and 1c (EMPA)
AN10-840220-03	Ex. 2 on La Chaumière building (EMPA)
AN10-840301-01	Prospectus of the new boiler
AN10-840301-02	Copy of a letter of Mazza + answer
AN10-840301-03	A correction of the document circulated (17/01/84)
AN10-840306-01	Letter from IKE with a few comments about the exercises
AN10-840328-01	Letter from IKE with the last values for the Ex. 3
AN10-840412-01	One sheet given an example of a NSHD provided by EMPA
AN10-840905-01	Exercise 2.5.: modern boiler with variable boiler temperature. Exercise 3.0.: simulation of the system coupled with the building using different control hypotheses (IKE)
AN10-840906-01	Exercises 2.5. and 3.0. : more information (IKE)

AN10-850109-01	Specification of exercise 3 "Simulation of the system coupled with the house" (IKE)
AN10-850121-01	Questions about the proposal for the specifications of exercise 3 (ULg)
AN10-850116-01	Ex. 3.9.-3.12. - Set point temperature of the thermostatic valve (IKE)
AN10-850205-01	Comments to the questions from LPB concerning exercise 3 (IKE/EMPA)
AN10-850311-01	Concerning heat emissions from pipes, La Chaumière (RIT)
AN10-850326-01	Proposal for hydraulic network simulations (VTT)
AN10-850410-05	Proposition - heat pump exercises La Chaumière (ETHZ)
AN10-850506-01	Comments to the heat pump exercise (IKE)
AN10-850610-01	Heat pump exercises on "La Chaumière" building (ETHZ)
AN10-850710-01	Heat pump exercise - complementary specification (EMPA)
AN10-851023-07	Exercise specifications - hydraulic calculation. proposals for further exercises (VTT)
AN10-851023-06	Heat pump ex. - Corrigenda (ETHZ)
AN10-851118-01	Heat pump ex. - Reviewed Specifications (ETHZ)
AN10-851209-02	Specifications of a new simplified dynamic multizone model (ULg)
AN10-860106-01	Heat pump exercise complements (ETHZ)
AN10-860409-06	Updated proposal for ex. 5 (VTT)
AN10-860609-01	New exercices 4.4.1/2/..9 on Heat Pump (ETHZ)
AN10-870326-01	Specification of exercise 5 on the "La Chaumière"building (VTT).
AN10-870828-01	Redefinition of Exercise 5.3. on the "La Chaumiere" building (VTT)
AN10-870910-03	Comments on exercise 5..3 (IKE)

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LA CHAUMIERE EXERCISES

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AN10-830706-01	Report on the exercise 1 a (IKE)
AN10-830901-02	Report on the exercise 1 a (EMPA)
AN10-831012-01	Report on the exercise 1 a (ULg)
AN10-831020-05	Report on the exercise 1 a (RIT)
AN10-831020-04	Analysis of exercise 1 a (EMPA)
AN10-831020-01	Report on exercise 1 b (ULg)
AN10-831020-03	Report on exercise 1 b (IKE)
AN10-831020-07	Draft report on exercise 1 b (RIT)
AN10-831020-06	Dynamic simulation of heating systems (ARUP)
AN10-840329-01	Report on the Ex. 1a, 1b and 1c (ULg)
AN10-840329-02	Partial results of Ex. 3 (ULg)
AN10-840323-01	Report on Ex. 1a (IKE)
AN10-840323-02	idem Ex. 2 (IKE)
AN10-840330-01	idem Ex. 1 b (IKE)
AN10-840330-02	idem Ex. 1 c (IKE)
AN10-840330-03	Comments to the building simplified model (IKE)
AN10-840411-01	Report on Ex. 1 a, 1 c and 2 (EMPA) + 1 sheet concerning the input data of Ex. 2 + 1 sheet concerning the results of Ex. 2
AN10-840411-02	Report on the Ex. 1 b (EMPA)
AN10-840411-03	idem Ex. 1 a (RIT)
AN10-840411-05	idem Ex. 1 a, 2.0., 2.1., 2.1.(PT)
AN10-840411-06	Results for La Chaumière - Ex. 1 a analysis (ABACUS)
AN10-840411-07	A summary description of the ESP wet central heating model (ABACUS)
AN10-840411-08	Results of the Ex. 2 (ULg)
AN10-840411-09	idem Ex. 1c : simulations of the heat distribution system and of the boiler with the curve $Q_{cons} = f(Q_u)$ (ULg)
AN10-840411-10	Report on the Ex. 3 (IKE)
AN10-840528-01	Report on the Ex. 1 b (RIT)
AN10-840528-02	Report on part of the Ex. 1 c (RIT)
AN10-840528-03	Report on the Ex. 2 (RIT)
AN10-840613-01	Complementary results of Ex. 2(ULg)
AN10-840928-01	Results of Ex. 2.5. (ULg)
AN10-841009-01	Report on the Ex. 2.5. (IKE)
AN10-841015-01	Analysis of the boiler simulations (Ex. 2) (EMPA)
AN10-841016-01	Report on Ex. 2 (PT)
AN10-841025-02	Report on Ex. 2.5. (EMPA)
AN10-841026-01	Report on Ex. 2.5. (RIT)
AN10-841105-01	Report on some results concerning Ex. 3.9.-3.10. (RIT)
AN10-841108-06	Activities of Finland in system simulation related to energy behaviour of buildings.
AN10-841108-07	Ex. 2.5. Errata (PT)

AN10-841108-08	Possible savings between Ex. 2.0.-2.5. (EMPA)
AN10-841106-01	Ex. 3.1.-3.8. Results (ULg)
AN10-841108-09	Report on some results concerning Ex. 3.1.-3.7. (RIT)
AN10-841108-10	Report on the Ex.3 (IKE)
AN10-850211-01	Simulation of a hydronic heating system; radiator modelling - paper submitted to Clima 2000 (08/85) (ULg)
AN10-850228-01	Ex.3.1.-3.8.-complementary report (ULg)
AN10-850228-02	Report on exercice 2 (ABACUS)
AN10-850228-03	Analysis of boiler combustion space - additional results - Ex. 2.3. and 2.4. (ABACUS)
AN10-850228-04	Additional simulation results for Ex. 2.5. (ABACUS)
AN10-850228-05	Some comments on the ABACUS - Ex. 2.3.-2.5. results (ABACUS)
AN10-850308-01	Ex. 1b-1c : analysis of the results (ULg)
AN10-850324-02	Insight acquired through the simulation of boilers - paper submitted to Clima 2000 (08/85) (EMPA)
AN10-850326-01	Report on results concerning exercices 3.1.-3.9. (RIT)
AN10-850409-01	Analysis of the boiler simulations - Ex.2 (EMPA)
AN10-850410-01	Hydraulic network simulation on La Chaumière building -preliminary calculations (VTT)
-02	Report on exercice 3 on La Chaumière building (IKE)
-03	Results on exercises 3.1., 3.5., 3.6. and 3.9. on La Chaumière building (ULg)
-29	Figures of exercices 3 on La Chaumière (IKE)
AN10-851023-01	Report of exercise 3 - La Chaumière building (ULg)
-02	Analysis of the results of exercise 3 - La Chaumière building (IKE)
-03	Heat pump exercise (PT)
-04	Heat pump exercise - first results (ULg)
-05	Heat pump exercise - results (EMPA)
-06	Heat pump exercise - corrigenda of the specifications (ETHZ)
-08	Hydraulic network simulation - results of exercise 5.1. (VTT)
AN10-860130-01	Heat pump exercises - results from PT
AN10-860325-01	Heat pump exercises - results from EMPA
AN10-860409-01	Comparison of building models (RIT)
-02	La Chaumière : Ex. 3. - new detailed building simulation model - results (IKE)
-03	La Chaumière - améliorations thermiques et réduction de la consommation d'énergie (EMPA)
-04	Heat pump exercises - preliminary analysis (ETHZ)
-05	Ex. 5.2.1. - stationary heat balance analysis (VTT)
AN10-861008-01	Additional study of the retrofitted "La Chaumière" building with the DOE-2 program (EMPA)
AN10-861016-01	Exercise 5.2.2. : Dynamic heat balance

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COLLINS BUILDING EXERCISES

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AIE-Annex 4 -	Physical definition and measurement program
JLN-840402-01	Description of the full scale experimental HVAC system installed in the LPB-ULg
AN10-840412-04	Proposed first exercises on the Collins Building system
AN10-840709-01	Exercises concerning the modelling of air conditioning systems (Oscar Faber Consulting Engineers)
AN10-840712-02	Appendix to AN10-840709-01(ULg)
AN10-840905-02	New choice of meteorological data for exercises on the Collins Building (EMPA)
AN10-840917-01	Notes on heating and cooling coils and on fan component model (LUT)
AN10-840920-01	Comments to V.HANBY's note AN10-840917-01 (ULg-LPB)
AN10-850107-01	Cooling coil model : Collins building (LUT)
AN10-850220-01	Revised specifications for Ex.1 and 2 (LUT)
AN10-850410-10	General geometrical data (PT)
AN10-850717-01	Air conditioning exercise 3 - specifications (ULg)
AN10-850920-01	Specifications for exercise 4 - plant simulation (LUT)
AN10-851118-02	Air conditioning exercises - Polynomials describing the chiller's catalog performance (ETHZ)
AN10-851209-01	Air conditioning exercise 3 : reviewed specifications (ULg)
AN10-860506-01	Air conditioning exercise 4 : reviewed specifications (LUT)
AN10-870406-04	Proposal : pressure drop calculations in a simple duct work (RIT)
AN10-870611-01	Meteorological periods for exercise 5 on Collins building (ULg)
02	Exercise 5 : proposal of a boiler (ULg)
AN10-870911-04	Chiller proposal- Ex. 5 (TNO)
AN10-871011-01	Collins building ex.5. (LUT)
AN10-871208-01	Ductwork system simulation exercise (LUT)

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AN10-841022-01	Report on Ex. 1a (ULg)
AN10-841108-13	Report on Ex. 1 and 2 on the Collins building (Flakt)
AN10-841108-12	Report on Ex. 1 and 2 on the Collins building (IKE)
AN10-841108-11	Air conditioning Ex. 1 and 2 (PT)
AN10-850324-01	Simulation ex. 1 and 2 on the 3rd floor VAV system of the Collins building (EMPA)
AN10-850410-06	Computer model-cooling coil (IKE)
07	Cooling coil exercises (PT)
08	Cooling coil models-comparison of calculation methods (Ove Arup)
09	Cooling coil exercise-comparisons (LUT)
11	Report on exercise 1 on the Collins building (IKE)
12	Collins building exercises-results of ex. 1 (ULg)
13	Results of the Collins building simulation - exercises 1 and 2 (ABACUS)
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15	Collins simulation exercises 1 and 2 (Ove Arup)
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28	Figures of the Collins building exercises (Ove Arup)
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02	The cooling coil exercise (ULg)
AN10-850709-01	A comparison between the various psychrometric routines (IKE)
AN10-851023-09	Collins building exercises - comparison of Daily Total Energy Requirements of the RLT plant simulation Runs from the various participants (IKE)
10	Collins building - preliminary results on exercise 2.2 (RIT)
11	Collins building - results of exercise 3 (ULg)
12	Results of exercise 3 - Collins building (PT)
13	Parametric study with the DOE-2 program on HVAC system and plants (EMPA)
AN10-860130-02	Air conditioning exercise 3 : results (from PT)
AN10-860227-01	Air conditioning exercise 3 : report (ULg)
AN10-860409-07	Collins simulation exercises 1 and 2 : results (TNO)
08	Results to Ex. 3 (OA)
09	Ex. 3 - results (IKE)
10	Preliminary results on Ex. 3 and 4 (RIT)
11	Analysis of the results on Ex. 3 (PT)

12	Results of Ex. 4 (LUT)
AN10-860610-01	Response to a step of air flow (ULg)
AN10-860704-04	Results of exercise 3 (TNO)
AN10-860710-01	Results of exercise 3 without considering the heat losses of the ducts (IKE)
02	Results of exercise 3 with considering the heat losses of the ducts (IKE)
03	Results of exercise 3.2. (IKE)
AN10-860731-01	Results of exercise 3.2. (ULg)
AN10-861008-02	Revised results of exercise 3 (TNO)
AN10-861008-03	Results of exercise 3.2. (TNO)
AN10-861014-01	Exercise 3. Reviewed simulation-selected results for Sept. 26 (RIT)
AN10-861014-03	Results of exercise 4.0. (IKE)
AN10-861014-04	Results of exercise 4.1. (IKE)
AN10-861014-05	Results of exercise 3.2. (PT)
AN10-861014-06	Analysis of the results of exercise 3.2. obtained by IKE-PT-ULg (PT)
AN10-861014-07	Exercise 3 : comparison of results obtained with different simulation time steps (PT)
AN10-861014-08	Exercise 4a : Temperature response to a step of air flow (RIT)
AN10-861014-09	Exercise 4B : Test of chiller circuit (RIT)
AN10-861022-02	Exercise 4 : Simulation of the air conditioning system (PT)
AN10-861117-01	Additional results of exercise 3.0. (TNO)
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AN10-870406-03	Complementary report on the Collins Building exercise (VTT)
AN10-871022-01	Collins building exercise 3. Analysis of the results (PT)
02	Collins building exercise 3.2. Analysis of the results (PT)
AN10-871127-03	Results of exercise 5.0. (TNO)
AN10-871227-04	Collins building exercise 5. Simulation results (ULg)
AN10-871223-01	Ductwork system simulation exercise (ULg)
AN10-880104-02	Simulation of the air distribution system coupled with the building (PT)
AN10-880122-01	Synthesis report - Hydraulic Network Simulation "La Chaumière" building (VTT)
AN10-880113-01	Heat pump - Exercices on "La Chaumière". Analysis of the results (EMPA)
AN10-880104-03	Analysis of the boiler - simulations (Exercice 2 on "La Chaumière" building) (EMPA)
AN10-880208-01	System Simulation - Exercise 5 - Simulation of the air distribution system coupled to the building (TNO)
AN10-880208-02	Collins building exercise 5 - Global energy simulation - plant and building (LUT)
AN10-880208-03	Ductwork system exercise - results (LUT)
AN10-880208-0	Results of hydraulic modelling of ductwork (TNO)