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MODELLING AN AIR-CONDITIONNING PLANT WITHIN THE TRNSYS ENVIRONMENT

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Abstract – *In the frame of the world energy crisis observed in the last decade, the task of reducing primary energy resources (gas, oil and fossil fuels) became an essential goal of many countires. The actual preoccupations are focusing on the building sector, which has been shown as a high energy consumer for the whole energy market. Moreover, in the field of HVAC systems equipping the buildings, the air-conditionning systems showed themselves as one of the highest energy consumers. In the light of these assumptions, the scope of the present paper was to calculate the energy consumptions linked to an air-conditionning plant of "all-air" type equipping a commercial store in Oradea, Romania. These calculations were performed by means of numerical simulations with the TRNSYS software, which enabled us to simulate the majority of the building thermal transfers, as well as the air-conditionning and regulation equipments. We used TRNSYS due to its complexity, its continuous development and its conformity with the actual reglementations related to the EPBD (European Performance Building Directive).*

The simulations results suggest some technical measures to be implemented in order to reduce the electrical, heating and cooling consumptions of the air-conditionning plant.

Keywords: air-conditionning, simulation, energy efficiency, component, single-zone

1. Introduction

Directive 2002/91/EC on the energy performance of buildings (the EPBD) [1] requires several different measures to achieve prudent and rational use of energy resources and to reduce the environmental impact of the energy use for buildings. This is to be accomplished by increased energy efficiency in both new and existing buildings. One tool for this will be the application by Member States of minimum requirements on the energy performance of new buildings and for large existing buildings that are subject to major renovation (EPBD Articles 4, 5 and 6). Other tools will be energy certification of buildings (Article 7) and inspection of boilers and air-conditioning systems (Articles 8 and 9).

According to [1], Romania, as a new EU member state from January 2007, has launched national research programs concerning the EPBD. Within one of these research programs (called INFOSOC – Information Society Romanian Project), Technical University of Civil Engineering of Bucharest proposed a

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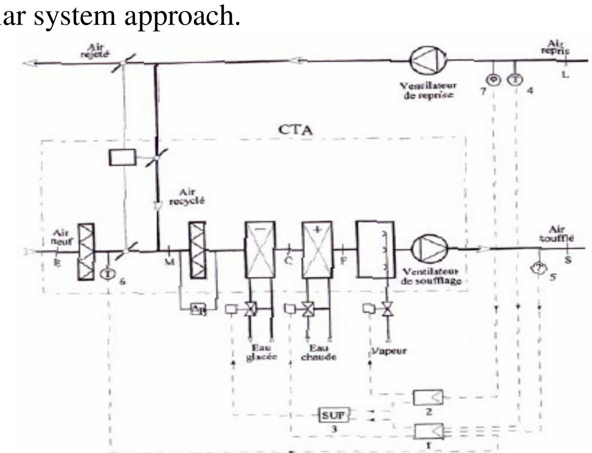
project dealing with simulation of HVAC (i.e. Heating, Ventilation and Air Conditioning) systems energy consumption. In order to realistically answer to these new demands dealing with the energy performance characteristics of the building and its installed equipment, the project is based on dynamic simulation methods. These methodologies become nowadays indispensable elements of thoroughly energetic analysis.

We present in this paper some of the results obtained within this study.

2. Numerical HVAC model

The numerical model for assessing energy consumption of HVAC systems is developed using of HVAC systems is developed using energy simulation program TRNSYS (TRaNsient System Simulation Program) [2]. This code is one of the most flexible tools available dealing with energy simulation applications due to its modular system approach.



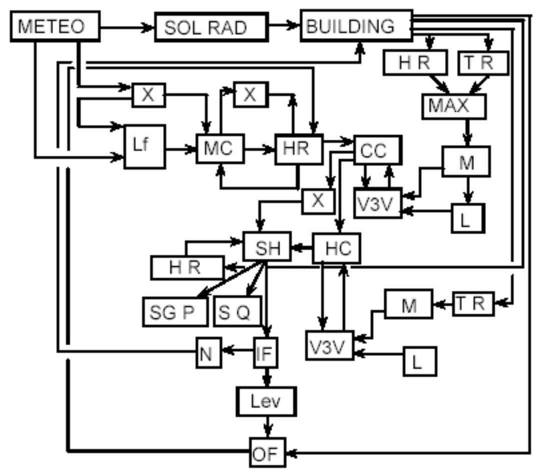
1 – temperature controller (Type P or PID)
2 – humidity controller (Type P or PID)
3 - signal comparator
4 – indoor temperature sensor
5 - temperature sensor for air supply
6 - temperature sensor for outdoor temperature
7 – indoor humidity sensor

Fig. 1 HVAC system scheme

TRNSYS include a graphical interface, a simulation engine, and a library of components that range from various building models to standard HVAC equipment to renewable energy and emerging technologies. TRNSYS also includes a method for creating new components that do not exist in the standard package. Each component is really a FORTRAN source code model. This simulation package has been used for more than 25 years for HVAC analysis and sizing, multizone airflow analyses, electric power simulation, solar design, building thermal performance, analysis of control schemes, etc.

The numerical model presented in this work is carried out for a single-zone usual HVAC system (constant air volume), fig. 1.

This numerical model consists of a total of 30 main components (fig. 2), including the specific components for the building and climatic data (temperature, humidity, solar radiation, etc.).



METEO – weather component

SOL RAD – solar radiation component
BUILDING – building description component
H R, T R – humidity, temperature regulator
X – psychometric component
Lf – fresh air flow rate calculation
L – water flow rate regulation component
MC – mixing chamber
HR – heat recovery unit
CC – cooling coil

M – command for three way vane
V3V - three way vane for heating and cooling coil
HC – heating coil
SH – steam humidifier
SG P – steam humidifier power calculation
SQ – steam (water) flow rate
N – air changes per hour calculation
IF – inlet fan
OF – outlet fan
Lev – exhaust airflow calculation

Fig. 2 Numerical model: component connections scheme within the model

In order to have a model able to simulate realistic situations of HVAC system functioning performance, we added new components for specific equipments and their regulation.

For instance, we focused on fresh air flow rate modulation, an important feature related to energy consumption of HVAC systems.

As a result, we developed and included in the model a component able to regulate the proportion of fresh air as a function of the external temperature (see fig. 3), this situation being frequently used by HVAC systems.

We focused as well on cooling, heating coil and steam humidifier regulation as the model is able to predict the functioning of HVAC systems aimed to adjust both indoor air temperature and humidity. We briefly present below the main principles of regulation loops, with the mention that we followed the functioning of real regulation systems (controllers and regulators) integrated within HVAC systems.

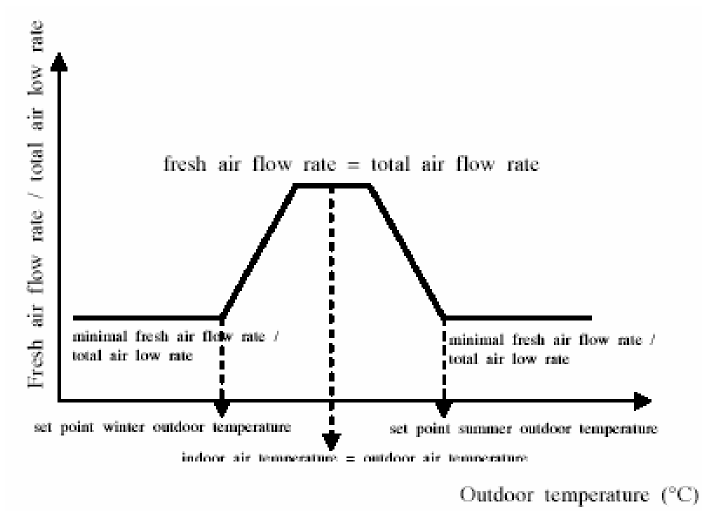


Fig. 3 Fresh air modulation as a function of outdoor temperature

a) Temperature regulation (fig. 4):

Based on indoor air temperature value and set point imposed for the temperature, the temperature controller sends the signal either to the vane control motor to adjust the three way vane position of hot water for the heating coil or to the signal comparator which commands the three way vane of cooled water for the cooling coil.

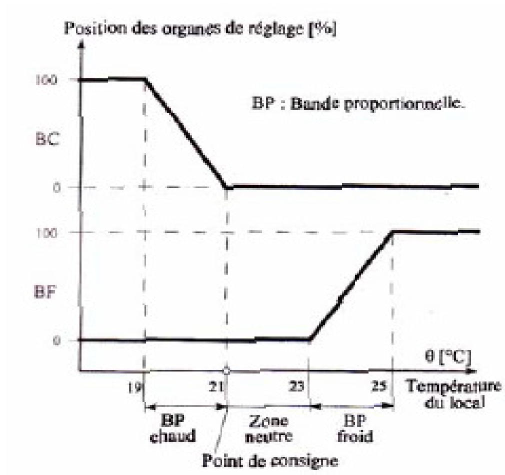


Fig. 4. Temperature regulation

b) Humidity regulation (fig. 5):

Based on relative humidity value of conditioned space (room) and set point defined for the indoor humidity, the humidity controller sends the signal either to the steam humidifier vane or to the signal comparator which commands the three way vane of cooled water for the cooling coil.

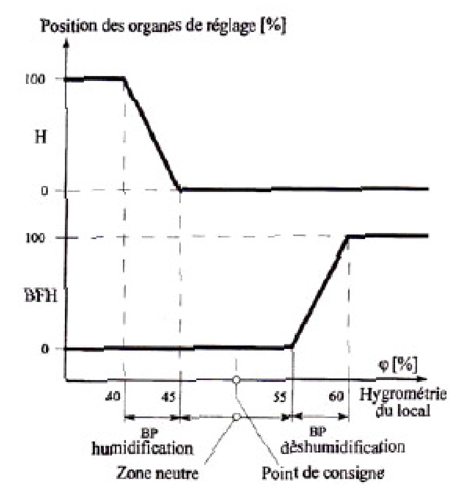


Fig. 5. Humidity regulation

In this manner, the temperature controller and the humidity controller command both the vane of the cooling coil: the first one demands cooling and the second one demands dehumidification. Because of that, we developed and included in our numerical model the signal comparator (a special FORTRAN component added in TRNSYS) which sends out to the three way vane of the cooling coil the greatest demand between cooling and dehumidification. In this way, the cooling coil will react to satisfy the greatest cooling demand (sensible or latent).

This regulation technique can lead to supplementary energy consumptions in summer when it is possible that the cooling coil is demanded for dehumidification and the heating coil is simultaneously demanded for heating (in order to fit the temperature). This is the reason why humidity control is reserved nowadays for special applications where rigorous humidity conditions are imposed.

This does not occur when only the level of indoor temperature is controlled by HVAC system, as it happens for most of installations.

Nevertheless, we introduced this kind of regulation in our numerical model in order to be able to take into account HVAC systems for humidity control, too.

3. HVAC model application

In order to test the numerical model, we considered the HVAC system designed for an office building supposed to be situated in Nancy, France. The conditioned space within the model is supposed to be the last floor of the building.

A. Descriptions of the envelope elements

The geometrical characteristics of the zone are given in Table 1.

Table 1

BUILDING THERMAL ZONE DIMENSIONS

Volume (m^3)	1250
Surface (m^2)	250
Height (m)	5
Ceiling surface (m^2)	250
Floor surface (m^2)	250
South wall surface (m^2)	235
North wall surface (m^2)	235
East wall surface (m^2)	20
West wall surface (m^2)	20
South window surface (m^2)	15
North window surface (m^2)	15
East window surface (m^2)	5
West window surface (m^2)	5

The wall thermal characteristics (opaque elements) are shown in Table 2, with the mention that the thermophysical properties of construction materials are calculated according to [3, 4].

The properties (thermal and optical) for transparent components (windows and glazing) are shown in Table 3 [5, 6]. South façade is provided with external shading devices.

Table 2

THERMAL CONDUCTANCE OF WALLS

Wall	Conductance, U-value (W/m^2K)
Vertical wall	0,473
Roof	0,280
Floor	0,382

Table 3

THERMAL AND OPTICAL PROPERTIES OF WINDOWS AND SHADING DEVICE

Type of glazing	double glazing (4/16/4) with krypton
U-value (W/m^2K)	1,1
g-value	0,598
ratio of frame area/ window area	0,15
solar absorptance of frame	0,6
shading factor (south façade)	0,5

B. Internal heat gains

The occupancy of the zone is defined as shown in Table IV, taken into account that the total number of persons (seated) is 40 (the occupied space density per person is 6,25 m^2). The metabolic heat rate of seated persons is considered according to [7].

Other gains are office equipments and lighting, with similar scenarios as those in Table IV. The total heat gain from computers, printers, photocopiers and other equipments inside the zone taken into account is estimated at 4600 W (18,4 W/m^2). The lighting level is 5 W/m^2.

Table 4

OCCUPANCY AND VACANCY RATES SCENARIO

Hour	Occupancy rate (%)
0 - 8.	0
8 - 18	100
18 - 24	0

C. Climatic data

Boundary conditions are the hourly values of the climatic data defined in the meteorological file for the city of Nancy. The climatic inputs are: ambient temperature, relative ambient temperature, fictive sky temperature, incident solar radiation and its angle of incidence.

D. HVAC system modeling

As shown in Fig. 1, the HVAC system taken into account in this work is constant air volume central air conditioning system for a single-zone. The components of the air handling unit modelled to determine the energy consumption are:

- *mixing chamber* with the possibility to adjust the fresh air flow rate and recirculated air flow rate as mentioned above (see Fig. 3).

- *cooling coil* with detailed description of its parameters (number of rows and number of tubes, outside and inside tube diameter, tube thermal conductivity, fin thickness, fin spacing; number of fins, fin thermal conductivity, tube spacing, etc.) and detailed regulation scheme with controller and signal comparator (see Figs. 4 and 5); the cooling coil model allows also to determine the dry and wet parts of the heat exchanger.

- *heating coil* (introduced as common heat exchanger, using its effectiveness) and detailed regulation scheme with controller (see Fig. 4).

- *steam humidifier*, we developed and included special components for this equipment to determine energy consumption for steam production and regulation (considered level of inlet water temperature: 15°C)

-*inlet and outlet fan* to estimate the energy consumption for airflow.

- *heat recovery unit* (rotating heat exchanger); modelling of this equipment allows extended energy consumption calculations for modern and efficient HVAC systems; this allows us to assess energy efficiency of air conditioning systems with heat recovery units.

4. Results

Several simulations were carried out for winter and summer conditions. Indoor conditions were set as follows:

- temperature 25°C (summer) and 20°C (winter)
- relative humidity: 50% (summer and winter)

We present here the results achieved for summer (more precisely for a period of 31 days – month of July).

We show in Fig. 6 the evolution of indoor and outdoor temperature for 2 air changes per hour as ventilation rate (meaning an air flow rate of 2500 m^3/h).

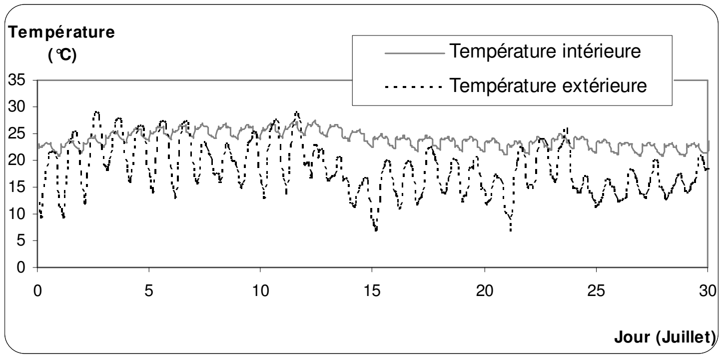


Fig. 6. Daily evolution of indoor and outdoor temperature

We can observe that the temperature set point is well reached meaning that the numerical model is able to correctly predict the complex functioning of HVAC system and its regulation.

As we focused within our numerical model on regulation aspects, we followed the behaviour of our regulation model components. In Fig. 7 is shown the mixing rate between the flow rate of chilled water (coming from the chiller with an imposed temperature of 7°C) and the flow rate of recirculated chilled water (see Fig. 1 – three way vane of cooling coil).

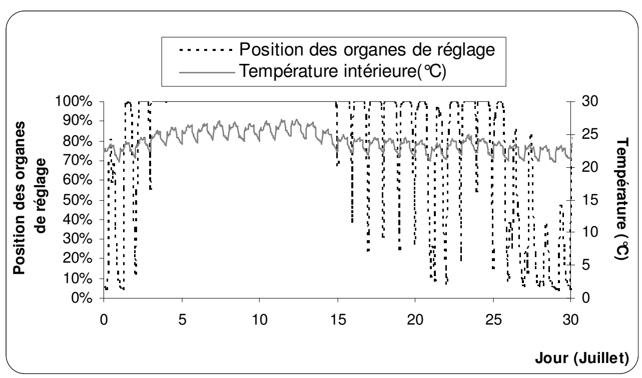


Fig. 7. Mixing rate “chilled water / cooling coil outlet water” as a function of indoor air temperature

We see that the regulation responds well as we notice that the flow rate of chilled water coming direct from the chiller (with temperature 7°C) is maximum when the air temperature reached the set point and the same flow rate goes down when the air temperature is below the set point.

We compared also energetic consumption for cooling, using different air flow rates and HVAC systems with or without recovery heat units, different building locations, etc. Some of the results are grouped in Table V.

Table 5

ENERGETIC CONSUMPTION FOR COOLING AIR SUPPLY

Case	HVAC system energy consumption (kWh)	Energy consumption per m^2 of building floor area (kWh/m^2)
1*	246,21	0,98
2**	286,37	1,14
3***	362,67	1,45
4****	526,25	2,10

*Air supply flow rate: 1250 m3/h; Heat recovery unit: Yes; Building location: Nancy
** Air supply flow rate: 2500 m3/h; Heat recovery unit: Yes; Building location: Nancy
*** Air supply flow rate: 2500 m3/h; Heat recovery unit: No; Building location: Nancy
****Air supply flow rate: 2500 m3/h; Heat recovery unit: Yes; Building location: Ajaccio

The values of Table V lead to interesting discussions. We notice that the heat recovery unit can help to save important amount of energy: up to 20% if we take into account the results for cases 2 and 3. In addition, the energetic consumption with heat recovery exchanger is almost equal to energetic consumption without heat recovery unit even if we doubled the air supply flow rates. This founding is extremely important as increased air supply flow rates mean better airflow inside buildings, improving the ventilation.

We observe also that changing the building location, from North-East of France to Ajaccio, leads to almost doubling the energy consumption for cooling air supply.

5. Conclusion and perspectives

The results issued from this study show that our numerical approach is an useful tool for dynamic energy consumptions analysis regarding the performance of air conditioning systems. We mention that within our research we developed similar numerical models for other kinds of HVAC systems (e.g. fan coil systems).

It is worthwhile to mention also that numerical results will be compared with experimental data obtained by the means of a BEMS (Building Energy Management System) unit for a real building in the next phase of this research.

The numerical model presented here will be improved by adding components for hot water supply systems (boilers) and chilled water supply systems (chillers) for HVAC installations.

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