A SIMPLE COMPUTER CODE FOR ESTIMATING ENERGY LOAD IN BUILDINGS AS RESULT OF MECHANICAL VENTILATION

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Abstract

Mechanical ventilation in buildings requires appropriate systems for heating and cooling. The costs of energy demand represent a high percentage of the global costs for climatisation. As a part of a project concerning these subjects the development of a computer code for evaluating energy load due to mechani d ventilation in buildings is in progress.
The mathematical model is based on s nplified equations to fit dynamically the psychometric curves. Inlet air flow rates are evaluated according to the more recent Italian regulations.
Energy amounts are calculated at hourly time-step taking into account time dependent operating conditions chosen by users such as: set-point temperatures, relative humidity, ventilation rates, use and occupancy of the rooms, scheduled time of operation. Meteo test reference years for the main Italian sites are used as default hourly climatic data.

1. Introduction

Within the frame of a research programme co-ordinated by ENEL Spa on air quality in non-industrial buildings, it was necessary to use an instrument for a quick estimation of thermal loads due to external air changes as a function of the expected climate trend, the choices made for running the systems, and the use of rooms. Literature already includes many softwares developed for this purpose, but their use is not always simple for non-expert users and the references to national regulations are not always up-dated. In order to have a product omplying with our requirements, we are developing the "VELA" (Ventilation Load Analysis) code. Reference norms are the Italian ones and in particular refs. (1), (2), (3).

2. The mathematical model

In its present version, the code allows to dynamically estimate, with an hourly calculation cycle, the energy requirement arising from the treatment (heating/cooling and at the same time humidification/de-humidification) of external air by a central system, without taking into account thermal dispersal. Fo the calculation of humid air mass-enthalpy J (J/kg) of the dry air/steam mix, the formulation reported in ref. (4) was chosen, obtained by assuming, as is commonly done, that the value of air enthalpy at 0°C and $101.325*10^3$ Pa pressure, is equal to zero:

$$J = cp_a * T + 2490.7 * 10^3 * X + cp_v * T * X \tag{1}$$

wherein:

X	= air water content (kg/kg)
cp_a, cp_v	= specific air and water heat (J/kg K)
T	= air temperature (°C)

For air water content, the following equation may be adopted which, during the concerned interval, approaches the values that can be obtained from the psychometric curves, ref. (5), having fixed temperature a' ...midity values:

$$X = U * 3.59 * 10^{-3} * \exp(0.0684 * T) / 100 \quad (2)$$

wherein U is the relative humidity.
Considering the subscripts i, e and r referred to internal, external and recirculating air respectively, the thermal load E (J) for the simulation period is determined as

$$E = \int_{1}^{2} (M_i \cdot J_i - M_e \cdot J_e - M_r \cdot J_r) dt \quad (3)$$

Heating and humidification during winter and cooling and de-humidification during summer are the only air treatments taken into account.
The mass of internal air M_i (kg/s) treated during the time unit is expressed as

$$M_i = \rho * Q_o \quad (4)$$

ρ = air density (kg/m^3)
Q_o = air flow to be treated during the time unit (m^3/s)

In the field of air conditioning both air and steam may be considered as perfect gases and therefore for dry air, one obtains

$$\rho = 10333 / (29.27 * (T + 273.15)) \quad (5)$$

The air flow Q_o to be heated or cooled is calculated as follows:

$$Q_o = c_l * Q_{op} * N \quad (6)$$

wherein
c_l = altitude correction coefficient
Q_{op} = specific air flow per person (m^3/s)
N = reference crowding for design purposes

The correction coefficient c_l is obtained by linear interpolation of the values of Table (1)

Table 1. Values of altitude correction coefficient

Altitude a.s.l. (m)	c_l coefficient
0	1.00
500	1.06
1000	1.12
1500	1.18
2000	1.25

Lacking certain data on the N number of people permanently present in rooms, the following relation may be used:

$$N = N_s * S \quad (7)$$

N_s = crowding index per surface unit ($1/m^2$)
S = useful floor surface (m^2)

The surface S is estimated considering a conventional occupied volume V (m^3) as a room portion defined by the following surfaces:

- floor;
- a horizontal surface placed at a height of 1.80 m above the floor;
- vertical surfaces places at a distance of 0,60 m from each of the room walls or the apparatuses for environment climatisation

The values of Q_{op} and N_s (number of people present for design purposes per each square meter of useful floor surface) may markedly differ, according to the use destination of rooms. Table (2) shows some reference values:

Table 2. Reference values of specific air flow per person and crowding index

TYPE	Q_{op} ($10^{-3}m^3/s$)	N_s ($1/m^2$)
Individual offices	11	0.06
Open space offices	11	0.12
EDP centres	7	0.08
Meeting rooms(+)	10	0.60
Reading rooms-libraries(+)	5.5	0.30
Museums(+)	6	0.30
Living rooms, bedrooms	11	0.04

For rooms to be used for public entertainment or meetings, marked by (+) in the Table (2), instead of Q_{op} the Q_{ope} real flow is utilised, obtained as follows:

if $V / N \leq 15$ then $Q_{ope} = Q_{op}$ (8a)
else if $V / N \geq 45$ then $Q_{ope} = Q_{opmin}$ (8b)

wherein Q_{opemin} is the minimum air flow allowed, calculated according to the following Table (3):

Table 3. Values of minimum air flow allowed

Q_{op} ($10^{-3}m^3/s$)			Q_{opmin} ($10^{-3}m^3/s$)
up	to	7	4
7	to	10	5,5
10	to	12.5	7
over		12.5	8,5

Lastly, if $15 < V/N \leq 45$ one obtains

$$Q_{ope} = Q_{op} + ((Q_{opmin} - Q_{op}) / 30) * (-15 + V / N) \quad (8c)$$

3. Code use

The computer code is written in MS Visual Basic™ language and is composed of some masks with curtain menus for input preparation and for the graphic visualisation of the results. The following input data are required:

- Choice of a simulation site from a database of the standard years of the main Italian sites; utilised data include relative humidity, hourly temperatures and site altitude.
- Surfaces of rooms to be conditioned and their use destination, room crowding. According to use destination and expected crowding, the air flows are calculated in different manners. As an alternative to crowding data, already tabled indexes are proposed. These calculations are carried out according to what is provided by ref. (1).
- Subdivision of the period to be simulated into one or more heating, cooling or in-between season periods. The chosen minimum duration of each period must correspond to a week. Periods provided by ref. (3) are proposed by default depending on the climate zone of the site.
- For each period so determined the standard week must be defined, namely for each days of the week one must specify the hours when the system is running, which hours need not being consecutive, in relation with the particular needs of users.
- Choice of the temperature and relative humidity to be achieved by external air to be treated during heating or cooling periods.

When all of the required data have been defined, it is possible to start the computation phase or review and modify any defined input parameter, also by means of the use of a printout of the whole of the selected data and the diagrams of meteo data of the concerned site.

As output, the code provides in form of diagrams and tables, for the different use destinations and the various periods, the energy requirements of air treatment systems for heating, cooling and humidifying rooms. Data are recorded every hour and the possible visualisations range from those of daily trends to those concerning the whole year. Heating and cooling requirements as well as sensible and latent energy loads may be visualised also separately. For the purposes of the work session, the case can be filed and added to a reference database. Filed cases may be consulted quickly, as a short description is associated to the file name, and input data of the stored file may be utilised for new simulations, making therefore the loading phase easier.

4. Application example

The simulation concerned the computation of the thermal load of a central system, due to sensible and latent heat. Two identical buildings were chosen in Rome and in Milan. For the definition of running limits of thermal systems in winter, reference has been made to DPR 26 August 1993 no. 412, ref. (3). Input data are shown in the Table (4).

As the specific heat of dry air at the atmospheric pressure of $101.325 \cdot 10^3$ Pa in the temperature interval from -40°C to 80°C ranges between 998.3 ÷ 1021.4 (J/kg K), a cp_a value equal to 1004,6 (J/kg K) was assumed. As specific heat of steam cp_v, the constant value 1925.6 (J/kg K) was adopted. Internal air recirculation is not considered.

In the calculation of the specific air flow per person Q_{op} and the reference crowding N, Eqs (7) and (8a) were used, as the $V/N \leq 15$ condition had taken place.

Diagrams show some results of the simulation. In particular, Figs. (1) and (2) show the monthly average temperature and relative humidity of external air for the two sites being examined. Thermal load trends for the various months of the year are shown in Fig. (3). It is possible to distinguish the heating, cooling and in-between season periods during which the system is not running.

Table 4. List of input data

Site	Milan and Rome
Surface assigned to offices	30 modules of 20 m^2
Surface assigned to meeting rooms	200 m^2
Surface assigned to EDP centres	100 m^2
Surface assigned to libraries	100 m^2
Room crowding	as per UNI 10339
Days of use of the system	Monday to Friday
Hours of working of the system	6:00a.m. to 7:00 p.m.
Winter and summer temperature set-point	22°C and 24°C
Winter and summer relative humidity set-point	50%
Duration of simulation	yearly
Duration of heating period	Milan: 15/10 - 15/4 Rome: 1/11 - 15/4
Duration of cooling period	15/6 - 15/9

5. Conclusions

The "VELA" code for the computation of energy consumption of HVAC systems in non-industrial buildings has been shortly summarised. In this first version the enthalpy differences ensuing from ventilation and humidification/de-humidification of external air are considered according to the Italian regulations in force. Further implementations shall concern the refinement of the evaluation of energy contributions, taking into account contributions such as the power required by fans and conditioning terminal units, the presence of possible heat recuperators, etc.

References

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