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COMPUTER PACKAGE FOR CALCULATION OF ENERGY SAVINGS IN NONRESIDENTAL BUILDINGS

Abstract. As non-residental buildings differs in their thermal behaviour from residental one, the separate computer package is developed. In this paper theoretical bases of this package are given together with flow charts and main equations used in it.

NOMENCLATURE

Quantities

A - Area of flow passage, m^2
C - Coefficient of resistance,-
C - Price, \$/J,
c - Specific heat capacity, J/(kg.K)
D - Outside diameter of pipe, m
d - Inside diameter of pipe, m
e - Emissivity of thermal radiation,-
F - Area, m^2
(F K) - Nominal overall conductance, W/m
h - High of room, m
K - Overall conductance, $W/(m^2)$
k - Thermal conductivity, W/(m.K)
L - Lenght of pipe, m
M - Money per year, \$/year
m - Mass rate, kg/s
N - number
P - nominal power, W
p - pressure, N/m^2, percentage, %
Q - Heat, energy, J
Q - Heat flux, power, W
R - Payback period, year
R - Resistance to air flow, $N.s^2/(m^8)$
r - density of air, kg/m^3

T - temperature, K
V - Volume rate, m^3/s
U - Funds, $
x - Insulation thickness, m

Indices

A - Area of passage, air
af - Air flow
b - Buoyancy
c - Ceiling
dr - Drayer
ds - Design
e - Electrical energy
ea - Energy auditing
eu - Efficient usage
ew - Outside wall
f - Fluid, floor
f1 - Fan 1
f2 - Fan 2
g - Gained
ht - Heater
i - Index of outside temperature
i - Investment
ic - Insulated pipe
in - in
ip - Insulated plane surface
j - Index of room
k - Index of flow passage
ka - Interest
L - Load
l - Lost
lt - Lightening
m - Index of air, motor
mat - Material
n - Index of heat transmission
nc - Non-insulated pipe
np - Non-insulated plane
o - Existing building
oe - Outside environment
p - Steam
pl - People
ppo - Latent heat
ppp - Sensible heat
r - Index of space heater

rs - Work
s - Steam, shift
sh - Space heating
t - Total
th - Technology heat
u - Input value
v - Temporal usage
w - Weather, working time
wd - Weekend
wi - Oustide window
y - Year
ys - Year without shift
yw - Year without weekend

1. INTRODUCTION

There is dramatic difference in energy perfomance between residental and non-residental buildings [1]. The same principles of energy conservation in residental buildings do not work for non-residental buildings because of the possible difference in their thermal haviness.

Thermally light building is one whose heating and cooling requirements are proportional to the weather. On the other hand thermally heavy building or space is defined as one whose heating and cooling requirements are nor proportional to the weather.

The procedure for the final selection of investment project for the thermally heavy buildings is given here. This procedure is the same as for the light one, but one can not use shortcats in his energy savings calculations as it was case with these calculations for thermally light buildings. Mean temperatures of heating and cooling periods are not used in these calculations but so-called relationship of average hours frequency of temperature.

This software is developed on the personal computer Spectrum 128 K and execution time is around 25 h when three different investment projects are considered.

2. GENERAL ALGORITHM

General algorithm for selection of energy saving projects is shown in Fig. 1. It can be seen that the program contains four subroutines: a) money savings, b) investment funds, c) evaluation of investment projects and d) ranking of investment projects.

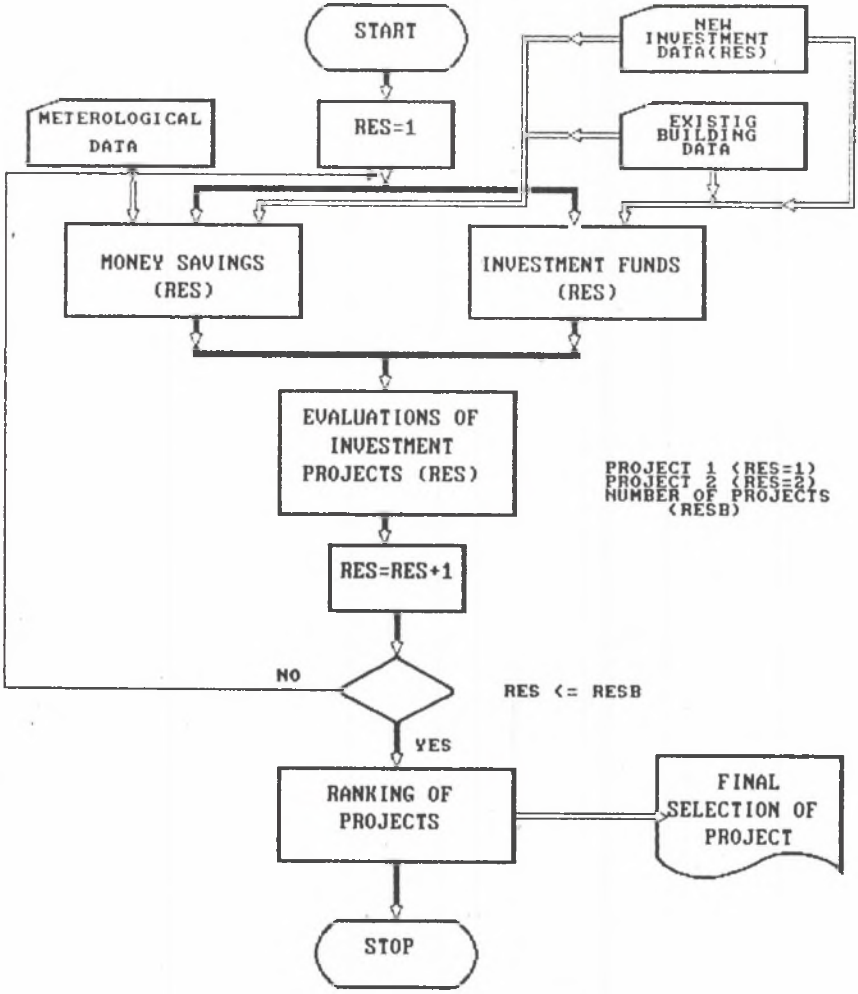

Fig. 1. General algorithm for selection of energy saving project
Rys. 1. Ogólny algorytm projektowania przedsięwzięć oszczędzających energię

If one wants to select an investment project leading to energy savings out of several of them, he should have relevant data for his decision. These data can be obtained through economical evaluations of all investment projects that are planned to be done and than ranking them so the best one can be selected.

To evaluate a particulat "res" investment project the money savings out of energy savings and funds needed for this investment project should be calculated. For these calculation data needed are meterological data, existing building data and new investment data.

2.1. Calculations of money savings

Money saving calculations start (see Fig. 2) with determination of thermal perfomance of existing industrial building. After that one also should predict what thermal perfomance of building will be after some of investment projects are applied.

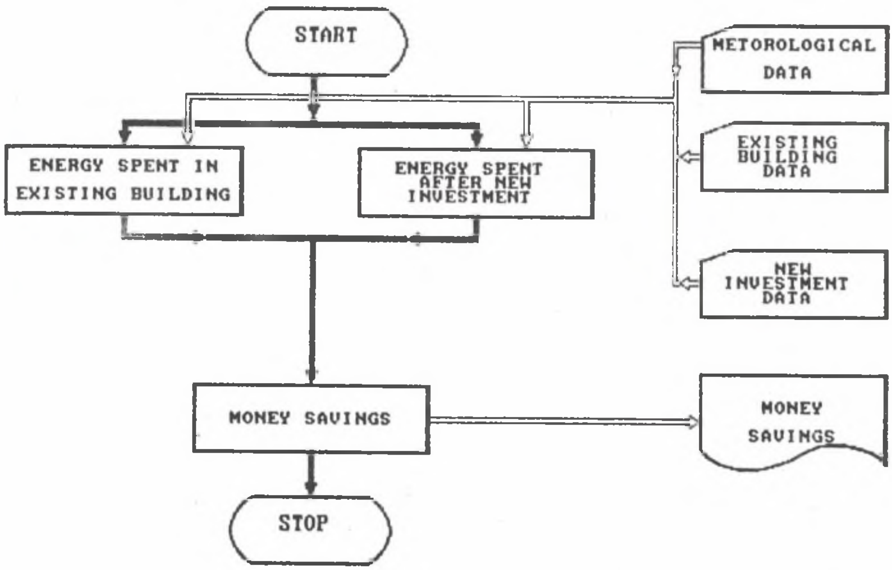

Fig. 2. Algorithm for calculations of money saved per year because of rational energy usage

Rys. 2. Algorytm obliczania rocznych oszczędności pieniężnych wynikających z racjonalizacji użytkowania energii

So thermal perfomances of building before and after applying saving projects are compared and energy savings obtained. Moreover, funds saved on different energies in building during one year are found:

$$(U_s th)_{res} = ((Q_{th})_o - (Q_{th})_{res}) C_{th}/(et_t)_{th} \quad (1)$$

$$(U_s sh)_{res} = ((Q_{sh})_o - (Q_{sh})_{res}) C_{sh}/(et_t)_{sh} \quad (2)$$

$$(U_s e)_{res} = ((Q_e)_o - (Q_e)_{res}) C_e /(et_t)_e \quad (3)$$

Here, index "o" stands for existing building and "res" for building when intended investment project "res" is realized. Index "th" is used for technology heat, "sh" space heating and "e" electrical heat. Quantity et_t is coefficient of efficiency of transfer of energy from the place where it is generated to the place where it is spent, Q particular spent energy and C price of unit of this energy.

Finally, total money saved per year is:

$$(U_s)_{res} = (U_s th)_{res} + (U_s sh)_{res} + (U_s e)_{res} \tag{4}$$

2.2. Investment funds

Investment funds needed for realisation of investment project are:

$$U_{ib} = C_{mat} + C_{rs} + C_{ds} \tag{5}$$

where C_{mat} is price of material, C_{rs} of work and C_{ds} of designing.

It can be written:

$$U_{ib} = C_{mat} (100 + p_{rs} + p_{ds})/100 \tag{6}$$

Here $p_{rs} = 100\ C_{rs}/C_{mat}$ and $p_{ds} = 100\ C_{ds}/C_{mat}$.

Gross investment funds needed are:

$$U_i = U_{ib} + C_{ka} \tag{7}$$

where C_{ka} is price of interest. Here $C_{ka} = p_k\ U_{ib}$ so

$$U_i = U_{ib} (1 + p_k/100) \tag{8}$$

and

$$U_i = C_{mat} (100 + p_{rs} + p_{ds}) (1 + p_k/100) \tag{9}$$

Here, p_{ka} is interest percentage.

2.3. Evaluation of investment projects

Central issue is how to evaluate the economic effectiveness of projects so these effectiveness can be compared.

Payback or payout period method of this evaluation is included in this software.

When one wishes to determine payback period than the number of years required invested capital U_i to be recovered from cash flows during every of years U_s is calculated:

$$R = (U_i + U_{ea})/U_s \tag{10}$$

This formula differs from classical formula because term U_{ea} representing funds required for energy auditing is also taken in account

$$U_{ea} = U_{eac} + N\ p_{sh}\ U_s/100 \tag{11}$$

Here, U_{eac} are funds payed by factory which do not depent on results of auditing, p_s percentage of share in obtained savings and N_y number of years this percentage is taken.

Finally it can be written:

$$R = \frac{U_i + U_{ac} + N_y\ p_{sh}\ U_s/100}{U_s} \tag{12}$$

It is clear that this method has its advantages and disadvantages. Its advantages are the fluidity of an investment is measured and it is commonly used and well understood. Its disadvantages are that it does not measure profitability, neglects life of assets and does not properly consider the time value of money.

There are also other methods for investment evaluation as: investors rate of return, annualized costs, present worth, internal rate of return etc. [2] but this time they are not included in this model.

2.4. Final selection of project

Final selection of project is done on the bases of ranging the projects from max to min payback period. The project with the fastest payback period is choosen as the first investment project to be realized.

3. THERMAL PERFOMANCE OF BUILDING

There is a lot of literature on thermal perfomance calculations of buildings [3, 4, 5].This software package does not use mean heating temperature for these calculations but the relationship between the number of hours t_i that particular outside temperature happens and this temperature $(T_{oe})_i$. This is the reason that the package can be applied for both thermally light and thermally heavy buildings, as well. Here, "i" is index of outside temperature.

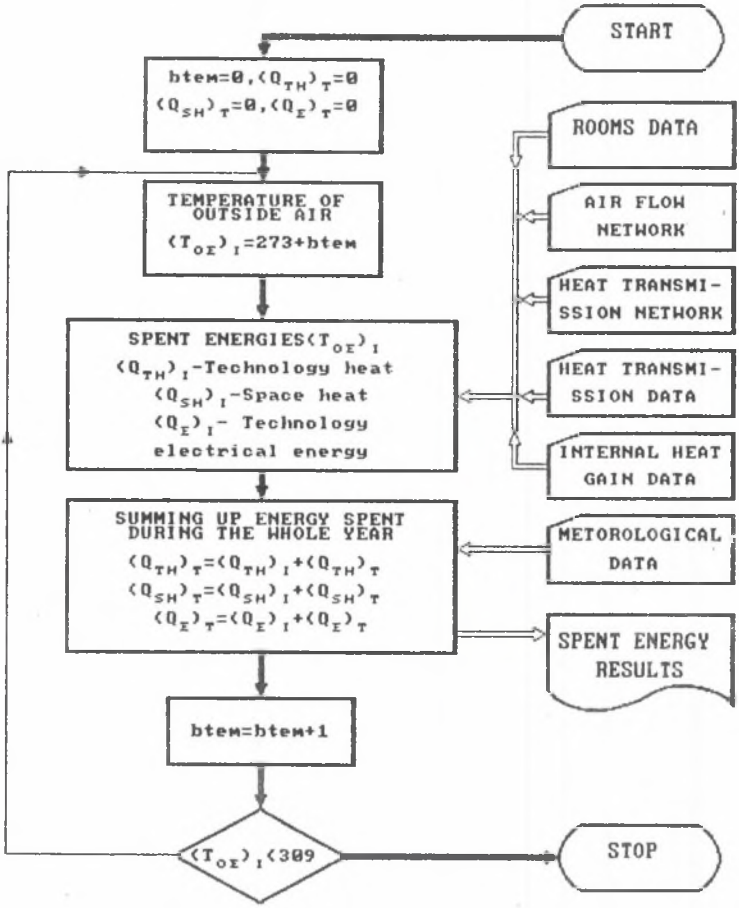

Fig. 3. General routine for calculation of energy spending of a building
Rys. 3. Ogólna procedura obliczania zużycia energii w budynku

Only these meterological data are applied in this model. The solar load data and wind data are not taken into account. It was found that this assumptions and assumptions stated furthermore did not have greater influence on the results of calculations. The difference of these calculations and measurement results of particular building are in the range of measurement errors.

Spent energy in the building is calculated for every of outside temperatures.Calculated energies for "i-th" outside temperature are: technology heat $(Q_{th})_i$, space heating energy $(Q_{sh})_i$ and technology electrical energy $(Q_e)_i$.

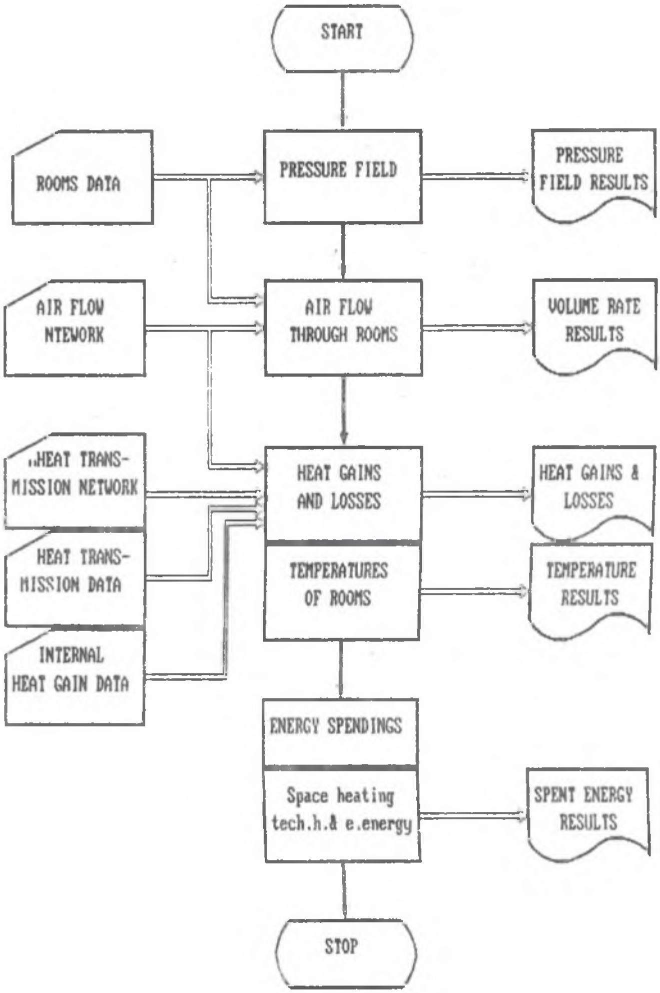

Fig. 4. Flow diagram for thermal performance calculations of some building for one value of outside temperature

Rys. 4. Schemat przepływowy do przeprowadzania obliczeń cieplnych budynku dla określonej wartości temperatury zewnętrznej

These energies are summed up for every of temperatures and total spent energies during one year are obtained as:

$$(Q_{th})_t = \sum_{i=1}^{11} (Q_{th})_i, \quad (Q_{sh})_t = \sum_{i=1}^{11} (Q_{sh})_i, \quad (Q_e)_t = \sum_{i=1}^{11} (Q_e)_i \qquad (13)$$

In Fig. 3, the general routine for these calculations is shown.

When thermal perfomance (spent energies) of building is calculated for some of outside temperatures, firstly, the pressure field is obtained, After that, the volume rates of air in every of rooms are found. Iterative computations of temperatures of rooms will follow evaluation of heat gains and losses. Finally, spent energies are determined. This routine is shown in Fig. 4.

3.1. Pressure field

In this mathematical model pressure field due to buoyancy is calculated via equation:

$$p_b = \left(\sum_{j=1}^{j1} (r_i - r_j)\, g\, h_j + \sum_{j=1}^{j2} (r_i - r_j)\, g\, h_j + \ldots\right)/m \qquad (14)$$

Here, "j" is index of particular room. Number of levels of this building is "m" and "j1" is number of rooms at level 1 and "j2" at level 2. Quantity r is density of air, h hight of room and g gravitational acceleration.

Data on r_j are generated by computed temperatures T_j of rooms and data on h_j are obtained out of room set of data.

The mouth pressures of process fans that are generated by them are designated as: p_{f1}, p_{f2} etc. Their values are obtained eather by measurements during their exploatation or computed out of nominal manufacturer fan data given to the end user.

3.2. Air flow

To simulate air flow through rooms and small holes and openings i.e. passages between these rooms building air flow network is formed with its loops and knots. In Fig. 6 one such a network is shown where small squares present rooms and lines between them are passages. Arrows notify direction of air flow through these rooms and passages.

In this model resistances to air flow are only given by the local resistances of passages. This is done via coefficient of resistance $C_k = 1.5$ [6]. Here, "k" is index of particular passage. It is writen:

$$R_k = r_k\, C_k/(2\, A_k^2) \qquad (15)$$

Here, r_k is density of air at "k"-th air passage and A_k ares of cross-section of passage.

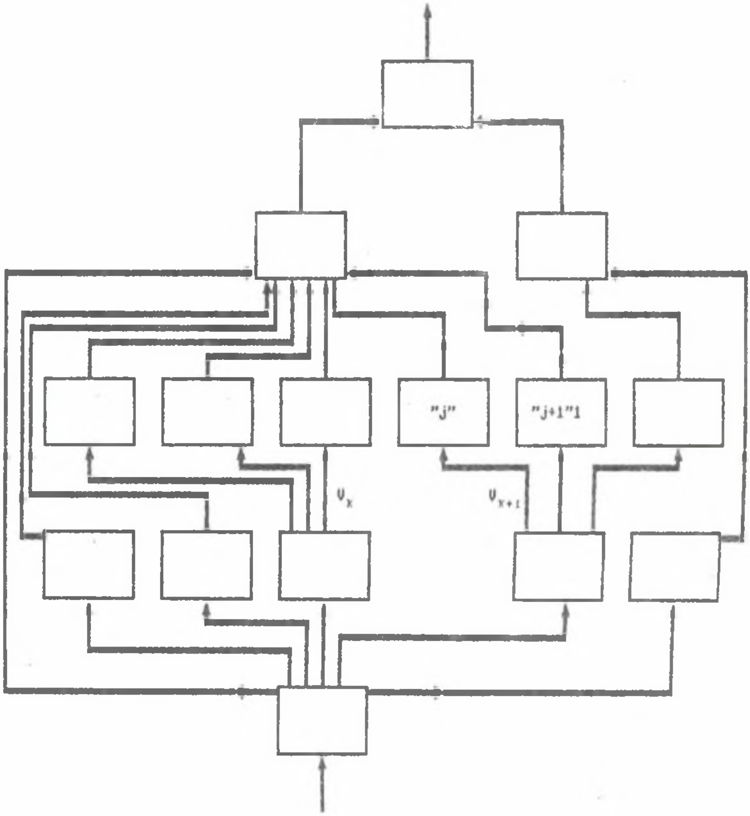

Fig. 5. Air flow network of building
▭ rooms, —— passages

Rys. 5. Sieć przepływu powietrza w budynku
▭ pokoje, —— przejścia

Furthermore, air rates through rooms and passages are found iteratively via Hard-Kros method [6]. For one of the loops it is:

$$(d\ p_{k1}) = \sum_{k=1}^{k1} R_k\ V_k^2 \tag{16}$$

where k1 is number of passages in particular room.

This equation is corrected by:

$$(d\ V_{k1}) = \sum_{k=1}^{k1} R_k\ V_k^2/(\sum_{k=1}^{k1} 2\ R_k\ V_k) \tag{17}$$

until $(d\ p_{k1})$ go to 0 and set of V_j is obtained.

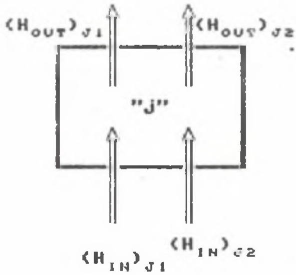

Fig. 6. Air flow and room "j"

Rys. 6. Przepływ powietrza przez pokój "j"

Sets of V_j can be found for different pressure fields. They can be found for buoyancy pressure field V_jb, fan 1 pressure field V_jf1 or fan 2 pressure field V_jf2 etc. They are arithmetically added:

$$V_j = V_jb + V_jf1 + V_jf2 + \dots \qquad (18)$$

It is realized that fluid flow phenomena are not linear but it is tried to make this model simpler for end users.

3.3. Heat gains

There are two kinds of heat gains that are included in this model: technology heat and air-conditioning heat.

Technology heat can be provided by steam, electrical energy, people etc. Air-conditioning heat is provided by space heating and space cooling. Here, until now space cooling and humidity control are not taken care of in this model.

3.3.1. Technology heat

Heat flux out of non-insulated pipe is given as [7, 8]:

$$(Q_{nc})_j = 0.962\ (T_f - T_j)^{1.585}\ (PI)\ D\ L \qquad (19)$$

where T_f is temperature of fluid flowing inside pipe, D outside diameter of pipe and L length of pipe.

Heat flux out of insulated pipe is given as [7]:

$$(Q_{ic})_j = 2\ (PI)\ k\ (T_f - T_j)\ L/\ln\ (D/d) \qquad (20)$$

where k is thermal conductivity and d inside diameter of pipe.

For non-insulated plane surfaces there is [9]:

$$(Q_{np})_j = (1.929\ (T_f - T_j)^{1.25} + 5.67\ e\,((T_f/100)^4 - (T_j/100)^4)) \qquad (21)$$

and for insulated plane surfaces [9]:

$$(Q_{ip})_j = k\ (T_f - T_j)\ F/x \qquad (22)$$

where e is coefficient of emissivity of thermal radiation, F area of plane surface and x insulation thickness.

The steam can be blowed out of machines. Examples of these machines are steam irons, steam presses and steam blowers in garment industry. Than there are:

$$(Q_{ppp})_j = (m_p)_j\ r_{ppp} \qquad (23)$$

$$(Q_{ppo})_j = (m_p)_j\ r_{ppo} \qquad (24)$$

Here, m is mass of steam, r_{ppp} latent heat of steam that is transfer into sensible heat when heat is blowing, r_{ppo} latent heat of steam that is not transfer into sensible heat during blowing, Q_{ppp} sensible heat flux and Q_{ppo} latent heat flux. These latent heats can be found on the bases of theory of isoenthalpic expansion.

Heat flux that is needed dryers to be operated is given as:

$$(Q_{dr})_i = (F\ K)_{dr}\ (T_s - T_i) \qquad (25)$$

Here $(F\ K)_{dr}$ is nominal overall conductance in dryer which can be found from manufacturer data about heater of dryer and its heater fan.

3.3.2. Electrical energy heat

The heat flux obtained out of technology electrical heaters (irons and presses in garment industry) is:

$$Q_{ht} = N_{ht}\ P_{ht}\ (et_v)_{ht} \qquad (26)$$

Here, N_{ht} is number of heaters, P_{ht} power of heater and $(et_v)_{ht}$ coefficient of temporal usage of electrical heater.

Heat flux is dissipated out of electrical motors (sewing machines, fans, etc.). The heat flux is given as:

$$Q_m = N_m\ P_m\ (et_v)_m\ (et_L)_m \qquad (27)$$

where N_m is number, P_m is nominal power, $(et_L)_m$ coefficient of load and $(et_v)_m$ coefficient of efficient usage of electrical motor.

Heat gain flux out of lightning is given as:

$$Q_{lt} = N_{lt}\, P_{lt}\, (et_v)_{lt} \tag{28}$$

where N_{lt} is number and P_{lt} power of particular light bulb.

3.3.3. People

Heat flux transfered from people to room is given by the relationship:

$$Q_{pl} = (F\ K)_{pl}\, (309.15 - T_j)\, N_{pl} \tag{29}$$

where $(F\ K)_{pl}$ is nominal overall conductance out of people to rooms taken to be constant. The value of this term is 5 W/K and calculated from condition that there is heat flux of 80 W on 295 K.

3.4. Space heating

Heat flux used for space heating by hot water in the heaters is obtained by general equation:

$$Q_{sh} = \frac{2\,(T_{wu} - T_j)}{2/(F\ K)_{sh} + 1/(m_A\ c_{pA})sh + 1/(m_w\ c_w)} \tag{30}$$

Here, there is $(F\ K)_{sh}$ nominal overall conductance and $(m_A\ c_{pA})_{sh}$ heat capacity of air taken as constant for particular space heater and obtained out of manufacturers data. Quantity c_w is specific heat capacity of water, m_w mass rate of hot water and T_{wu} temperature of hot water at heater enterance.

With higher T_{oe} temperature T_{wu} is lowered by boyler operator. This is approximated by linear equation:

$$T_{wu} = A - B\ T_{oe} \tag{31}$$

Coefficients of this equations A and B are constant and obtained by this approximation.

Usually there is temperature control in the room. If temperature of the room is higher than the temperature set on the controler than m_w and so Q_{sh} are made lower.

In this model heat gains out of space heating are taken into account only during so-called heating days. They will also not be taken into account when heat gains in the room are enough high so space heating is not necessary the required temperature of the room to be obtained. Also there are such outside temperatures when required heat for particular room is partially obtained by space heating and partially by heat gains.

3.4. Heat losses

There are two kinds of heat lossestaken into account in this mathematical model: 1. air flow heat losses,2. transmission heat losses.

3.4.1. Air flow heat losses

For room "j" we have (see Fig. 6)

$$(Q_{af})_j = (H_{out})_j - (H_{in})_j \tag{32}$$

There is $(H_{out})_j$ is enthalpy rate of ir flow going out of room, $(H_{in})_j$ enthalpy rate of air flow going in rom.

It is:

$$(H_{in})_{jm} = (r_{in})_{jm} (V_{in})_{jm} c_p (T_n)_{jm} \tag{33}$$

$$(H_{out})_{jm} = r_j (V_{out})_{jm} c_p T_j \tag{34}$$

so

$$(H_{in})_j = \sum_m (H_{in})j_m = c_p \sum_m (r_{in})_{jm} (T_{in})_{jm} \tag{35}$$

$$(H_{out})_j = \sum_m (H_{out})_{jm} = r_j c_p T_j \sum_m (V_{out})_{jm} \tag{36}$$

3.4.2. Transmission heat losses

If transmission network of building is used from Fig. 7 than it can be written for room "j" (see Fig. 8):

$$(Q_{tr})_j = (Q_{tr})_{j1} + (Q_{tr})_{j2} + .. + (Q_{tr})_{jn} + ... \tag{37}$$

Since

$$(Q_{tr})_{jn} = (F\ K)_{jn} (T_j - T_{jn}) \tag{38}$$

there is

$$(Q_{trr})_j = \sum_n (F\ K)_{jn} (T_i - T_n) \tag{39}$$

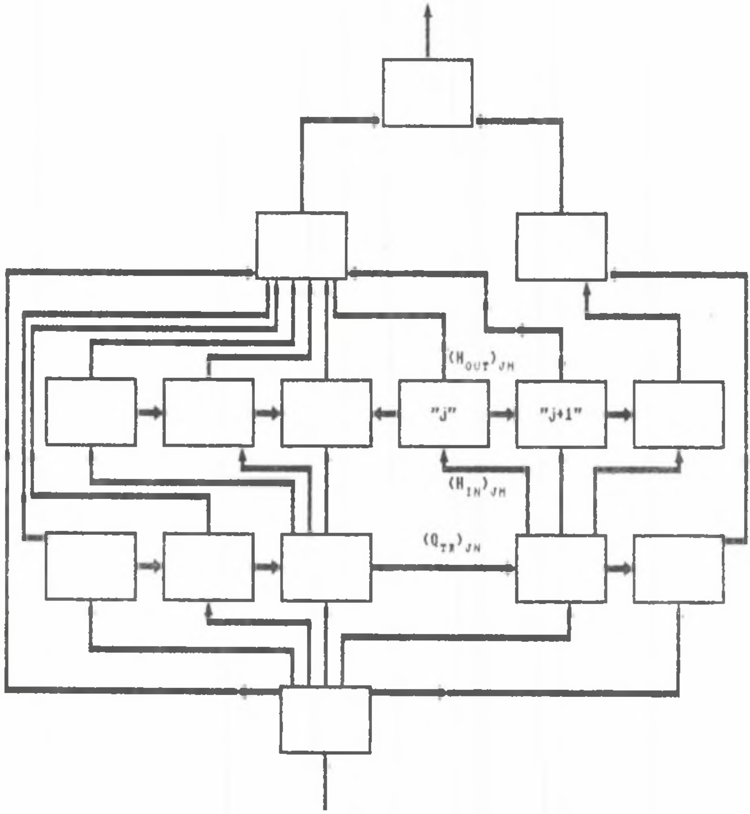

Fig. 7. Transmission network of building
▭ rooms, —— passages
Rys. 7. Sieć przepływowa budynku
▭ pokoje, —— przejścia

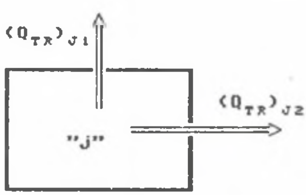

Fig. 8. Transmission heat losses and room "j"
Rys. 8. Przepływowe straty ciepła w pokoju "j"

Quantity "F K" is nominal overall conductance of particular partition between rooms taken in this model to have constant value for all values of temperatures of rooms and all air flow rates through them.

On the other side we have:

$$(Q_{ew})_j = (F\ K)_{ewj}\ (T_j - T_{ew}) \tag{40}$$

$$(Q_c)_j = (F\ K)_{cj}\ (T_j - T_{ew}) \tag{41}$$

$$(Q_f)_j = (F\ K)_{fj}\ (T_j - T_f) \tag{42}$$

$$(Q_{wi})_j = (F\ K)_{wij}\ (T_j - T_{wi}) \tag{43}$$

Here index "ew" stands for outside wall , "c" for ceiling, "f" floor and "wi" outside window.

So finally

$$(Q_{tr})_j = (Q_{trr})_j + (Q_{ew})_j + (Q_c)_j + (Q_f)_j + (Q_{wi})_j \tag{44}$$

3.5. Temperatures of rooms

To calculate temperature of rooms, the energy bilans equation for every of rooms is used:

$$(Q_g)_j = (Q_l)_j \tag{45}$$

where $(Q_g)_j$ is heat gained in particular room "j" and $(Q_l)_j$ heat lost in this room.

It is:

$$(Q_g)_j = (Q_{nc})_j + (Q_{ic})_j + (Q_{np})_j + (Q_{ip}))_j + (Q_{ppp})_j + \\ + (Q_{ht})_j + (Q_m)_j + (Q_{lt})_j + (Q_p)_j + (Q_{shh})_j \tag{46}$$

$$(Q_l)_j = (Q_{af})_j + (Q_{tr})_j \tag{47}$$

Iterative solving of equation (45) gives T_{jj}. Iterative calculations are done for all rooms of building and the temperature distribution in the whole building obtained.

3.6. Energy spending

After temperature distribution of building is obtained for one value of outside temperature for this particular temperature one can calculate technology heat spending:

$$(Q_{th})_i = (Q_{nc} + Q_{ic} + Q_{np} + Q_{ip} + Q_{ppp} + Q_{ppo} + Q_{dr})t_i\ (et_v)_{wt} \tag{48}$$

space heating energy spending

$$(Q_{sh})_i = Q_{sh}\ t_i\ (et_v)_{wt} \tag{49}$$

and electrical energy spending

$$(Q_e)_i = (Q_{ht} + Q_m + Q_{lt})\, t_i\, (et_v)_{wt} \tag{50}$$

Here coefficient of usage of working time is given as:

$$(et_v)_{wt} = et_y\, et_{wd}\, et_s \tag{51}$$

where $et_y = t_{yv/ty}$ is coefficient of vacation during year, t_y = 8760 h, t_{yv} time during year without vacation, $(et)_{wd} = t_{yw}/t_{yv}$ coefficient of weekends, t_{yw} time during year without weekends and vacations, $(et)_s = t_{ys}/t_{yw}$ coefficient of shifts abd t_{ys} working time during year. These coefficients are taken to be constants in this model.

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PAKIET PROGRAMÓW KOMPUTEROWYCH DO OBLICZANIA OSZCZĘDNOŚCI ENERGII W BUDYNKACH NIEMIESZKALNYCH

S t r e s z c z e n i e

Opracowano oryginalny pakiet programów komputerowych dla budynków niemieszkalnych, ponieważ ich charakterystyka cieplna jest odmienna niż w przypadku domów mieszkalnych. W pracy podano podstawy teoretyczne programów zawierające zasadnicze równania wraz z wykresami o postaci sieciowej.

ПАКЕТ ВЫЧИСЛИТЕЛЬНЫХ ПРОГРАММОВ ДЛЯ ОПРЕДЕЛЕНИЯ СБЕРЕЖЕНИЯ ЭНЕРГИИ В НЕЖИЛОЙИХ ДОМАХ

Р е з ю м е

В работе представлено пакет вычислительных программов для нежилойих домов. Эти домы имеют отличную термодинамическую характеристику чем жилойи домы. В работе даны теоретические ооновы программов которые содержают принципиальные уравнения а тоже сетевые диаграммы.