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Dr Habil Eng. H. Koczyk

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ANALYSIS OF HEATING MAINTENANCE PARAMETERS USING THE MATRIX METHOD

H. Koczyk

Introduction

One of the problems related to the calculations of heat transfer in buildings is to answer the question what is the energy requirements for buildings during some chosen periods, e.g., twenty four hours, a week or a year. Such information is to help analyse of long-term heating and cooling demands for building. It may be used for designing energy saving buildings.

The paper presents an application of the matrix method to calculation of heating requirements and parameters of heating maintenance in Annual Cycle Energy Storage.

1. Problem formulation

The question under consideration is heat transfer in a building composed of many zones characterized by different appropriation and maintenance. Axonometry of the heated building is shown in Fig. 1.

The following assumptions have been made:

- walls forming the enclosure are discussed as multilayered plane walls,
- air temperature is assumed to be equal in a zone space,
- heat conduction is considered as being one-dimensional disregarding thermal bridges,
- heat transfer on internal surfaces of the walls takes place with constant heat convection coefficients,
- climatic factors and productiveness of heat sources in zones are periodic time functions with a period equal to 24-hours or a year,
- overall heat-transfer coefficient from water to air in a zone is constant and water mean temperature in heater is an arithmetic mean of supply and return temperatures.

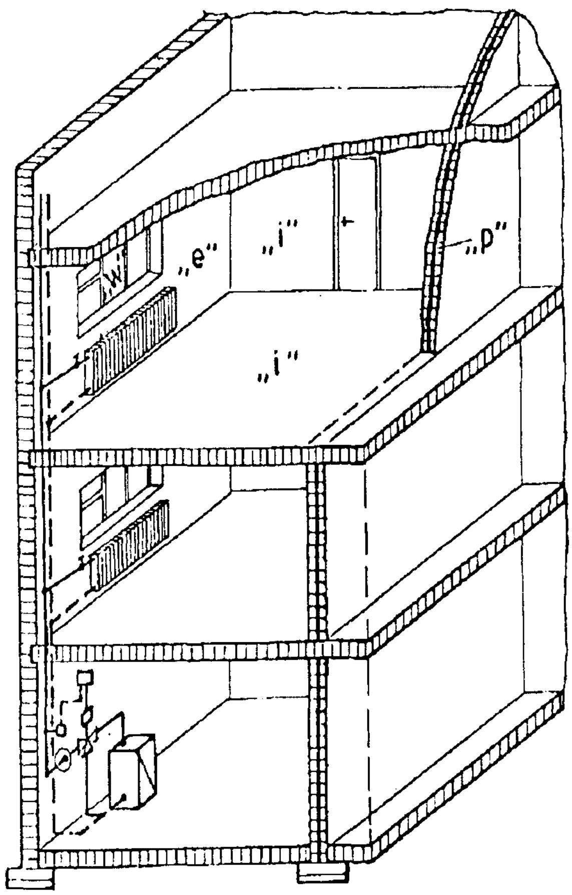

Fig 1. A fragment of a heated bulding

By assuming periodicity it is possible to disengage the model from the influence of initial conditions. A mathematical model of a building (3) constitutes a system of parabolic Fourier-Kirchhoff partial differential equations which describes heat conduction in material layers, equations of heat balance of the air for each zone and equations describing heat transfer in radiator cycle for each zone. System of model equations is completed by boundary conditions system.

2. Method of solution

To solve a model of heated building the matrix method has been used [3,4,5,6,7].

The building is considered as a set of zones characterized by different internal temperatures, connected by walls of different construction and heated by heaters of definite thermal characteristics. Each element of heated building (walls forming the building enclosure and elements of heating system) are characterized by means of catenary matrix. Owing to the catenary matrix it is possible to determine complex temperature and heat flux density harmonics on one side of the element on the basis of their values on the other side. Catenary matrix may be expressed as :

$$\begin{bmatrix} \vec{t}_{ej,k} \\ \vec{q}_{ej,k} \end{bmatrix} = \begin{bmatrix} A_{j,k} & B_{j,k} \\ C_{j,k} & D_{j,k} \end{bmatrix} \begin{bmatrix} \vec{t}_{ij,k} \\ \vec{q}_{ij,k} \end{bmatrix} \tag{1}$$

where:

$A_{j,k}$, $B_{j,k}$, $C_{j,k}$, $D_{j,k}$ designate elements of the catenary matrix of the j-th element for the k-th harmonic,

$\vec{t}_{ij,k}$ - the k-th temperature harmonic inside the j-th element,

$\vec{t}_{ej,k}$ - the k-th temperature harmonic outside the j-th element,

$\vec{q}_{ij,k}$ - the k-th heat flux density harmonic inside the j-th element,

$\vec{q}_{ej,k}$ - the k-th heat flux density harmonic outside the j-th element.

Elements of the wall catenary matrix [3,4,5,6,7] are obtained by postmultiplication of the catenary matrix of particular material layers and matrices including surface film conductances. The catenary matrix of the material layer with thickness e and heat assimilation coefficient s has the following elements:

$$\begin{aligned} A = D &= \cosh \frac{es\sqrt{i}}{\lambda} \\ B &= \frac{1}{s\sqrt{i}} \sinh \frac{es\sqrt{i}}{\lambda} \\ C &= s\sqrt{i}\ \sinh \frac{es\sqrt{i}}{\lambda} \end{aligned} \tag{2}$$

The heat assimilation coefficient of material layer depends on material thermo-physical parameters c, ρ, λ and angular velocity ω

$$s = \sqrt{c\omega\rho\lambda} \tag{3}$$

where c - specific heat, ρ - material density, λ - thermal conduction, ω - angular velocity $\omega = 2\pi/t_p$

The catenary matrix of the element with thermal resistance Rj is expressed by :

$$A = D = 1\,;B = Rj\,;C = 0 \tag{4}$$

The catenary matrix of the element with thermal capacity Cj is expressed by :

$$A = D = 1\,;B = 0\,;C = Cj\omega_K i \tag{5}$$

The elements with thermal resistance may be, e.g. air-gaps, planes of surface film conductance and planes of overall heat transfer (planes of heater and distributing pipes of radiator cycle). The elements with thermal capacity may be, e.g. water volume of heating system, energy accumulator, etc. The zone of building is considered as a set of walls and each of them is in contact with the air by an unknown course $t_i(\tau)$ heated by means of heaters connected with source, e.g. boiler. With regard to boundary conditions outside the model, there can be distinguished:

- external walls "e" for which the course of external air temperature $t_e(\tau)$ is given,
- external transparent walls (e.g.windows) "w" for which the course of solar gain $Q_s(\tau)$ is given,
- internal walls "i" located between rooms characterized by identical air temperature courses $t_e(\tau)=t_i(\tau)$,
- internal symmetric filling "s" located inside the zone for which the symmetry of construction and temperature distribution may be assumed,
- plane heaters "p" for which the function of productiveness of heat source defined in terms of time function $q_p(\tau)$ is given.

The basic elements which represent heating system are:

- heat source (boiler) for which the function of productiveness defined in terms of time function $Q_K(\tau)$ is given,
- distributing pipes conveying heating medium,
- heaters with given overall heat transfer coefficients.

Tabl.1 Comparison of maintaining parameters for different heating systems in comparative heating season.

Month	Kind of day	Kind of heating	Temperatures [^oC] external max min	internal max min	supply max min	return max min
January	cloudy	continuous	1.6 -3.4	20.0 20.0	66.0 59.1	54.0 49.6
		night reduction		20.1 17.9	79.4 38.0	63.1 33.0
		night+day reduction		19.6 17.9	80.3 44.7	63.9 38.1
January	solar	continuous	0.9 -4.7	20.0 20.0	68.4 60.5	55.8 49.9
		night reduction		20.1 17.9	81.8 40.1	64.8 34.5
		night+day reduction		19.6 17.9	82.5 46.3	65.5 42.7
ebruary	cloudy	continuous	1.8 -3.4	20.0 20.0	65.9 58.8	53.8 48.0
		night reduction		20.1 17.9	79.4 37.8	63.2 32.9
		night+day reduction		19.5 17.9	80.1 44.3	63.8 38.5
ebruary	solar	continuous	2.9 -5.6	20.0 20.0	69.6 57.4	56.5 47.7
		night reduction		20.2 17.8	83.4 38.6	66.1 36.6
		night+day reduction		19.6 17.9	84.2 45.7	66.8 39.2
March	cloudy	continuous	8.1 0.6	20.0 20.0	56.6 46.6	46.6 39.6
		night reduction		20.2 17.8	72.7 29.6	59.0 27.6
		night+day reduction		19.7 17.9	73.6 34.2	59.8 30.6
March	solar	continuous	9.0 -0.7	20.0 20.0	59.5 45.7	49.1 39.0
		night reduction		20.3 17.8	74.9 28.9	59.2 27.1
		night+day reduction		19.6 17.8	75.8 35.3	61.4 31.0
April	cloudy	continuous	11.3 - 2.7	20.0 20.0	52.8 40.1	44.2 34.9
		night reduction		20.2 17.8	69.3 25.2	57.0 23.0
		night+day reduction		19.6 17.8	70.3 30.2	57.9 27.2
April	cloudy	continuous	14.2 - 1.2	20.0 20.0	54.7 35.7	45.6 31.6
		night reduction		20.3 17.8	69.3 25.2	57.0 23.0
		night+day reduction		19.6 17.8	71.6 25.7	59.0 23.8

In relation to each harmonic component, the heat balance equation of the air in the zone should be expressed as:

$$A_{ij}\,\vec{q}_{ij,k} + \vec{Q}_{kk} + \vec{Q}_{sk} = 0 \qquad (6)$$

where:

A_{ij} - internal surface of the j-th wall in the zone

$\vec{q}_{ij,k}$ - heat flux density on internal surface of the j-th wall,

$\vec{Q}_{kk}$ - productiveness of heat source,

$\vec{Q}_{sk}$ - solar heat gains.

In the model ventilation is considered by introducing an additional external wall with a suitable catenary matrix. Heat flux densities on internal wall surfaces $q_{ij,k}$ can be determined from (1) accordingly taking into account boundary conditions on external wall surfaces with reference to each harmonic component separately in succession:

- for external walls "e"

$$\vec{q}_{ij,k} = -\vec{t}_{ik}\,\frac{A_{j,k}}{B_{j,k}} + \vec{t}_{ek}\,\frac{1}{B_{j,k}} \qquad (7)$$

- for internal walls "i"

$$\vec{q}_{ij,k} = -\vec{t}_{ik}\,\frac{A_{j,k}-1}{B_{j,k}} \qquad (8)$$

- for internal symmetric filling "s"

$$\vec{q}_{ij,k} = -\vec{t}_{ik}\,\frac{C_{j,k}}{D_{j,k}} \qquad (9)$$

- for plane heaters "p"

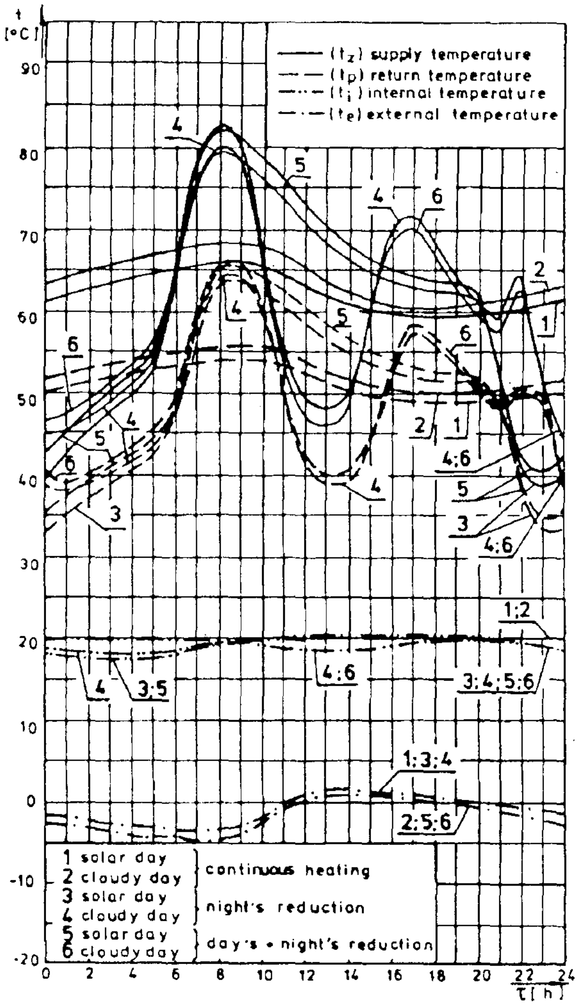

Fig. 2. Twenty four hours courses of heating maintenance parameters for representative days in January (in TMY of Poznań)

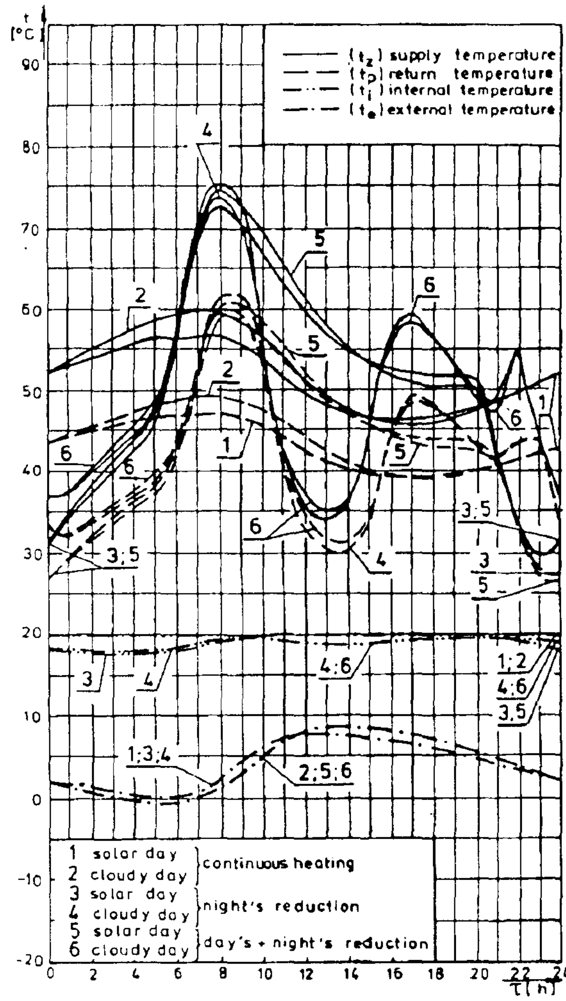

Fig. 3. Twenty four hours courses of heating maintenance parameters for representative days in March (in TMY of Poznań)

$$\vec{q}_{ij,k} = \frac{\vec{q}_{pj,k}}{D_{j,k}} - \vec{t}_{ik}\,\frac{C_{j,k}}{D_{j,k}} \qquad (10)$$

Thermal balance equation for single zone may be written as follows :

$$\sum_e A_{ie}\left(\vec{t}_{ej,k}\,\frac{1}{B_{j,k}} - \vec{t}_{ik}\,\frac{A_{j,k}}{B_{j,k}}\right) +$$

$$\sum_i A_{ii}\left(-\vec{t}_{ik}\,\frac{A_{j,k}-1}{B_{j,k}}\right) + \sum_s A_{is}\left(-\vec{t}_{ik}\,\frac{C_{j,k}}{D_{j,k}}\right) + \qquad (11)$$

$$\sum_p A_{ip}\left(\frac{\vec{g}_{pj,k}}{D_{j,k}} - \frac{C_{j,k}}{D_{j,k}}\,\vec{t}_{ik}\right) + \vec{Q}_{kk} + \vec{Q}_{sk} = 0$$

Designations to be used are:

- e - external walls summation,
- i - internal walls summation,
- s - internal filling summation,
- p - plane heaters summation.

An unknown in the equation (11) can be : the harmonic component of internal air temperature $\vec{t}_{ik}$ or the harmonic component of required energy output (productiveness of heat source) $\vec{Q}_{kk}$. Harmonic synthesis is necessary for the determination of time function $t_i(\tau)$ or $Q_k(\tau)$.

The harmonic components of basic parameters of heating exploitation can be assigned directly from equations describing heat transfer in radiator cycle.

Numerical model of multizone building includes calculation of harmonic components of the heat fluxes on internal walls surfaces, composition systems of thermal balance equations for nodes representative of zones of building, their solution and harmonic synthesis of output functions.

3. Results of calculation

The ground floor of lightweight experimental building (Canadian construction) located in the area of Technical University of Poznan was taken as a model for calculation. Comparative Heating Season was taken as a model of external climate for Poznan. This model was elaborated by means of Older Synthetical Test Reference Year Method on the ground of meteorological data from ten years period [1]. Before these calculations the analysis of solar heat gains for the same building was done [2]. The calculations were applied to unstationary heatings. Three kinds of maintenance conditions: continuous heating securing constant internal temperature, heating with reduction during the night (reduction of internal temperature $\delta t_i=2K$ during 22^{oo} -6^{oo} hours), heating with reduction during the midday and the night (reduction of internal temperature $\delta t_i=2K$ during 11^{oo}-15^{oo} and 22^{oo}-6^{oo} hours) were considered. Exemplary results in form of 24 hours courses of characteristic temperatures for the building are shown in Fig. 2 and Fig. 3.

Fig. 2 satisfies external temperature conditions for representative days in January and Fig. 3 in March.

Four groups of curves characterizing 24 hours courses of temperature are as following: external air temperature t_e, internal air temperature t_i , return water temperature t_p, supply water temperature t_z. The comparison of maintaining ing parameters for different heating systems is shown in Table 1.

Energy savings resulting from heating reduction during the night were equal to 3.5% - 6% regarding to energy requirement for continuous heating. Analogically energy savings for heating reduction during the midday and the night were equal to 5.4% - 9.5%.

4. Conclusions

The presented model may be used in other investigations of energy storage in walls forming the enclosure of building and heating requirements for buildings. This model provides the possibility to calculate heating parameters which are needed for energy saving maintenance of heating system and prediction of costs.

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ŠILDYMO PARAMETRŲ ANALIZĖ, NAUDOJANTI MATRICŲ METODĄ

H.Koczyk

Santrauka

Straipsnyje nagrinėjama, kaip taikyti matricų metodą šilumos perdavimo modeliui sukurti tokiems šildomiems namams, kurie susideda iš skirtingos paskirties ir naudojimo patalpų. Pasiūlytas būdas, kaip skaičiuoti šildymo parametrus. Jis reikalingas norint taupiai eksploatuoti šildymo sistemą ir iš anksto paskaičiuoti išlaidas. Pateikiami pavyzdiniai šildymo reikalavimų rezultatai klimatinėms Poznanės sąlygoms (pagal lyginamąjį šildymo sezoną).

Halina KOCZYK. Dr Habil Eng. Poznan University of Technology, 3A Piotrowo Str. 60-965 Poznan, Poland.

Professor at Dept of Heating, Air Conditioning and Air Protection. Institute of Environmental Engineering. Vice-dean of Faculty of Civil and Environmental Engineering and Architecture. M Sc (Eng) diploma in 1970, Ph D in 1978, habilitation in 1990 at Poznan UT. Research interests: heat transfer in buildings, energy savings.