Vasyl Zhelykh, Christina Kozak

MODELING OF THERMAL PROCESSES IN THE SOLAR AIR HEATER

1. The analysis of existing publications

The social position in the world in the coming decades to large extent will depend upon how energy problems common to all mankind are resolved.

Approximately one third of organic energy sources such as coal, oil and gas, is converted into heat, while a large part of it is used for heating and hot water supplying of buildings. The changes in climate and dependence on non-renewable energy sources, reserves of which significantly reduced over the past decade forced to seek alternatives to methods of heating.

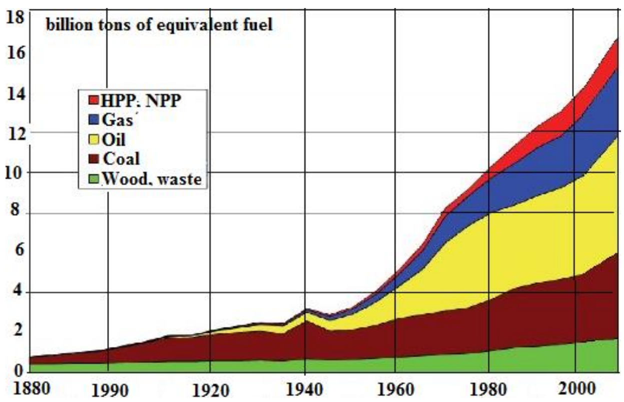

Fig. 1. The dynamics of world energy consumption in 20th century and at the beginning of 21th century

One solution to this problem is the use of solar energy for heating residential and administrative buildings. To some extent, thermal comfort in rooms can be provided by solar air heating systems. Compared with air heating solar water have several drawbacks and advantages. Due to its properties of air they are nearly ideal medium for heating in solar collectors: it does not freeze or boil under any natural conditions, is non-toxic, generally does not cause corrosion.

The peculiarity of air as the heat carrier is low heat capacity and specific weight. As a result, solar air heating systems are used in buildings where they must heat the large volumes of the room for a short period of time.

To increase the efficiency of air heating system there are used the following measures: increasing the size of the air heliosystems, insulation and sealing hull of solar collector and duct heating system if any available, increase in the area of heat absorbing plate air heater due to its developed form surfaces and more. Usually for more effective functioning of the solar heating system installed accumulators power. The best in this role proved fire resistant floor with the ability to pass air. Such measures are cost-effective only in the construction of buildings, the funds invested in the reconstruction generally do not pay off.

Basically air heliocollectors are set for heating buildings. They are also used for heating various types of administrative buildings, including warehouses and offices. Solar air heaters also are used for drying agricultural products, wood and other industrial processes where hot air is needed [1, 2].

Nowadays in Ukraine there increases using solar heliocollectors for hot water supplying of small individual houses. Solar air heaters are met mainly in the Crimea. Not enough quest of selection and engineering methods of calculation of such devices requires additional research and development of science-based methods.

This work is devoted to modeling of heat transfer processes in thermosyphon solar collector with application graph theory.

2. The main material

For modeling the thermal processes in the thermosyphon solar collectors we used graph theory. Graph of heat flows in the solar air heaters is presented in Figure 2.

Heat containers of thermosyphon heliocollector - the air in the solar collector (A), heat absorbing plate (HP) and hull of solar collector (H).

Sources of heat are: solar radiation ($Q_{s.r.}$); outdoor air (Q^{o}_{air}); air in the solar air heater ($Q^{s.c}_{air}$); air in the heating room (Q^{r}_{air}); heat absorbing plate ($Q_{h.p.}$); heat loss through the hull of solar collector ($Q_{h.l.}$), that were depicted as the top (V1) of graph (G1). Heat flows *qi*, which correspond to heat transfer between the sources of heat and heat capacities shown on the graph as edges (E1), that connect nodes (Fig. 2). Consequently, plural vertices of the graph are:

$$V_1(G_1) = \{A; HP; H; Q_{h.p..}; Q_{h.l.}; Q_{s.r.}; Q_a^{s.c.}; Q_a^{r}; Q_a^{o}\} \quad (1)$$

and number of edges:

$$E_1(G_1)=\begin{Bmatrix}(Q_a^{s.c.},H);(Q_{h.p.},H);(Q_a^o,H);(Q_{h.p.},A);(Q_{h.l.},A);\\(Q_{s.r..},HP);(Q_a^r,HP);(Q_{h.l.},HP)\end{Bmatrix} \quad (2)$$

For thermal containers that included into the top graph as the number of edges is equal to:

$$\deg(H)=3,$$
$$\deg(A)=2,$$
$$\deg(HP)=3.$$

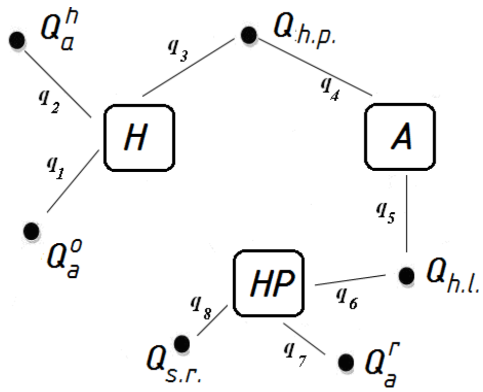

Fig. 2. Oriented graph of heat containers of solar air heater

Incidence matrix M1 for graph G1, in which the rows correspond to the top (heat containers) and columns - edge (heat flows) is:

	q_1	q_2	q_3	q_4	q_5	q_6	q_7	q_8
A	0	0	0	1	1	0	0	0
H	1	1	1	0	0	0	0	0
HP	0	0	0	0	0	1	1	1

(3)

On the basis of the graph shown in Figure 2, presents an extended matrix interactions thermal correspond.

$$\begin{bmatrix} & A & H & HP & Q \\ A & 0 & Q_{a-h} & Q_{a-h.p} & Q_{h.p.}+Q_{h.l} \\ H & Q_{h-a} & 0 & 0 & Q_a^{s.c}+Q_{h.p}+Q_a^o \\ HP & Q_{h.p-a} & 0 & 0 & Q_{s.r}+Q_a^r+Q_{h.l} \end{bmatrix} \quad (4)$$

The balance of heat flows for thermosyphon solar collector will be as follows:

$$\pm Q_{h.p.} \pm Q_{h.l.} \pm Q_{s.r} \pm Q_a^{s.c} \pm Q_a^r \pm Q_a^o = 0 \quad (5)$$

The amount of heat supplied to the heat carrier from the heat absorbing plate, $Q_{h.p.}$, W, is given by the formula [3]:

$$Q_{h.p.} = \alpha_{h.p.} \cdot F_{h.p.} \cdot (t_{h.p.} - t_a^r) \quad (6)$$

where: $\alpha_{h.p.}$ - heat transfer coefficient of the heat absorbing plate to the air from the room, W/(m^2·°C); $F_{h.p.}$ - area of the heat absorbing plate, m^2; $t_{h.p.}$ - the average temperature of the heat absorbing plate, °C; t_a^r - temperature of the air coming into the solar collector from the room, °C.

The amount of heat accumulated in the body of heliocollector, $Q_{h.l.}$, W, is:

$$Q_{h.l.} = \alpha_h \cdot F_h \cdot (t_a^h - t_{h.l}) \quad (7)$$

in which α_h - coefficient of heat transfer from the air in heliocollector to the body of solar air heater, W/(m^2·°C); F_h - area of the hull of heliocollector, m^2; t_a^h - temperature of heat carrier in the body solar collector, °C; t_h - body surface temperature solar air heater, °C.

The heat revenues from the body of the solar collector to the environment, Q_a^o, W, are determined from the dependence:

$$Q_a^o = \alpha_o \cdot F_h \cdot t_a^o \quad (8)$$

where: α_o - coefficient of heat transfer from the hull of heliocollector to the environment, W/(m^2·°C); t_a^o - ambient air temperature, °C.

The heat that enters where the air from the room in the solar collector, Q_a^r, W, is determined by the formula:

$$Q_a^r = L_{in} \cdot \rho_a \cdot C_a \cdot t_a^r \quad (9)$$

in which L_{in} - volumetric flow rate of air entering into the heliocollector, m^3/hour; ρ_a - the density of air in the room, kg/m^3; C_a = 1.005 kJ/(kg·°C) - specific heat of air.

The heat coming from the heat absorbing surface to air in the heliocollector is determined from the dependence:

$$Q_a^h = \alpha_{in} \cdot F_{h.p.} \cdot t_a^{c.s} \quad (10)$$

α_{in} - coefficient of heat transfer from the heat absorber to the air in the heliocollector, W/(m^{2}°C).

Conclusions

There were presented the main advantages and disadvantages of air as a heat carrier for solar heating systems, as well as outlining the main scope of their application. Based on the theory of graphs it was developed a simplified physical model of heat transfer processes occurring in the thermosyphon solar collector. The authors also presented a method for determining the thermal characteristics of passive solar stove.

References

[1] Holloway D.R., A Simple Design Methodology for Passive Solar Houses with a Brief History of Solar Energy Utilization in the Built Environment 2011, http://dennisrhollowayarchitect.com/simpledesignmethodology.html

[2] Marcken Ch., Designing systems of air solar collectors 2003, http://spareworld.org/rus/sites/default/files/solar-air-rus.pdf

[3] Ion V., Martins J.G., Design, developing and testing of a solar air collector, The annals of “Dunarea de jos”, University of Galati, 2006.

[4] Duffie J.A., Beckman W.A., Solar Engineering of Thermal Processes, Wiley, New York 1991, 320 p.

[5] Kapalo P., Analysis of Ventilation Rate and Concentrations of Carbon Dioxide in the Office, Lviv Politekhnick Publ. 756, 2013.

[6] Zhelych V., Lesuk H., Thermosiphon solar collector. A utility model patent number 55948, 2012.

[7] Wozniak O., Zhelykh V., Basic Research in Construction, Lviv Politekhnick Publ., Lviv 2003, 174 p.

[8] Altfeld K., Leiner W., Fiebig M., Second law optimization of flat-plate solar air heaters, Solar Energy 1988, 41, 2, 127-132, 309-317.

[9] Bejan A., Keary D.W., Kreith F., Second law analysis and synthesis of solar collector systems, Journal of Solar Energy 1981.

[10] Farahat S., Ajam H., Sarhaddi F., Optimization of linear parabolic solar collectors with exergy concept, Proceedings of 19th International Power System Conference, Tehran 2004.

Abstract

The article sets out the place of solar energy in the world today. There are provided basic advantages and disadvantages of air quality heat capacity for solar heating system. Data for modeling heat flow system with passive energy use have been presented. Discussed methodology allows to determine the thermal characteristics of the air in the collector of the passive use of solar energy.

Резюме

Определено энергетическое положение в мире в настоящее время. Поданы основные преимущества и недостатки воздуха в качестве теплоносителя для солнечной системы отопления. Представлены данные по применению теории графов для моделирования тепловых потоков в пассивном солнечном воздухонагревателе. Приведена методика определения тепловых характеристик воздушного гелиоколлектора с пассивным использованием солнечной энергии.