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OPTIMIZATION OF OPERATION OF A HEAT-PUMP FACADE SYSTEM OF HEATING DURING OBSERVANCE OF THE REQUIRED PARAMETERS OF THERMAL COMFORT OF RESIDENTIAL BUILDINGS

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Statement of the problem. The influence of the speed of wind of areas inside backyards of urban multi-storeyed quarters on a decrease in thermal comfort in premises is considered. Loss of saved thermal energy affects an internal microclimate of structures. A drop of the temperature of the internal air of a part of a construction generally affects its thermal mode, which leads to an increase in the operational costs of maintaining the required parameters of the microclimate and deterioration of the indices of the power efficiency of a building.

Results. In order to maintain the acceptable parameters, a heat-pump system (HPS) of façade regulation is considered. The described model consists of two consistently connected thermal pumps and systems of sensors as well as two contours of a system of heating. During the operation of the equipment the excess thermal energy for heating of the rooms located on the side of the building less exposed to winds goes into the colder premises from the part of the facade which is more exposed to winds.

Conclusions. The option for optimizing the operation of a HPS during consecutive connection of condensers is considered and parallel evaporators of thermal pumps for the consumption of the conditional fuel for smooth functioning of the system. Studies of the model of a heat-pump station where the efficiency of the first thermal pump exceeds that of the second one are presented. Their effect on the consumption of conditional fuel as a result of redistribution of thermal energy between premises on different facades of the building is investigated.

Keywords: thermal comfort, system of façade regulation, optimization of a heat pump, buildings with low energy consumption.

Introduction. In modern urban construction practice in the Russian Federation new residential areas mainly consist of high-rises, which is within investors' interests but neglects comfort levels. The fact that there is almost no greenery also has a negative impact on a wind mode of buildings. A rise in the speed of wind in the areas surrounding high-rises, an emerging wind tunnel effect around them contributes to blowing of accumulated heat of facilities on the along-wind side [8, 14, 15]. Therefore a reduction in the admissible parameters of the inside air of a part of a construction has an effect on its overall thermal mode and leads to an increase in energy costs for heating decreasing the energy-sustainable performance of a building.

The temperature and speed of the air is one of the major characteristics of microclimate of facilities [2, 7]. For the above conditions, the temperature and wind speed inside facilities will not be as specified in "The Set of Rules" (СП) 60.13330.2012, which will have a negative impact on heat comfort levels [12, 13, 16].

Studies of how to reduce heat losses in buildings and structures using a variety of methods are highly relevant [1, 7, 10, 12, 17, 19]. However, for a high-rise construction it is necessary that stitches of outside framing are hermetically sealed [17]. Wrong operation of framing and untimely maintenance leads to seal failures and considerable heat losses [18, 20]. The importance of the problem is that a heat pump system might facilitate an even distribution of heat inside residential structures. The suggested system of heat pump systems is instrumental in reducing the temperature of a heat-carrier that is needed to heat facilities on the along-wind side directing it for heating on the cross-wind side.

1. Statement of the problem. A reduction in loads on a heating system and maintenance of the required temperature parameters of the inside air is possible provided that a heat pump system is implemented. Using façade regulation in combination with heat pumps, a heat mode of facilities on the along-wind side of a building depending on deviations of the temperature of the air in a facility, changes in the temperature of the outside air, solar radiation onto the outside wall and effects of high-speed wind flows [1, 19]. The optimization of the operation of a heat pump system allows heating costs to be significantly cut.

A maximum effect from façade regulation should occur for quick and sufficient reactions of a system to changes in weather conditions: a drop in the water temperature in the supply heating system according to changes in loading. The opportunities offered by automatic sets of a system of façade regulation with a heat pump system allow algorithms of changes in the temperature of a heat-carrier inside the system to be employed, which is implemented in actual operation [6, 10]. An extra effect is achieved by using a system of façade regulation with thermostat sensors fitted in the heating equipment [4] (Fig. 1).

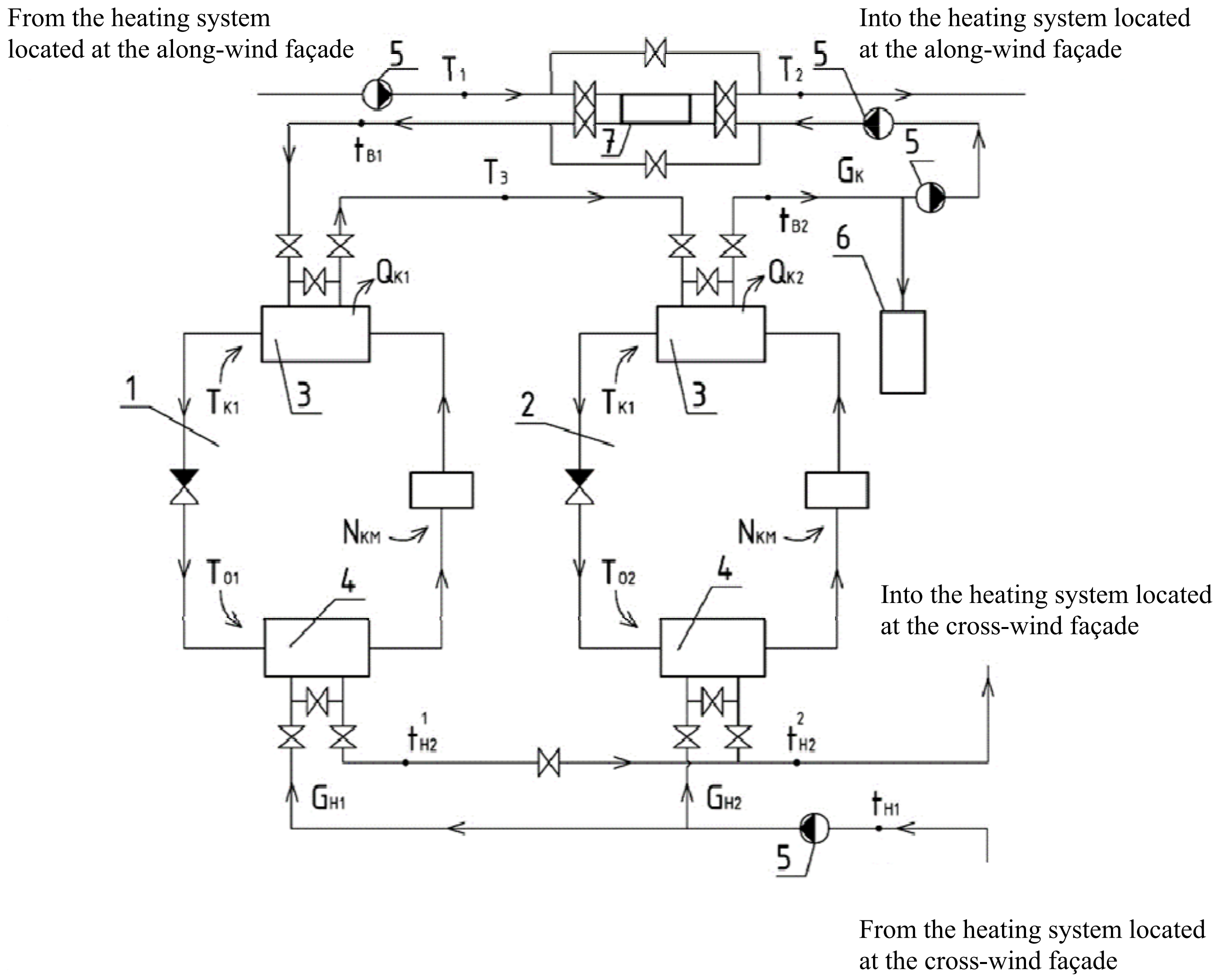

Fig. 1. Principal scheme of a HPS operating in conjunction with a system of façade regulation: 1 is a heat pump HP1; 2 is a heat pump HP2; 3 is a condenser; 4 is an evaporator; 5 is a network pump; 6 is a tank accumulator, 7 is a heat-exchanger; Q_k is thermal load of the HP condenser, kWatt; T_O is the temperature of evaporation of the HP operating body, K; G_{H1} is the mass consumption of water in the heating system on the under-wind facade, kg/sec; G_C is the mass consumption of water in a heating system at the along-wind façade, kg/sec; t_{H1}, t_{H2} is the temperature of water at the input in the second one and at the output from the first HP evaporator, K; t_{B1}, t_{B2} is the temperature of water at the input in the first and at the output of the HP condenser respectively, K; t_{K1}, t_{K2} is the temperature of condensation of the HP1 and HP2 operating body respectively, K; $T1$ and $T2$ is the temperature of a heat-carrier of a heating system at the along-wind façade before and after the HPS respectively

2. Use of a heat pump system. In this study a model of an individual heating spot of a heating system is that includes a façade system and two heat pumps. Condensers of a heat pump system are joined in a sequence and evaporators in parallel. The latter "pump" excess thermal energy that is needed for heating the windy or sunny side of the facade in order to supply heat to the along- and cross-wind sides of a building.

The investigated system has two circulation contours and can be used in buildings with rectangular floor plan. An advantage of the described model is transformation of heat in a wider temperature range than the one suggested earlier [2, 13] as for each cycle of a heat pump an operating substance with the best properties in required ranges of change in the parameters.

Losses of a conditional fuel for the operation of a heat pump system are the main optimization criteria. The necessary operational parameters are chosen according to their smallest value [11]. The consumption of a conditional fuel of the system B_{HPS}, kg. t. c./f, [5, 9] is given by the formula:

$$\begin{aligned} B_{THC} = {} & \frac{34.1\cdot 10^{-6}(T_{K1}-T_{O1})}{\eta_K^Э\cdot(1-\phi_{CH})\cdot\eta_{Э.C.}\cdot\eta_1\cdot T_{K1}} c_P\cdot G_C\cdot(T_{K1}-\Delta T_{K1}-T_3)+ \\ & +\frac{34.1\cdot 10^{-6}\left(T_{K2}-T_{O2}\right)}{\eta_K^Э\cdot(1-\phi_{CH})\cdot\eta_{Э.C.}\cdot\eta_2\cdot T_{K2}} c_P\cdot G_C\cdot(T_{K2}-\Delta T_{K2}-T_{K1}+\Delta T_{K1}), \end{aligned} \tag{1}$$

where T_{O1}, T_{O2} is the temperature of evaporation of an operating body HP1 and HP2, К; T_{K1}, T_{K2} is the temperature of condensation of an operating body HP1 and HP2 respectively, К; c_p is a specific chosen isobar thermal conductivity of water, kJ/(kg·К); ΔT_{K2}, ΔT_{K1} is the final difference between the temperatures of an operating body and heat-carrier in the condenser HPS2 and HPS1 respectively, К; T_3 is the temperature of water before the second condenser HP, К; G_C are the mass consumption of a heat-carrier in a heating system, kg/sec; $\eta_K^Э$ is the coefficient of efficiency at condensation electric power stations; φ_{CH} is the coefficient of own needs of an condensation electric power station; $\eta_{Э.\ C.}$ is the coefficient of efficiency of an electric network.

Let us accept that dimensionless temperatures of condensation of the operating body classified as corresponding evaporation temperatures in the evaporators HP1 HP2 and dimensionless complexes of constants [3] determined by the formula:

$$\begin{gathered} X=T_{K1}/T_{O1},\quad Y=T_{K2}/T_{O2}, \\ a_O=34.1\cdot 10^{-6}C_P,\quad a_1=\eta_K^Э\cdot\eta_{ЭC}\left(1-\phi_{CH}\right), \\ \varepsilon_1=\left(\eta_2-\eta_1\right)/\eta_1,\quad \varepsilon_2=\left(\Delta T_{K2}-\Delta T_{K1}\right)/T_{O2}, \\ \delta_O=T_{O1}/T_{O2},\quad c_1=\left(\Delta T_{K1}+T_3\right)/T_{O1}, \end{gathered} \tag{2}$$

where ε_1 is a relative difference of the coefficient of efficiency of HP1 and HP2; ε_2 is a relative final difference of the temperatures in the HP condensers (to the evaporation temperature of the operating body in the HP evaporator); δ_O is a ratio of the temperatures of the operating body in the HP1 and HP2 condensers.

By introducing the transformations (2) into a dimensionless function of the total consumption of conditional fuel [6], we get:

$$U(X,Y)=\frac{\eta_2\cdot a_1}{a_O\cdot T_{O2}\cdot(G_C+G_\Gamma)}B(X,Y)=$$
$$=\delta_O\left(X+\varepsilon_2^O\right)/Y+\varepsilon_1\cdot\delta_O\cdot X+c_1^*\cdot\delta_O/X-1-\delta_O\left(1+c_1^*+\varepsilon_1+\varepsilon_2^o\right), \quad (3)$$

where $c_1^*=c_1\cdot(1+\varepsilon_1),\ \varepsilon_2^o=\varepsilon_2/\delta_o$;

the description of the function c_1 is given in [6].

Let us conduct an analysis of the effect of the coefficient of efficiency of heat pumps joined into a system in the following way: the condensers in a sequence and evaporators in parallel. Let us consider that when condensers are joined in a sequence, final differences of the temperatures of a cooling agent and heat-carrier in each of them are almost equal. Let us evaluate a combination of values when a parameter of the heat transfer is $\tilde{\varepsilon}_2 \ll 1$ and a parameter of the coefficient of efficiency $\tilde{\varepsilon}_1$ is within $\left(\varepsilon_1^*, 1-\eta_2\right)$, i. e. the coefficient of efficiency of the first heat pump is larger than of the second one.

As a result of the studies, an expression was obtained that determines the optimal temperatures of condensation of the HP operating bodies and making the following purpose function as small as possible:

$$X^{(3)}\approx\frac{A}{\delta_0}\cdot\left(Y_0^{(3)}\right)^2+x_1\cdot\frac{\tilde{\varepsilon}_2}{\delta_0}+x_2\cdot\left(\frac{\tilde{\varepsilon}_2}{\delta_0}\right)^2,$$
$$Y^{(3)}\approx Y_0^{(3)}+2\frac{\tilde{\varepsilon}_2}{A\cdot\Delta_0\cdot Y_0^{(3)}}-\frac{3\Delta_0^2-12\Delta_0-8}{\Delta_0\cdot Y_0^{(3)}}\cdot\left(\frac{\tilde{\varepsilon}_2}{A\cdot\Delta_0\cdot Y_0^{(3)}}\right)^2, \quad (4)$$

where $x_1=1+\frac{4}{\Delta_0}$; $x_2=-2\frac{A\cdot Y_0^{(3)}}{\delta_0\cdot c_1^*}\cdot\frac{3\Delta_0-2}{\Delta_0^3}$; $\Delta_0=\frac{Y_0^3-4\cdot B_1^{*3}}{B_1^{*3}}$; $B_1^3=\frac{\delta_0^2\cdot c_1}{A^2}$;

$$Q=1+2\sqrt[3]{4}\cdot B_1\cdot\tilde{\varepsilon}_1\cdot\sqrt{1-\tilde{\varepsilon}_1}\cdot\left(K_++K_-\right);\ K_\pm\left(\tilde{\varepsilon}_1\right)=\sqrt[3]{1\pm\sqrt{1-\left(\frac{4\sqrt[3]{4}}{3}\cdot B_1\right)^3\cdot\varepsilon_1^3\cdot\left(1-\varepsilon_1\right)}};$$

$$Y_0^{(2)}=\frac{1+\sqrt[4]{Q}}{4\cdot\tilde{\varepsilon}_1}\cdot\left[1+\sqrt{\frac{2-\sqrt{Q}}{\sqrt{Q}}}\right];\quad X_0^{(2)}=\frac{A}{\delta_0}\cdot\left(Y_0^{(2)}\right)^2;$$
$$Y_0^{(3)}=\sqrt[3]{4}\cdot\frac{B_1^*}{\sqrt[4]{Q}}\cdot\frac{K_++K_-}{\sqrt[4]{Q}+\sqrt{2-\sqrt{Q}}};\quad X_0^{(3)}=\frac{A}{\delta_0}\cdot\left(Y_0^{(3)}\right)^2.$$

The function c_1, A is described in [6].

For energy efficient performance of the HP, it is important to factor in a sequence of heat pumps with different coefficients of efficiency in the direction of heating of a heat-carrier. Based on the dependence (4), in case the coefficient of efficiency of the operation of the HP1 is more than a similar value of the HP2, the final difference of the temperature of a cooling agent and a heat-carrier in the condenser HP1 is more than that of the HP2:

$$\varepsilon_1 < 0, \quad |\varepsilon_2| << 1, \quad \eta_{TH1} > \eta_{TH2}, \quad \Delta T_{K2} < \Delta T_{K1}.$$

The main parameters of the operation of the system of heat pumps are presented in Table.

Table

Parameters of the heat pump station

η_1	η_2	$\varphi_{сн}$	$\eta_{эс}$	$\eta_K^Э$	ΔT_{K1},°C	ΔT_{K2},°C	T_{02},°C	T_{01},°C	G_C, кг/с	T_1, °C	T_2, °C
0.36…0.5	0.3	0.05	0.95	0.33	5	4.1	20	20	0.364	95	70

Based on the obtained data (Fig. 2), it can be concluded that when in heat pumps of a heat station condensers are joined in sequence and evaporators in parallel, if the coefficient of efficiency of the HP1 is more than a similar of the HP2, it is not economically viable to install the second heat pump.

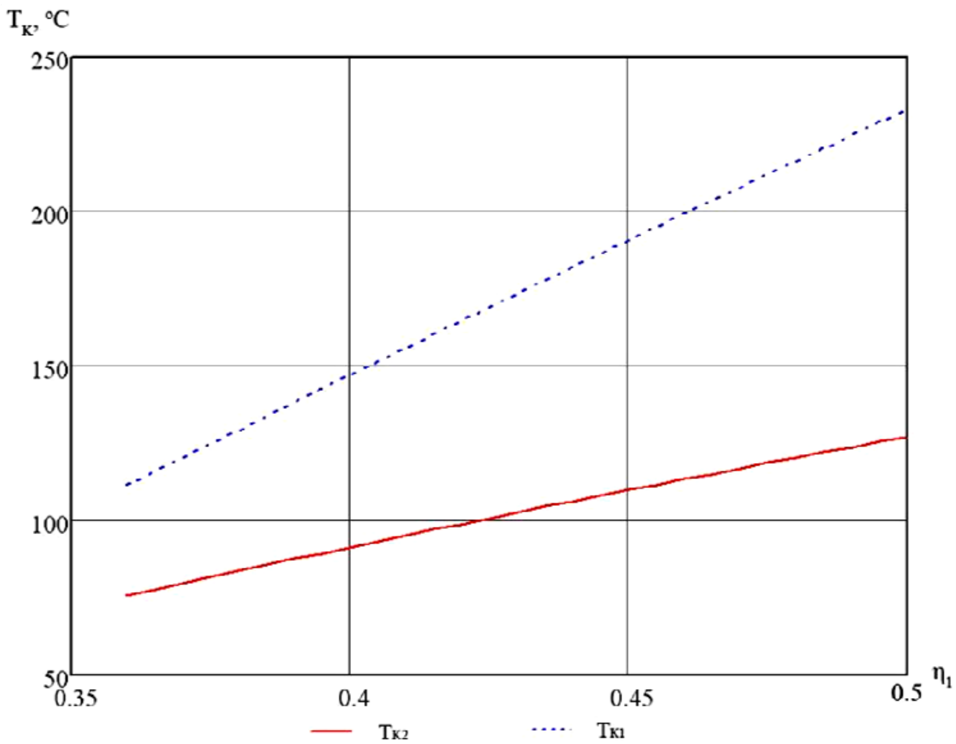

Fig. 2. Graph of the optimal condensation temperatures of the operating bodies depending on the coefficient of efficiency of the first heat pump

It is not viable to make use of the second HP as the optimal temperature of the condensation of the operating body of the first heat pump is higher than that of the second one. Therefore the heat-carrier of the interior contour in the first heat pump is heated till it reaches the temperature the second heat pump will not be capable of increasing at viable temperatures of a heat pump station. A thermal load is covered only by the first heat pump and installing the second one leads to an unjustifiable increase in financial and operational costs.

Conclusions

1. It was found that the use of a system of façade regulation operating in conjunction with heat pumps contributes to comfortable living and standardized temperature parameters of the microclimate that get disrupted due to wind flows outside a building.

2. The principal scheme of the HPS working in conjunction with a system of façade regulation is set forth. The suggested system transfers excess thermal energy for heating warmer facilities from the along-wind side or/and on the sunny side of the façade, for supplying heat of rooms on the windy or/and dark rooms.

The criterion for the optimization of the operation parameters for viable use of thermal energy is consumption of conditional fuel.

3. It was found that when in heat pumps at a thermal station condensers are joined in sequence and evaporators in parallel, if the coefficient of efficiency of the HP1 is larger than that of a similar parameter of HP2, installing the second heat pump is not economically viable.

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