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Solar Ventilation: Analysis and Developments

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ABSTRACT

In this article, existing solar heaters used for ventilation purposes are analyzed. Investigation reveals that for the design of solar air heaters, in most cases a rule of thumb should be applied. A method is developed for determining the correct construction parameters of solar air heaters. The analysis made shows the low efficiency of existing ones, including so called "transpired air solar heaters," which at present are in rather wide use. It is also shown that a glass covering is indispensable to increasing the efficiency of solar heaters. A new, simple construction of an air solar heater for ventilation purposes is developed, as well as a method for evaluating the energy efficiency of solar air heaters. An example of finding the required sizes of a suggested solar air heater to be used for ventilation of a house is presented. The analysis proves that the developed system of solar ventilation and the methods for its calculation allow the design and implementation of high efficiency ventilation in houses.

INTRODUCTION

Ventilation of buildings in winter, especially in cold climatic conditions, requires rather large quantities of heat, resulting in significant cost. To provide low cost ventilation of houses during the recent decade, much attention has been paid to the problem of developing and implementing simplified low-initial-cost solar air heaters for preheating outside air before it is supplied to the house [1,2,3]. One example of these kinds of solar heaters is "transpired air collectors" [1].

Transpired air collectors use a simple technology to capture the sun's heat to warm buildings. The collectors consist of dark, perforated metal plates installed over a building's south-facing wall. A 10-20 sm-thick air gap is created between the wall and metal sheet facade. The dark outer facade absorbs solar energy and rapidly heats up. A fan draws ventilation air into the building through tiny holes in the collectors and up through the gap between the collectors and the south wall of the house. According to a recent article on the subject[1], solar energy absorbed by the collectors warms the air flow by up to 40°F (or 22.2°C). However, it is not specified in what climatic conditions and with what sizes of collector the noted temperature can be provided. The article states that transpired solar collectors are very cheap, unlike other space heating technologies, as they require no expensive glazing. It also states that transpired air collectors are most suitable for large buildings with high ventilation loads to pre-heat the air passing into a heat recovery ventilator.

Our investigation showed that at present no scientifically proven methods exist for determining the dimensions and other construction or energy parameters for transpired and other types of air solar heaters. The referenced article [1] doesn't give a method for determining any values about the cost effectiveness of transpired air collectors. To get more information about dependence of heated air temperature on dimensional parameters of the mentioned air solar heaters, we developed a method for calculations.

Method for Calculation of Transpired Solar Collector

The goal of calculations for the heater is to determine the size, including the width (b, m), length (l, m) and depth (d, m) of the collector for providing the required quantity G_v, kg/sec. and temperature t, °C of the warm air under given outside air temperature t_{out}, °C and intensity I, W/m^2 of solar radiation. Derivation of formulas for calculation is based on the scheme of construction and operation of the air heater shown in Figure 1.

The quantity of absorbed solar heat Q_{sol} by the dark surface of the collector makes:

$$Q_{sol} = FIp \tag{1}$$

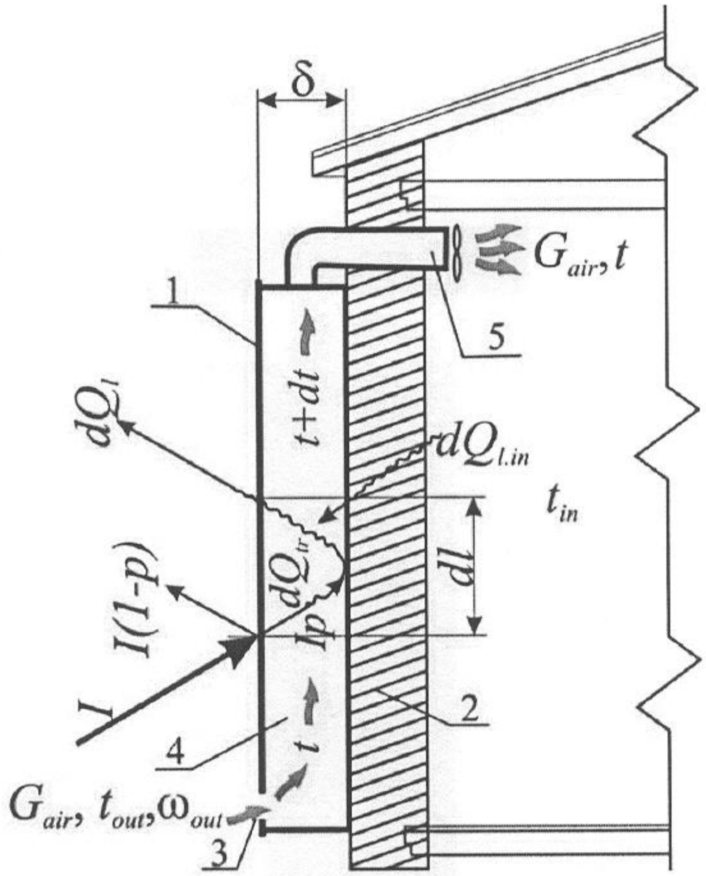


Figure 1. Operation scheme and thermal balance of the solar air heater

1) solar rays absorbing metallic 2mm-thick plate mounted on the surface of south-facing wall; 2) south-facing wall of the house; 3) inlet gap of solar heater for entering of outside fresh and cold air; 4) warm air flow; 5) outlet of heated air.

where

I = hourly average intensity of solar radiation falling on the solar collector mounted on the surface of south-facing wall, W/m^2

p = rate of absorption of solar rays by dark surface of solar collector, which should be at least 0.9 – 0.95

As a result of absorption of solar rays, the surface of the metallic plate is heated up to a so-called radiation temperature t_{Rs}, °C, the value of which is determined by the following formula:

$$t_{Rs} = T_{out} + \frac{I_p}{\alpha_{out}} \tag{2}$$

where

t_{out} = outside air temperature, °C

α_{out} = heat convection value on the external surface assumed 23 $W/m^2{}^\circ C$

As a result of the difference of temperatures ($t_{Rs} - t$) between the surface and air flow in the collector, a quantity of heat Q_{tr}, W is transferred from external surface of the collector to the air flow inside the collector. The value of Q_{tr}, W can be determined as follows:

$$Q_{tr} = kF(t_{Rs} - t) \quad (3)$$

where

k = heat transfer value of 1-2mm-thick metal sheet of the collector, making $k = 5.95\ W/m^2{}^\circ C$

t = current temperature of the air flow along height of the collector, °C

Besides heat gain Q_{tr} there is also heat lost from the air flow in the collector to the outside colder air through the side walls having other orientations and not being lighted by solar rays. The value of heat lost $Q_{l.side}$, W through the side walls is determined by the following formula:

$$Q_{l.side} = KF_{side}(t-t_{out}) \quad (4)$$

where F_{side} = the surface of side walls of the collector, which can be determined by the doubled production of deepness δ, m and height l, m of the collector; that is to say:

$$F_{side} = 2\delta l \quad (5)$$

At the same time there is a heat gain $Q_{l.in}$, W from the inside space of the house to the air flow in the heater through the south wall construction, which is determined by the formula:

$$Q_{l.in} = K_w F(t_{in}-t) \quad (6)$$

where

t_{in} = inside space temperature of the house, °C

So, the quantity of useful heat absorbed by the air flow inside the collector Q_{us}, W is equal to the following sum:

$$Q_{us} = Q_{tr} - Q_{l.side} + Q_{l.in} \tag{7}$$

To solve the problem, the last energy balance should be presented by the following differential equation:

$$K(t_{Rs} - t)dF - K(t - t_{out})2 \bullet dF_{side} + K_w\,(t_{in} - t)dF = dQ_{us} \tag{8}$$

where

δQ_{us} = the elementary quantity of useful heat absorbed by the air flow inside the collector due to the air flow being heated.

Thus, the following energy balance takes place:

$$\delta Q_{us} = Gcdt \tag{9}$$

where

G = air flow in the collector, kg/sec
c = specific heat of air, J/kg°C

Substituting (9) in (8), the differential equation of energy balance obtains the following form:

$$dF\left[K(t_{Rs} - t) + K_w(t_{in} - t) - K\,\frac{2F_{side}}{F}\,(t - t_{out})\right] = Gcdt \tag{10}$$

Replacing the value t_{Rs} by formula (2) and taking into account that

$$F_{side} = \frac{F\delta}{b}$$

After some simplifications, the equation (10) can be represented as follows:

$$dF\left[Kt_{out} + K\frac{Ip}{\alpha_{out}} + \frac{2K\delta}{b}t_{out} + k_w t_{in} - t\left(K_w + K + \frac{2K\delta}{b}\right)\right] = Gcft$$

or

$$dF\left[A-t\left(K_w+K+\frac{2K\delta}{b}\right)\right]=Gcdt$$

or (11)

$$dF=\frac{Gcdt}{\left[A-t\left(K_w+K+\frac{2K\delta}{b}\right)\right]}$$

where

$$\mathrm{A}=\left(Kt_{out}+K\frac{Ip}{\alpha_{out}}+\frac{2K\delta}{b}t_{out}+k_w t_{in}\right)$$

Integrating the equation (11), we obtain:

$$F=-\frac{Gcdt}{K_w+K+\frac{2K\delta}{b}}\,ln\left[A-t\left(K_w+K+\frac{2K\delta}{b}\right)\right]+c \tag{12}$$

For defining the value of constant of integration c, the following boundary conditions should be applied: $F=0\Rightarrow t=t_{out}$, which results in the following:

$$c=-\frac{Gc}{K_w+K+\frac{2K\delta}{b}}\ln\left[A-t_{out}\left(K_w+K+\frac{2K\delta}{b}\right)\right]$$

Substituting the value of c in (12), and after making formula manipulations, the following equation is obtained:

$$F=\frac{Gc}{K_w+K+\frac{2K\delta}{b}}\ln\frac{Kt_{out}+K\frac{Ip}{\alpha_{out}}+\frac{2K\delta}{b}t_{out}+K_w t_{in}-t_{out}K_w-t_{out}K-t_{out}\frac{2K\delta}{b}}{\left[\left(Kt_{out}+K\frac{Ip}{\alpha_{out}}+\frac{2K\delta}{b}t_{out}+K_w t_{in}\right)-t\quad K_w+K+\frac{2K\delta}{b}\right)\right]}$$

or finally:

$$F=\frac{Gc}{K_w+K+\frac{2K\delta}{b}}\ln\frac{K\frac{Ip}{\alpha_{out}}+K_w\left(t_{in}-t_{out}\right)}{K\left(\left(t_{out}-t\right)\left(1+\frac{2\delta}{b}\right)+\frac{Ip}{\alpha_{out}}\right)+K_w\left(t_{in}-t\right)} \tag{13}$$

Taking into account that the heat absorbing surface of the collector is $F = bl$ and the mass of air flow is $G = b\delta\omega\rho$, the last equation can be written in the following way:

$$l = \frac{\delta\omega\rho c}{K_w + K\left(1 + \frac{2\delta}{b}\right)} \ln \frac{K\frac{Ip}{\alpha_{out}} + K_w\left(t_{in} - t_{out}\right)}{K\left(\left(t_{out} - t\right)\left(1 + \frac{2\delta}{b}\right) + \frac{Ip}{\alpha_{out}}\right) + K_w\left(t_{in} - t\right)} \tag{14}$$

where

- δ = depth of collector perpendicular to the south wall, m, (distance from wall)
- ω = velocity of air flow inside the collector, m/sec
- K = heat transfer rate of front (south-facing) and side metal plates of the collector, $W/m^2{}^\circ C$
- K_w = heat transfer rate of south-facing wall construction of the house, $W/m^2{}^\circ C$
- b = width of collector along the south wall, m

The obtained formula (14) allows finding the height l, m of the collector for providing given temperature t, °C of warmed air on the outlet of the heater.

As can be seen from Equation (14), the value of l depends on many factors, such as the deepness δ, m of the collector, velocity of air flow ω, m/sec inside the collector, intensity of solar radiation I, W/m, heat transfer rates of metal plates K, $W/m^2{}^\circ C$ and south-facing wall of the house K_w, as well as on outside air t_{out}, and house inside space air t_{in}, °C temperatures.

To make more visible the dependence of l on listed factors, computer-aided calculations were made for the example of a house located in climatic conditions with $I = 350 W/m^2$ and $t_{out} = 4°C$. The values of heat transfer rates were assumed as $K = 6\ W/m^2{}^\circ C$ and $K_w = 1.0\ W/m^2{}^\circ C$. The values of δ and ω were assumed variable within $\delta = 0.1$ to 0.5m in case of $\omega = 0.05$m/sec. The width b, m of the collector is taken $b = 4$m. The results of calculations are represented by diagrams in Figure 2.

Analysis of the diagrams of Figure 2 shows that for given conditions the maximum temperature of the air can reach up to $t = 17°C$ at the height l = 2.8 m of the collector. This limit of the temperature t is conditioned by the radiation temperature t_{Rs} = 17.7°C on the dark surface of the collector. The increase of the depth δ, m brings a reduction of final temperature t and an increase of the height l,m of the collector as the heat lost from side walls of the collector increases.

Based on formula (14), the following equation for determining the value of temperature t°C at given height l, m of the collector is obtained:

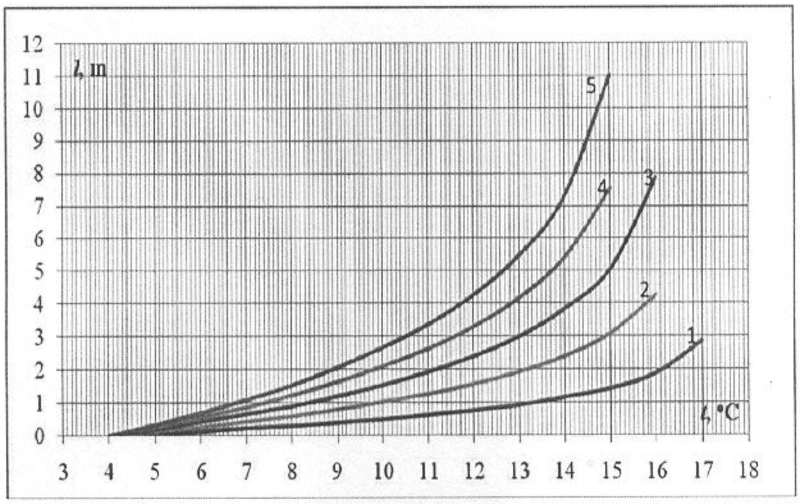


Figure 2. Heights l, m of solar air heater providing various final temperatures t, °C of air, in case of b = 4 m, ω = 0.05 m/sec = const and variable values of δ, m for the example of a house located in climatic conditions with I = 350W/m², t_{out} = 4°C and t_{in} = 20°C. 1) δ = 0,1m; 2) δ = 0,2m; 3) δ = 0,3m; 4) δ = 0,4m; 5) δ = 0,5m.

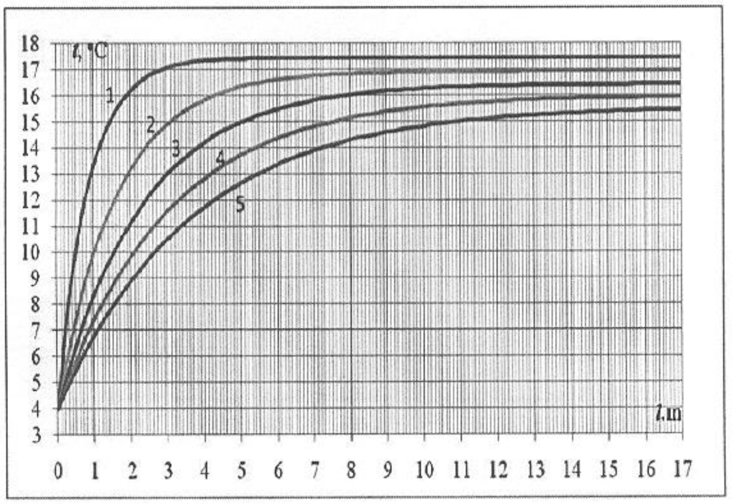


Figure 3. Final temperatures t, °C of air depending on heights l, m of solar air collector in case of b = 4 m, ω = 0.05 m/sec = const and variable values of δ, m for the example of a house located in climatic conditions with I = 350W/m², t_{out} = 4°C and t_{in} = 20°C. 1) δ = 0.1m; 2) δ = 0.2m; 3) δ = 0.3m, 4) δ = 0.4m; 5) δ = 0.5m

$$t = \frac{Kt_{out}\left(1+\frac{2\delta}{b}\right)+K\frac{Ip}{\alpha_{out}}+K_w t_{in}-\left(K\frac{Ip}{\alpha_{out}}+K_w\left(t_{in}-t_{out}\right)\right)e^{-\frac{l\left(K_w+K\left(1+\frac{2\delta}{b}\right)\right)}{\delta\omega\rho c}}}{\left(K_w+K\left(1+\frac{2\delta}{b}\right)\right)} \tag{15}$$

The calculations made for the same above-mentioned conditions to find the dependence of outlet temperatures t on the height l of the collector are shown by diagrams in Figure 3. The diagram shows that for given conditions the maximum temperature t of the air can reach up to t = 17°C at the height l = 2.8m of the collector. The further increasing of the height l, m doesn't help to increase the temperature t. This can be explained by establishing equality of heat gains and heat lost in the collector.

The calculations show that under negative temperatures of outside air the final temperatures of heated air can also be negative, which requires large quantities of energy for the heating of ventilation air up to the inside temperature t_{in}.

The analysis accomplished above shows the rather low efficiency of the discussed construction of a transpired solar collector that is conditioned by the relatively low radiation temperature t_{Rs} on the south-facing surface of a dark plate. The calculations also show that decreasing the value of heat convection coefficient a_{out}, W/m^2°C brings an increase of temperature t. This can be achieved by covering the surface of the collector by a glass sheet.

Development of Simple Construction of a Solar Air Heater for Ventilation and a Method for Its Design and Evaluation of Efficiency

A scheme for simplified construction of a solar air heater is suggested in Figure 4. The solar air heater consists of a rectangular hermetic box (1), the bottom (2), and side walls of which are insulated. The upside face of the box is covered by glass or other transparent single, double, or triple sheets (3). Side frames of the box are made of insulated metal sheets. Inlet (4) and outlet (5) air ducts are connected to the fascade walls of the box.

The heater operates in the following way: Solar rays penetrate through a glass cover (3) into the box and are absorbed by a black internal bottom and side surfaces. As a result, the internal surfaces and space

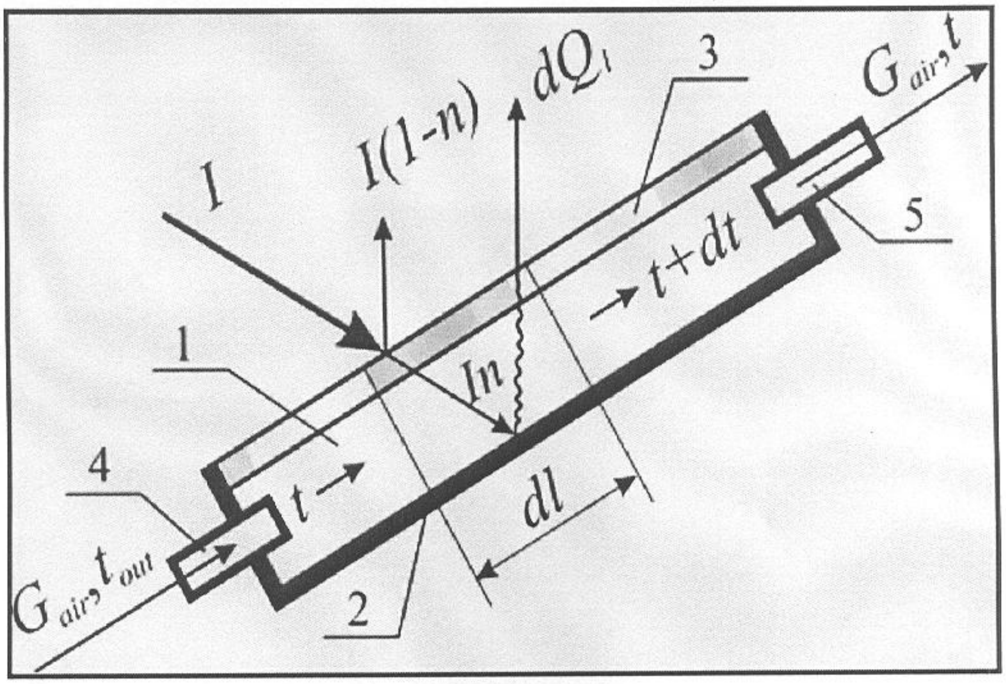


Figure 4. Simple construction of solar air heater

are heated. Ambient air enters the box through inlet duct (4), where it contacts the hot surface and gets hot. Heated air exits the collector and passes via the duct (5) into the ventilation system of the house.

The following method for calculation and design of the described solar air heater was developed. The quantity of solar heat Q_{sol} penetrating through the glass cover into the box makes:

$$Q_{sol} = FIn \tag{16}$$

where

F = surface of glass cover of solar heater, m^2

I = hourly average intensity of solar radiation falling on the solar collector mounted on southern facing part of the roof and inclined 30° relative to horizontal surface, W/m^2

n = rate of penetration of solar rays through glass cover, which is 0.55 for single-glazed, 0.44 for double-glazed, and 0.352 for triple-glazed covers.

A Q_l,W part of absorbed solar heat Q_{sol}, W is lost to outside air through the surface of glass cover, which makes:

$$Q_l = KF(t\text{-}t_{out}) \tag{17}$$

The quantity of useful heat Q_{us}, W received by the air flow in the heater makes:

$$Q_{us} = Q_{sol} - Q_l \tag{18}$$

The goal of calculations for the suggested heater is to determine the size of the hot box, including the width (b, m), length (l, m) and depth (δ, m) for providing required temperature t, °C of required quantity G_v, kg/sec. of the hot air under given outside air temperatures t_{out}, °C and solar radiation intensity I, W/m^2.

For describing the mentioned correlation, the method of calculation and design has been developed based on the following differential equations (18′) of energy balance (see Figure 4):

$$[In - K(t - t_{out})]\ dF = G_v c_{air} dt \text{ or } [(In + Kt_{out}) - Kt]\ dF = G_v c_{air} dt \tag{18′}$$

where:

- K = heat transfer coefficients of the glass cover, which are equal to 5.9 W/m^2°C for single-glazed, 2.9 W/m^2°C for double-glazed and 1.1 W/m^2°C for triple-glazed covers
- t_{out} = outside (ambient) air temperature, °C
- t = current air temperature along the heater, °C
- F = glass cover's surface of the solar heater, m^2
- G_v = ventilation air flow through the heater, kg/sec
- c_{air} = specific heat of air, J/kg°C

Denoting and integrating the equation will obtain:

$$F = -\frac{G_v c_{air}}{K} \quad 1n[A - Kt] + c \tag{19}$$

The value of the constant c of integration should be determined for the boundary conditions $F = 0 \Rightarrow t = t_{out}$, and then the following equation is obtained:

$$c = -\ \frac{G_v c_{air}}{K} \quad 1n[A - Kt_{out}]$$

Substituting the values of c and A in the equation (19), the following formula for determining F is obtained:

$$F = -\frac{G_v c_{air}}{K} \ln \frac{I \cdot n}{In + K(t_{out} - t)} \tag{20}$$

Taking into account that $F = b$ and $G_v = b\delta\omega\rho$, and substituting them in the equation (19), the following equations are obtained for determining the main characteristics of the solar air heater:

1. For determining final temperature t, °C of the air at the outlet of the heater in case of given length l, m:

$$t = t_{out} + \frac{I \cdot n}{K}\left(1 - e^{-\frac{Kl}{\delta\omega\rho_{air} c_{air}}}\right) \tag{21}$$

2. For determining required length l, m of the heater in case of given final temperature t, °C at the exit of the heater:

$$l = -\frac{\delta\omega\rho_{air} c_{air}}{K} \ln \frac{I \cdot n}{I \cdot n + K(t_{out} - t)} \tag{22}$$

where:

ω = velocity of the air in the heater, m/sec

ANALYSIS

Analysis of the last equations above prove that for providing higher temperatures of the air, the heater should have as low as possible values of height δ, m and velocity of the air ω, m/sec. It is recommended to keep the said values $\delta = 0.05$m and $\omega = 0.05$m/sec. However, in the case of a need for a large quantity of G_v, kg/sec air, such low values result in a large width b, m of the solar heater. For finding the best conditions for operation of the heater, special computing experiments have been executed. The final temperatures t, °C were determined depending on various values of length l, m and outside temperatures t_{out}, °C. As the heater serves for the preheating of ventilation air, the final temperature of the air is adopted equal to the required inside temperature t = 18-20°C of the heating period. The outside design temperature for the heating season is taken t_{out} = –19°C (climatic conditions of Yerevan, Armenia) and δ = 0.05m, ω = 0.05m/sec. The results of the calculations are shown in Figure 5.

As follows from the diagrams, the increase of the length l, m provides higher final temperatures of the air, which tends to a limit value and stays practically unchanged. The analysis shows that the limit values of final temperatures t °C of the air take place in case of the following lengths of heaters: for single-glazed heater l = 3m, which provides final temperature t = 13.5°C; for double-glazed heater l = 4m, which provides final temperature t = 32°C; and for triple-glazed heater l = 10m, which provides final temperature up to t = 88°C.

The diagrams in Figure 5 also show that required ventilation air temperature t = 18-20°C can't be provided in a single-glazed solar heater having even 10 m length, if outside air design temperature is t_{out} = -19°C. In double- and triple-glazed heaters having length l = 2m, the ventilation air under outside temperature t_{out} = –19°C is heated, respectively, up to 24°C and 40°C, considerably higher than the temperature t = 18°C needed for ventilation air. However, the double- and triple-glazed heaters are more costly. Thus, it is becoming clear that the factor of optimization of the heaters in the solar ventilation projects should be taken into account.

The diagrams also explain that under higher outside temperatures t_{out}, the final temperature t of the heated air grows. For example, under t_{out} = +8°C in the 2m-long, single-glazed heater the final temperature can reach up to 40°C, and in double and triple-glazed heaters up to 50°C and 64°C, respectively. This means that during the most part of

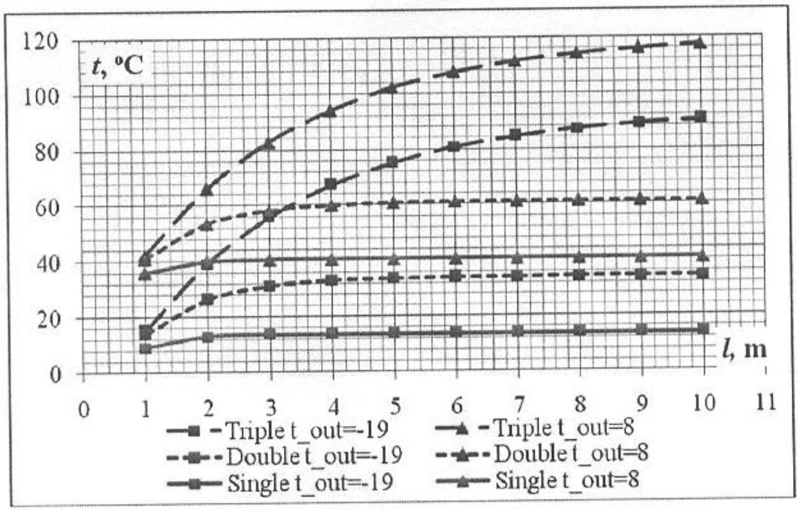


Figure 5. The final temperatures t,°C of the air in solar heaters of various lengths l, m under various outside temperatures starting from t_{out} = -19°C to t_{out} = +8°C. (δ = 0.05m, ω = 0.05m/sec.)

heating season the final temperatures of the heated air will be much higher compared to the design final temperature (t = 18-20°C) needed for ventilation.

The diagrams of Figure 5 are plotted for heaters having fixed parameters δ = 0.05m and ω = 0.05m/sec, and variable lengths l, m. To evaluate the influence of those parameters on the values of final temperatures, computing experiments were executed with the values of δ and ω variable and the length l = 2m constant. The results of calculations made for single- and double-glazed heaters are represented, respectively, in Figure 6a and Figure 6b.

From the diagrams in Figure 6, it follows that increasing values of δ and ω brings a decrease of final temperatures t of air. Therefore, the design of the heater should be made for acceptable temperatures and constructive parameters. For satisfying the stated conditions, it is important to first select the heater's technically possible or acceptable length l, which should not exceed 6-8m. Then, the width b, m of the heater has to be defined for given ventilation air flow G_v, kg/sec, using the following fraction:

$$b = \frac{G_v}{\rho_{air}\delta\omega} \tag{23}$$

In the last formula (23) the value of the production $\delta\omega$ can be replaced by the following equation obtained after modifying the formula (22):

$$\delta\omega = \frac{IK}{\rho_{air} c_{air}\, lk \dfrac{I}{1 + \dfrac{K(t_{out} - t)}{I \bullet n}}} \tag{24}$$

Substituting the obtained value of $\delta\omega$ in the equation (22), the following equation is obtained for determining the required value of the heater's width b, m if the length l, m, climatic conditions, and quantity of ventilation air G_v, kg/sec are given:

$$b = \frac{Gvc_{air}}{lK} \ln \frac{I}{1 + \dfrac{K(t_{out} - t)}{I \bullet n}} \tag{25}$$

Figure 6a. Final temperatures of air for single-glazed heaters (K = 5.9W/m²°C) under variable values of δ and ω. 1) ω = 0.05m/sec; 2) ω = 0.25m/sec; 3) ω = 0.45m/sec; 4-ω = 0.65m/sec.

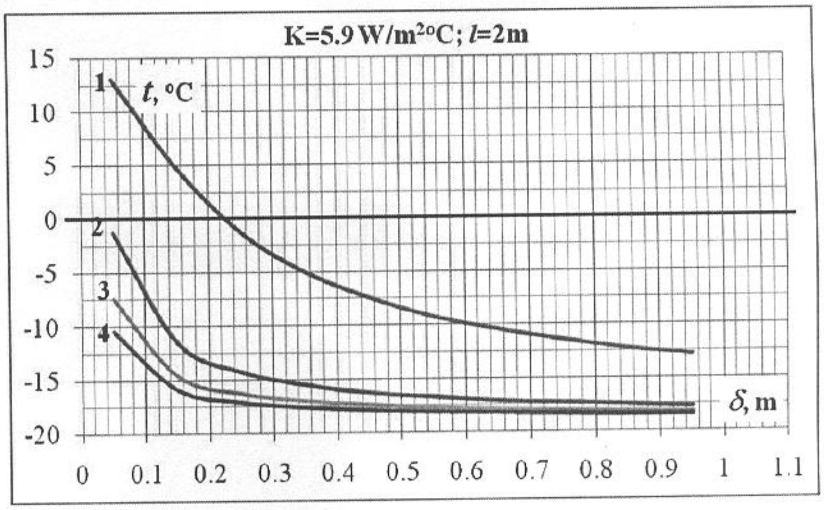
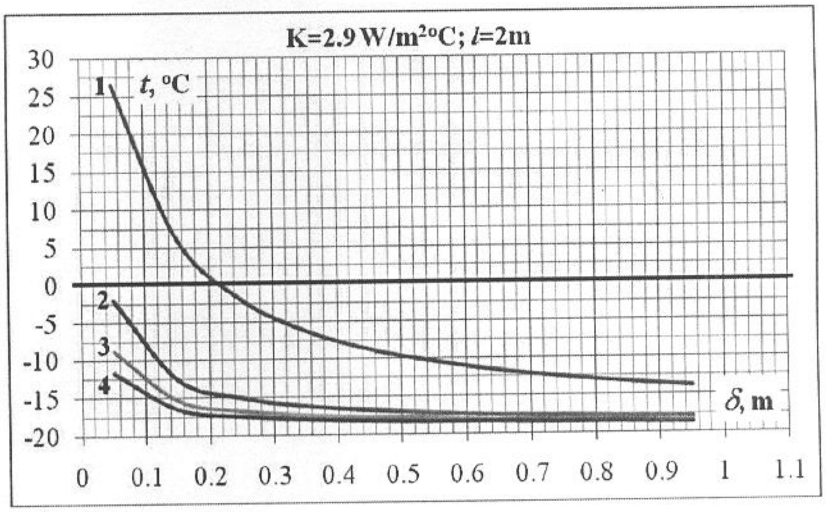


Figure 6b. Final temperatures of air for double-glazed heaters (K = 2,9W/m²°C) under variable values of δ and ω. 1) ω = 0.05m/sec; 2) ω = 0.25m/sec; 3) ω = 0.45m/sec; 4) ω = 0.65m/sec.



If the width *b*, m of the heater exceeds the available technical facilities, then a double- or triple-glazed heater should be selected, and the same calculation has to be executed until all thermal and constructive conditions are satisfied.

The thermal productivity or useful heat of the heater can be determined by the following formula:

$$Q_{us} = G_v c_{air}(t - t_{out}) \tag{26}$$

ENERGY EFFICIENCY OF SOLAR HEATERS

To find the most effective conditions for using the suggested construction of a solar air heater, it is necessary to have a method for evaluating its energy efficiency. As a value of energy efficiency we suggest using the ratio of the solar energy (absorbed by the heater) that is transformed into useful heat to the total incident solar radiant heat on the glazed surface of the heater. According to this definition, the energy efficiency $\eta_{s.h}$ of a solar air heater is determined by the following fractions:

$$\eta_{s.h} = \frac{Q_{us}}{IF} \text{ or } \eta_{s.h} = \frac{Q_{us}}{Ibl} \text{ or } \eta_{s.h} \text{ or } \frac{G_v c_{air}(t - t_{out})}{Ibl} \quad (27)$$

If replacing G_v by $G_v = b\delta\omega\rho$, formula (26) will be expressed in the following way:

$$\eta_{s.h} = \frac{b\delta\omega\rho c_{air}\,(t - t_{out})}{Ibl} \text{ or } \eta_{s.h} \; \frac{\delta\omega\pi c_{air}\,(t - t_{out})}{Il} \quad (28)$$

Substituting in the last equation (28) the value of t from the formula (21) and making simplifications, the following final expression for determining the energy efficiency $\eta_{s.h}$ is obtained:

$$\eta s.h = \frac{\delta\omega\rho c_{air} n}{lK} \; 1 - e^{-\frac{Kl}{\delta\omega\rho c}}) \quad (29)$$

Based on formula (29) calculations were made to evaluate possible values of energy efficiency $\eta_{s.h}$ of solar air heaters for different combinations of δ, m; ω, m/sec; and lengths l, m.

RESULTS

The results of calculations are represented by diagrams in Figure 7a and Figure 7b. Analysis of formula (29) and diagrams in Figure 7 prove that the energy efficiency $\eta_{s.h}$ of the described air solar heater is conditioned by its main δ and l constructive characteristics, the number of glazings of the cover sheets, and the velocity of air ω. Specifically, the longer the heater, the lower its efficiency. Increase of δ and ω brings a significant increase in energy efficiency $\eta_{s.h}$ of the described air solar heater, regardless of the number of glazings of the cover sheets. However, in this case the efficiency $\eta_{s.h}$ of a single-glazed heater is higher than for double- and triple-glazed heaters. Despite the noted advantage, it should be taken into account that in the case of $\delta > 0.05m$ and $\omega > 0.05m/$

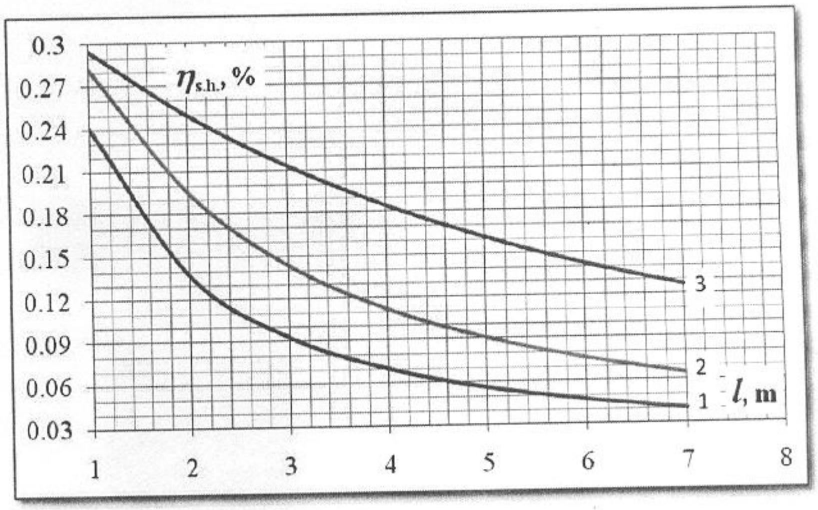


Figure 7a. Diagrams for determining energy efficiencies $\eta_{s.h}$ of air solar heaters in case of δ = *0.05* m, and ω = *0.05m/sec.* Curve 1- in case of single-glazed cover. Curve 2- in case of double-glazed cover. Curve 3-in case of triple glazed cover.

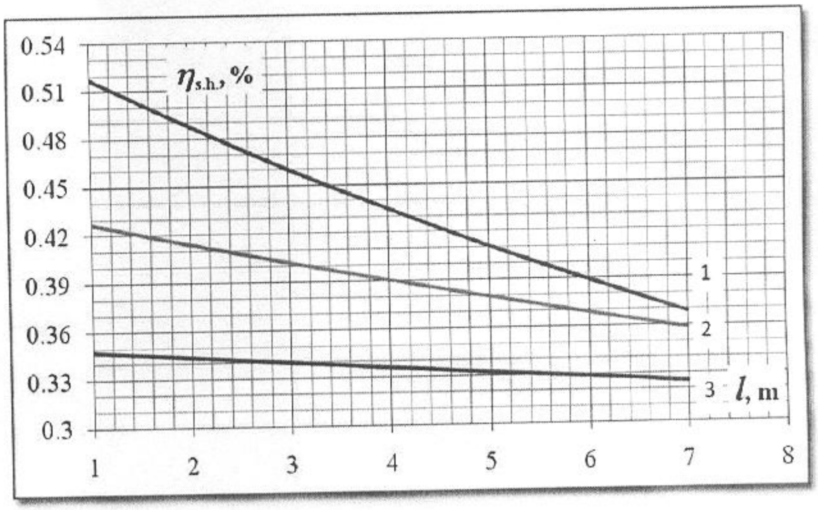


Figure 7b. Diagrams for determining energy efficiencies $\eta_{s.h}$ of air solar heaters in case of for δ = *0.2* m and ω = *0.2m/sec.* Curve 1- in case of single-glazed cover. Curve 2- in case of double-glazed cover. Curve 3-in case of triple-glazed cover.

sec, the single-glazed heater doesn't provide high enough temperatures as those required for ventilation air.

Using the diagrams of the energy efficiency $\eta_{s.h}$ of Figure 7, it is possible to determine the width b, m and other constructive parameters of the heater. For this purpose the following formula can be used:

$$b = \frac{Q_{us}}{\eta_{s.h} I l} \tag{30}$$

In the formula (30) the ventilation heating load is determined by the help of the following equation: $Q_v = G_v c_{air}(t_{in}\text{-}t_{out})$ in which the value of quantity of ventilation required air is calculated by the following product:

$$G_v = 0.0067N \tag{31}$$

where

0.0067 kg/sec/pers = ventilation air normative quantity for one person
N = number of persons (occupants) of the house

The value of intensity of solar radiation I, W/m^2 on the south-oriented surface of the heater can be taken as average $I = 350\ W/m^2$. The length l, m of the heater is determined from the provision of required temperature of ventilation air $t = t_{in} = 18°C$. For this purpose the diagrams in Figure 5 have to be used with the help of the number of glazing sheets of the heater, as well as the values of δ, m and ω, m/sec.

The value of the energy efficiency $\eta_{s.h}$ is determined in Figure 7 according to the determined values of δ, m and ω, m/sec. Substituting the mentioned values in the formula (30), the correct design value of the width b, m can be determined.

EXAMPLE OF DESIGN

Based on the developed method, a suggested type of solar heater was designed for ventilation of a 7-inhabitant house.

The house is located in Yerevan city, Armenia, having the following climatic parameters:

1. Outside design temperature $t_{out} = -19°C$.
2. Required temperature of the ventilation air at the outlet of solar heater $t = t_{inv} = 18°C$.
3. Solar radiation average intensity on the south-facing orientation $I = 350 W/m^2$.
4. Required quantity of ventilation outside fresh air flow for 7 inhabitants $G_v = 0.0466$, kg/sec
5. The ventilation heating load makes:

$$Q_v = G_v c_{air}(t_{in}-t_{out}) = 0.0466*1000(18-(-19)) = 1724W$$

From the diagram in Figure 5, it can be seen that t_{in} = 18°C air can be prepared by a double-glazed l = 2 m-long heater having height δ = 0.05m and air velocity ω = 0.05m/sec. From the diagram in Figure 7a the efficiency is taken for a chosen double-glazed heater, which makes $\eta_{s.h}$ = 0.19.

Substituting the determined values Q_v = 1724W, $\eta_{s.h}$ = 0.19, I = 350W/m^2, and l = 2 m in the formula (30), the value of width b, m for designing of the appropriate solar air heater is determined:

$$b = \frac{1724}{0.19 \cdot 350 \cdot 2} = 12.96m$$

Thus, a solar heater designed by the obtained constructive parameters l = 2m, δ = 0.05m and b = 12.96m can provide the required heating load Q = 1724W for ventilation of the example house, even with outside air design temperature t_{out} = –19°C. It is obvious that during the heating season, when the outside air temperatures are higher (t_{out}> –19°C), the chosen heater can provide much more heat than is needed for ventilation and, therefore, will additionally cover a significant part of the heating load of the house.

It is clear that if we choose a triple-glazed heater, the width b, m of the heater will be significantly less than would be obtained for a double-glazed heater.

CONCLUSIONS

1. The existing construction of a transpired-type air solar heater should have limited use because of low efficiency.
2. The suggested construction of a solar ventilation system and method for its calculation allow developing, designing, and implementing high efficiency ventilation in residential houses and saving large quantities of fuel.
3. The method for evaluation of energy efficiency can be used for other types of solar collectors too.
4. To make a final decision for the selection of proper dimensions for a solar air heater, "efficiency/cost" optimization analysis should be performed.

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