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# HEAT PUMPS. CALCULATION ELEMENTS FOR SOLAR AIR HEATERS

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***Abstract:*** *Solar energy is an alternative source of green, free and widely available energy. It can meet all current and future needs of the world respecting the conditions of sustainable development. Heat pumps are devices that convert energy from external heat sources (air, water, etc.) into useful heat, which can then be used to heat premises and/or supply hot water in residential or commercial buildings. In this paper, a classification of heat pumps and several types of solar air heaters are presented. Also presented are some calculations for determining their energy performance to improve the heat transfer rate.*

***Keywords:*** *Heat pumps, solar panels, solar air heaters, renewable energy*

## 1. Introduction

Heating is the largest final energy consumption, accounting for almost half of total energy consumption in most countries.
Energy efficiency and renewable energy are of paramount importance in the European Union (EU) strategy for sustainable development. The ambitions for low-carbon economies and secure and competitive energy systems were endorsed in Directive (EU) 2018/2001 of the European Parliament [1].
Various factors are demotivating the growth of conventional fuels for power generation, such as limited availability of nuclear power and coal reserves and pollution threats, which harm flora and fauna. It is therefore necessary to meet the energy consumption target by using such energy resources that are abundantly available in nature and create less pollution [2].
Heat pumps are energy recovery systems that use some of the electricity to transfer heat at higher temperatures from external soil or air to a building's heating and hot water circuits. Aerothermal, geothermal and hydrothermal energy are considered renewable energy sources [3].
Heat pumps are becoming an increasingly popular choice for a home's heating and cooling needs. Flexibility, efficiency, long-term return on investment and low environmental impact are just some of the reasons homeowners are looking to replace older heating equipment with heat pumps that use renewable energy. The sun provides the most readily available source of energy available on earth as direct solar irradiation and indirect forms such as wind, agriculture, hydropower, and the sea [4].
The heat pump can be connected to radiators, underfloor heating, fan coils or domestic hot water, in a similar way to how the boiler is currently connected. What differentiates the heat pump from the boiler is how heat is generated, not how it is distributed. Thus, instead of burning fuel to generate heat, a heat pump uses a process of evaporation and condensation of the refrigerant.
The principle of operation of heat pumps is based on the essential element in the process of capturing and yielding energy, on the refrigerant in the inner circuit of the heat pump.
The refrigerant can go from liquid to cold vapor. The liquid refrigerant enters the evaporator, where heat transfer occurs through vaporization, from the energy source to the refrigerant. At the outlet of the evaporator, the refrigerant is in a state of cold vapor.
Cold refrigerant vapors enter the compressor, where with the help of electricity, their pressure and temperature increase occurs. Hot refrigerant vapor enters the condenser, where heat transfer occurs (by condensation) to the thermal agent in the closed circuit of the heating system. At the exit of the condenser, following condensation, the refrigerant is in liquid state. The liquid refrigerant passes through the expansion valve, where its temperature and pressure decrease and from this moment the cycle resumes.

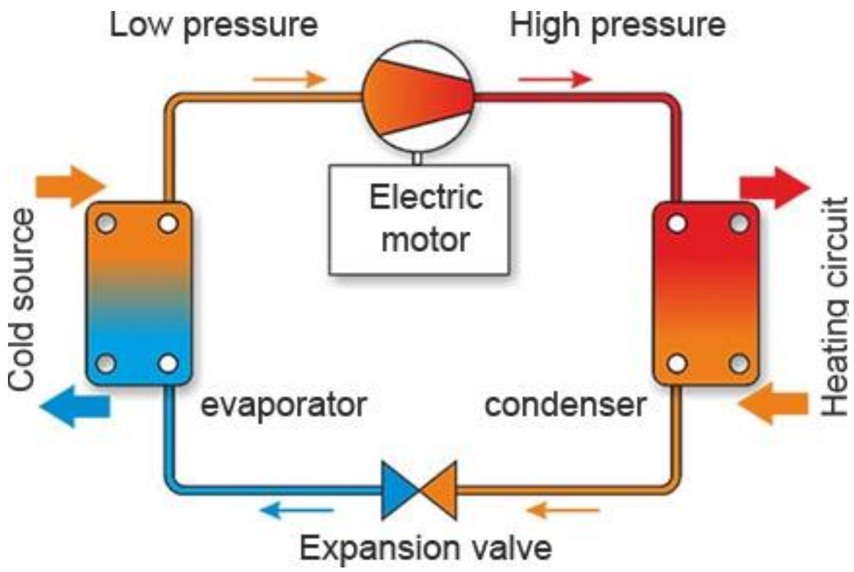



**Fig. 1.** The principle of operation of heat pumps

**Table 1:** Types of heat pumps [2]

| | | |
|---|---|---|
| 1. | Air-to-air heat pump | Air-to-air heat pumps, commonly known as air conditioners, are an easy-to-install option with little investment. The heat pump uses energy from the air to provide both heating and cooling capacities in an energy-efficient way. |
| 2. | Air-to-water heat pump | The air-to-water heat pump extracts heat from the outside air to heat the refrigerant (e.g. R32) which in turn passes it on to the water circulating through the heating systems in the home. This pump variant is considered to be the most economical in terms of investment and can operate efficiently up to an outside temperature of up to -28°C. |
| 3. | Ground-to-Water Heat Pump | The ground-to-water heat pump uses ground energy, also known as geothermal energy, to produce heat and chilled water. It works on the basis of a closed circuit, consisting of the heat pump, geothermal drilling (vertical or horizontal collectors depending on the existing land surface and drilling possibilities) and the heating system in the house. By extracting energy from the ground, geothermal heat pumps are extremely reliable, even in the coldest climates. Soil temperatures remain stable throughout the year, making it an ideal renewable energy source. |
| 4. | Ground-to-air heat pump | A dual source heat pump is a solution that combines an air source heat pump and a geothermal heat pump. |
| 5. | Water-Water Heat Pump | It uses groundwater in the groundwater as a source for heat production. Water from lakes or rivers can also be used for heating. Water-to-water heat pump requires vertical well drilling. In order for it to be properly connected to the water source, the direction of groundwater flow must be taken into account. At the same time, it is a suitable solution for houses and dwellings close to a water source. |

## 2. Solar Air Heaters

A solar air heater is a device used to heat air as an energy transfer medium that has several advantages over liquid solutions. Various problems are associated with liquid solar heaters, corrosion problems, fluid leakage and fluid transfer power [5]. All these problems are eliminated by using air instead of liquid in solar heating devices. Solar air heaters collect cooled air from the bottom of the space and distribute it through solar heat exchangers (fig 2). Since these simple methods and direct transfers do not store heat, they are ineffective at night or in gloomy conditions [6].

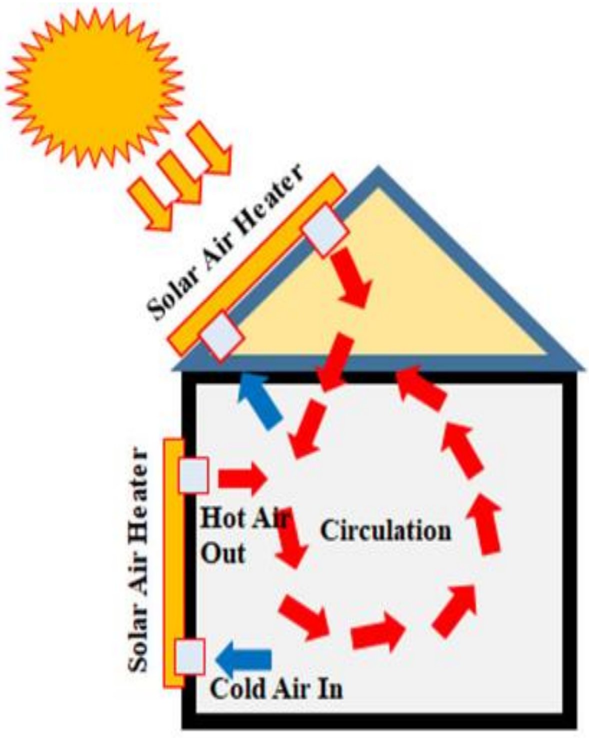
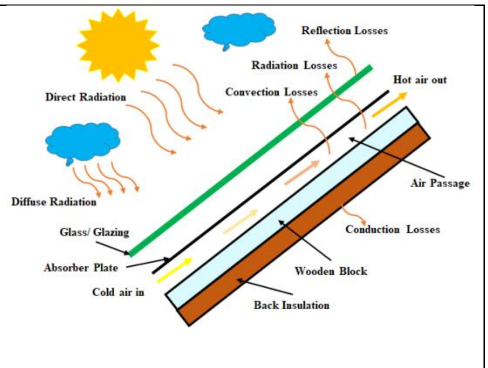
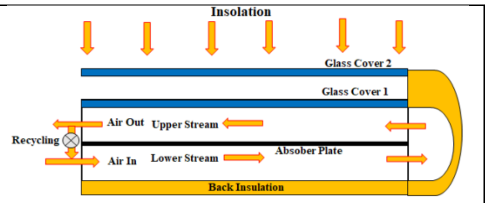
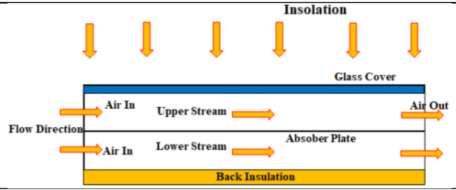
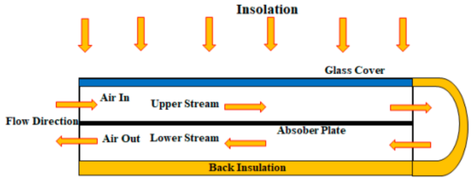
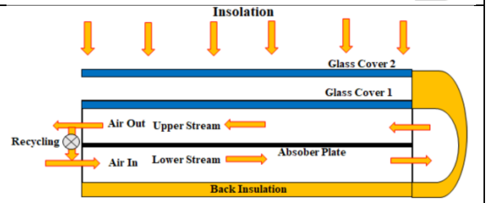
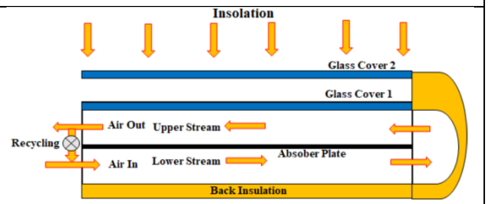



**Fig. 2.** Air circuit in heating systems with solar air heaters

Solar air heaters are classified according to their glass coatings, absorbent material, flow characteristics, flow types, absorbent surface texture, hybrid systems, and applications.

**Table 2:** Classifications of solar air heaters

| | | | |
|---|---|---|---|
| 1. | Single-pass | A single-pass solar air heater has air as its working medium. It has a glass cover, a single flow channel, an absorbent plate that has heat absorption capacity due to a dark paint or color, and insulation to cover the back of the channel to reduce thermal losses in the surrounding area. Generally, a blower is attached to the solar air heater to create a forced circulation of working fluid in the system [7]. |  |

| | | | | |
|---|---|---|---|---|
| 2. | Double-pass | | The Double-Pass SAH (DPSAH) concept has been designed to limit heat loss in the surrounding area. Air passes along both sides of the motherboard, extracting heat from the motherboard, and then air blows in both directions of the motherboard in a double-pass configuration [8]. |   |
| | 2.1 | Parallel flow | In this type, air passes between the back insulating layer and the motherboard. The second air passage is positioned slightly above the motherboard and between the glass covers and the motherboard. |   |
| | 2.2 | Counter current | The counter current model is attractive because it allows additional heat to be extracted, resulting in improved thermal performance. |   |
| | 2.3 | Recycling | The mixture of air and the intensity of forced heat convection have recently been shown to play a critical role in increasing heat transfer. Part of the heated output air is redirected to the intake duct and mixed with new inlet air using a blower. |   |
| 3. | Multi-pass | | The use of two or more glass coatings is a common practice when the solar air collector is operating at relatively high temperatures or is exposed to strong winds. This helps prevent convection and heat loss from the collector caused by radiation. Due to the absorption and reflection of sunstroke by the roofs, the amount of solar energy coming into contact with the heated surface is reduced when using many glass caps [9]. |   |

## 3. Calculation elements for solar air heaters [2]

The thermal performance of a solar air heater refers to its ability to improve heat transmission. The effectiveness of a solar air heater is the energy balance, comprised of the solar-irradiation energy yield to the collectors, the useable energy gained by airflow, and the losses to the environment.
The energy balance under controlled conditions for a collector is given as:

$$Q_u=[I(\tau\alpha)-U_t(T_{pm}-T_a)] \tag{1}$$

Where

$Q_u$ = useful heat again, W/m$^2$;
$U_t$ = total loss coefficient, W/m$^2$K;
$T_{pm}$ = average plate temperature, K;
$T_a$ = ambient temperature, K.

The effective transmittance 0 product ($\tau\alpha$) is a factor that handles the dynamic interactions of the optical characteristics of the glass and the absorber surface. In reality, the configuration of the absorber, incident solar energy, fluid velocity, and fluid characteristics all influence the mean temperature of the base plate and can be calculated with the formula (2):

$$Q_u=F^{'}[I(\tau\alpha)-U_l(T_{fm}-T_a)] \quad (2)$$

However, the mean absorber-plate temperature, $T_{pm}$, and average fluid temperature, $T_{fm}$, are generally unknown. The above equation can be modified for more practical use and is given as follows:

$$Q_u=F_r[I(\tau\alpha)-U_l(T_{fi}-T_a)] \quad (3)$$

Where: the heat-removal factor ($F_R$) can be calculated as formulas (4):

$$F_r=\frac{\dot{m}C_p}{U_l}\left[1\text{-}\exp\left(\frac{-F^{'}(U_l)}{\dot{m}C_p}\right)\right] \quad (4)$$

The thermal efficiency ($\eta_{th}$) of a solar air heater can be calculated as formulas (5):

$$\eta_{th}=\frac{Q_u}{I} \quad (5)$$

From Equations presents the following relationships can be obtained as formulas (6), (7),(8):

$$\eta_{th}=\left[\tau\alpha-U_l\frac{(T_{pm}-T_a)}{I}\right] \quad (6)$$

$$\eta_{th}=F^{'}\left[\tau\alpha-U_l\frac{(T_{fm}-T_a)}{I}\right] \quad (7)$$

$$\eta_{th}=F_R\left[\alpha\tau-U_l\frac{(T_{fi}-T_a)}{I}\right] \quad (8)$$

The above Equations (6)–(8) are recognized as the Hottel–Whillier–Bliss equations. Bondi [10] provided the expression for solar air heater thermal efficiency ($\eta_{th}$) that applies to the air-outlet temperature to calculate the $\eta_{th}$ of solar air heater when pulling air from the atmosphere:

$$\eta_{th}=F_R\left[\tau\alpha-U_l\frac{(T_{f0}-T_{fi})}{I}\right] \quad (9)$$

Where: $F_o$ is the heat-removal factor based on the temperature of the output air and is written as formula (10):

$$F_0=\frac{\dot{m}C_p}{U_l}\left[\exp\left(\frac{F^{'}U_l}{\dot{m}C_p}\right)\text{-}1\right] \quad (10)$$

## 4. Heat transfer performance of solar air heaters

A solar air heater performance may be determined using this efficiency with the ratio of helpful energy gain to solar radiation during a limiting time. Mathematically, it can be expressed as formula (11):

$$\eta=\frac{\int_0^\theta Q_u d\theta}{A_c \int_0^\theta I d\theta} \quad (11)$$

Where:

*η* = average collector efficiency over a period of time;
*I* = intensity of global incident radiation, W/m$^2$;
$Q_u$ = useful heat gains over a period of time;
$A_c$ = collector-plate area, m$^2$;
*θ* = time interval, seconds.

For any short period, the $\eta_{th}$ of a collector is simply the ratio of the rate of useable energy to the intensity of incoming radiation at that precise moment in time and may be expressed as (12):

$$\eta_{th}=\frac{Q_u}{I} \quad (12)$$

The thermal efficiency $\eta_{th}$ can be expressed as (13):

$$\eta_{th}=\frac{\dot{m}C_p(T_{f0}-T_a)}{IA_c} \quad (13)$$

The $\eta_{th}$ evaluations of the solar collector are required to obtain the fundamental design data utilized to develop collector systems. (a) The National Bureau of Standards (NBS) and (b) the American Society of Heating Refrigeration and Air Condition Engineering (ASHRAE) standards 93-77 are the two techniques for solar-collector standard testing.
NBS recommends the following $\eta_{th}$ equation (14):

$$\eta_{th}=F^{'}\left[\tau\alpha-U_l\frac{(T_{fm}-T_a)}{I}\right] \quad (14)$$

It is recommended [11] the following equation for $\eta_{th}$:

$$\eta_{th}=F_R\left[\tau\alpha-U_l\frac{(T_{fi}-T_a)}{I}\right] \quad (15)$$

Where: $F_R$ = receiver heat-removal factor.

Configuration for a solar collector of predefined specifications ($\eta_{th}$) can be indicated in the following set of equations (16)-(20).

**Case A:** with air recycling, i.e., ($T_{fi} > T_a$)

$$\eta_{th}=F^{'}\left[\tau\alpha-U_l\left\{\frac{(T_{f0}-T_a)+(T_{fi}-T_a)}{I}\right\}\right] \quad (16)$$

$$\eta_{th}=2\dot{m}C_p\left[U_l\left\{\frac{(T_{f0}-T_a)+(T_{fi}-T_a)}{I}\right\}\right] \quad (17)$$

**Case B:** without air recycling, i.e., ($T_{fi} = T_a$)

$$\eta_{th}=F^{'}\left[\tau\alpha-U_l\left\{\frac{(T_{f0}-T_a)}{2I}\right\}\right] \quad (18)$$

$$\eta_{th}=F^{'}\left[\tau\alpha-U_l\left\{\frac{(T_{f0}-T_a)+(T_{fi}-T_a)}{2I}\right\}\right] \quad (19)$$

$$\eta_{th}=2\dot{m}C_p\left[\left\{\frac{(T_{f0}-T_a)}{2I}\right\}\right] \quad (20)$$

These characteristics are shown in Fig. 3, known as design curves [12].

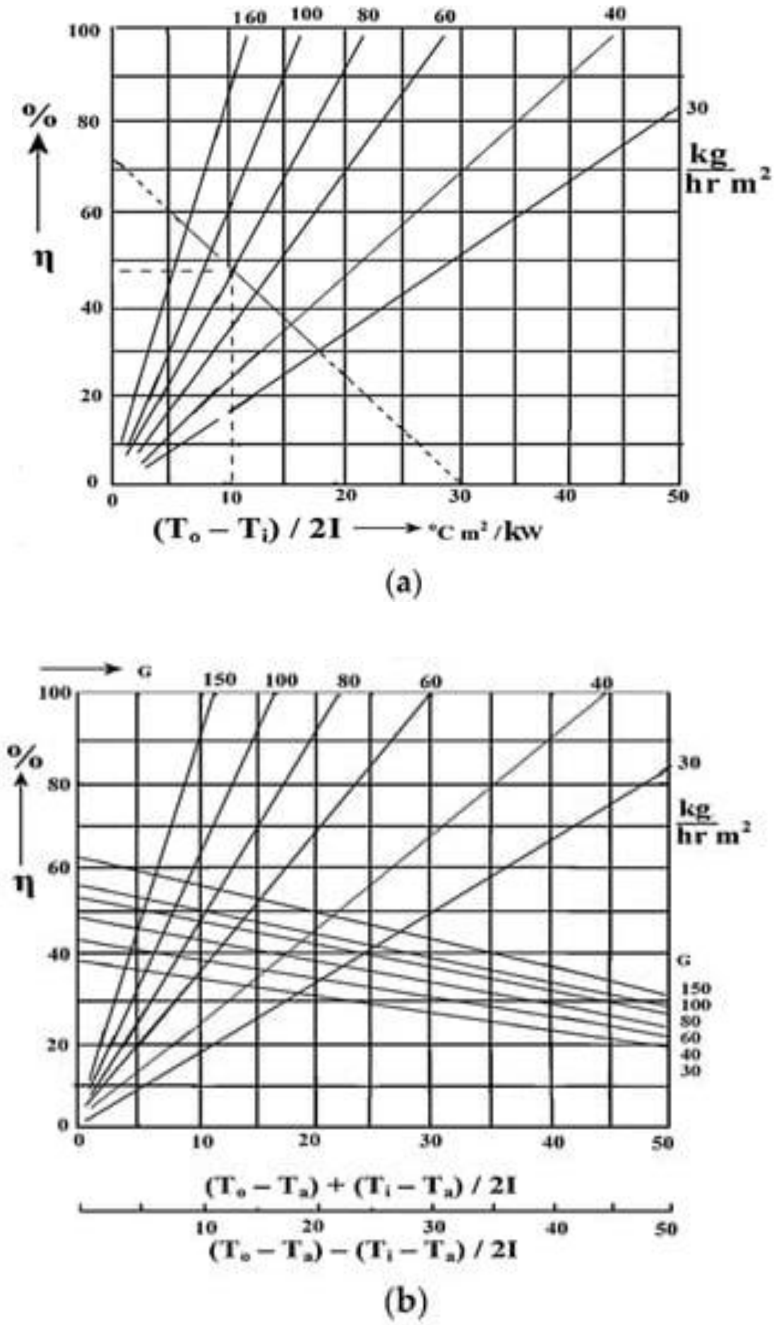



**Fig. 3.** Design curves (**a**) with air recycling and (**b**) without air recycling.

## 5. Conclusions

The performance of solar air heaters is greatly influenced by solar irradiance, atmospheric and air temperatures and air velocity, and energy from heated air cannot be stored yet.
Further research into solar air heaters could lead to new, efficient and low-cost hot air generating equipment solutions alone or in combination with other heating systems resulting in simpler, high-efficiency, environmentally friendly heating equipment that contributes to long-term sustainability.

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