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UTILIZATION OF SOLAR ENERGY IN COLD CLIMATE

Bachelor's thesis

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DESCRIPTION

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Abstract <p>Solar radiation is a source of life on the Earth. The sun heats the atmosphere and the surface of our planet. Because of the sun winds are blowing, circulation of water is happened, seas and oceans are heated, and plants are growing. Nowadays people know how to transfer solar radiation straightly into energy. The subject of the project is to research the possibilities of utilization of solar energy in cold climate. At this project the model of calculation solar energy is shown. Following factors are taken into account: location, geographic latitude first of all; position of the Earth on the orbit because of the rotation around the Sun; time of the day depend on Earth spinning motion; solar energy absorption and solar radiation dispersion of clear atmosphere. Next group of factors which influence on solar radiation are climatic factors. It includes real weather conditions (clouds, rains, haziness), anthropogenic pollution (impacts of different factories, traffic).</p> <p>As an example of utilization of solar energy one family house in Tyumen (Russia, Siberia) is taken. Now only natural gas is used for heating for this kind of buildings in this region. Values of solar energy there are very low during winter period. That is why it is decided to use solar energy only for heating hot domestic water during summer period. Discount cash model is used for cost efficiency calculation. Project is cost efficient. Investment cost of equipment which transforms solar energy into heat looks too high in comparison with costs of natural gas or light oil. Sometimes it is not cost-beneficial to use solar systems. However fossil fuel usage has a great influence on the ecology of our planet.</p>		
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Introduction

Solar radiation is a source of life in the Earth. The sun heats an atmosphere and surface of our planet. Because of sun winds are blowing, circulation of water is happened, seas and oceans are heated, and plants are growing. Fossil fuels exist because of sun. Nowadays people know how to transfer solar radiation straightly into electricity and heat.

Solar energy became very popular. It has a lot of benefits. First of all solar energy is free of charge. Of course it has an investment costs (costs of equipment) but operating cost are very low.

The next point is that ecological situation in our world is so good, as we want. So, we must try to prevent this situation and find solutions for ecological problems. Fossil fuels such as coal, oil, and natural gas in one side are fundamental parts of industry and the other side they are harmful for nature and environment. Using solar energy we will have no impacts, it is absolutely environmentally friendly.

The next problem is so, that fossil fuels are not renewable. Of course we need energy, and it's consumption must be enough for normal life, but can we protect our future? Solar energy is renewable, it is the greatest benefit.

Solar energy can be used for electric generation, for solar drying (solar croup drying technology), for solar cooking, for distillation of water, and of course for heating water. HVAC designers use solar energy in domestic hot water systems, in heating systems (including floor heating), and in pool heating.

Solar thermal technologies are very common for southern countries. The reason is that the total solar radiation is highest in the equator, especially in sunny, desert areas. Amount of solar radiation depends on many factors. For example: geographical location, cloud cover, hours of sunlight per day, etc.

The aim of my work is to answer the question: Is it possible to use solar radiation in northern regions? The angle at which sun strikes the earth's surface

changes during the year, so, the solar radiation changes. Thus, in northern countries in winter, where the sun is low in the sky, solar energy is very low. So, it is a question, can we use solar energy in this regions full year or only in summer time?

Because of cold climate maybe we can't get high temperatures, so, I would like to determine the potential ways of using these temperatures in systems.

I want to answer these questions using the example. My example is utilization of solar energy in one family house in my native city Tyumen (Russia, Siberia). Now only gas is used for this kind of buildings in this region. I would like to research is there any possibility of using solar energy. Of course it is a question of cost also. I would calculate costs efficiency of this project.

1. General information about usage of energy

Nowadays traditional ways of getting energy are used. Heat power plants and hydroelectric power plants are built, nuclear power plants are popular in many countries. These main branches of energetics are parts of global system, which is named “blood-vascular system” of our civilization, provide living standard, but on the other hand they damage environment.

It is known, that mineral resources are not renewable. But it is not the main problem. The real problem today is their bad influence on nature. The main imperfection of the fuel in thermal power plants is pollution of environment with harmful emissions. Even modern power plants are not safe from ecological point of view. In addition, production, treatment, and transportation have their harmful effect.

Hydroelectric power plants (produce 15% of total energy consumption) also damage nature. Construction of dams on the rivers and large areas of storage ponds can cause serious ecological problems.

Disadvantages of nuclear power stations are well known. Storage and treatment of radioactive waste has very harmful effect. There is a risk of radiation pollution in time of emergency, like in Chernobyl disaster.

Maybe thermonuclear power stations will be safe in future, many scientists are involved in this project. Nowadays required total consumption of using energy is near 11,791 billion tones of equivalent fuel (one ton of equivalent fuel gives 11,63 MWh of energy) /1/. This value rises all the time. Firstly because of increase in population (now it is 6 billion people and it will be as predicted 7,4 billion by year 2020). Secondary because of growth of people’s living standard, especially in developing and in highly industrialized countries.

Global demand of energy will rise many times and will be 34 million tones of equivalent fuel per year till 2020. This increasing of energy production will influence

too match on the Earth environment, and may become one of the reasons of global warming.

Using of alternative or renewable energy sources can help to solve this problem. They are more environmental friendly, than traditional source of energy.

Solar energy is the most attractive renewable resource. Solar energy comes to the earth billions of years, and is involved to each process. It is totally ecologically clean. Solar radiation must be used in a large scale to save the unique climate of our earth.

Every year $1,03 \cdot 10^{18}$ kWh of solar energy comes to the earth./1/ We can use 1,5% of solar radiation or $1,6 \cdot 10^{14}$ kWh without an influence on Earth ecology (without changes in climate and nature energy exchange). It is more than 100 times higher, than total yearly energy consumption.

Solar radiation depends on time of the day, season, and weather conditions. Average value of solar radiation on the Earth surface is not high. For example, when angle of latitude is 40° , solar radiation is near $0,3 \text{ kW/m}^2$. /1/ It is five times lower, than it is in the border of the atmosphere ($1,4 \text{ kW/m}^2$). Solar radiation must be collected from large areas and accumulated.

Development of utilization of solar radiation becomes one of direction of public policy in many leading countries. UNESCO, European Commission U.N.O., energy department of U.S.A. are looking at this question. Worldwide organization of development and spreading of energy technologies ODET is created and it works quit well.

2. Nature of solar radiation

Solar radiation characteristics on the Earth surface.

Solar radiation is different in different places on the Earth. The reasons are:

1. Solar radiation is not perpendicular to Earth surface all the time.
2. Daylight hours are limited.
3. Part of solar radiation is absorbed and diffracted in clear atmosphere.
4. Solar radiation is absorbed and diffracted by clouds and anthropogenic particles.

2.1. Influence of geographical and astronomic factors.

Basic principle of calculation of total consumption of solar radiation in different parts of the Earth are shown in **figure 1**.

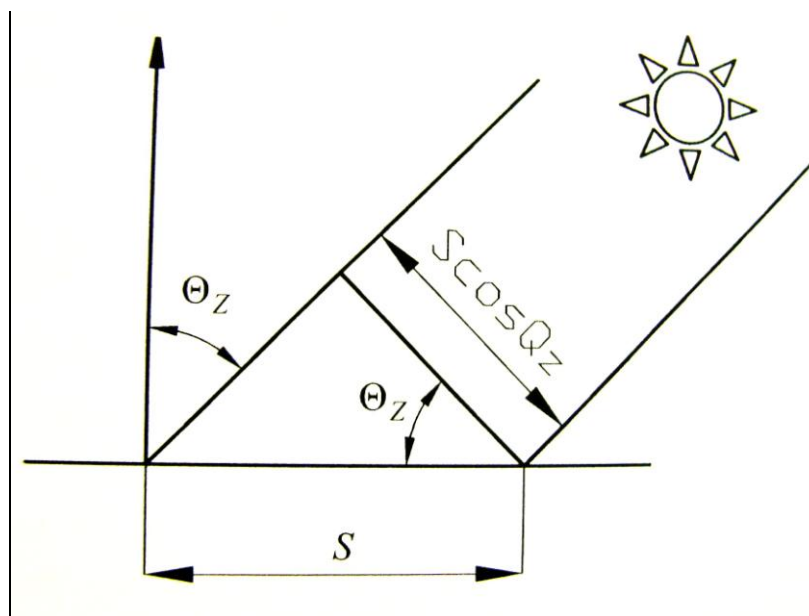


Figure 1. Scheme of inflow of solar radiation on horizontal surface./1/

Abbreviations on the **Figure 1** mean:

S - area of horizontal surface;

Θ_Z - angle of sight of solar radiation;

$S \cdot \cos \Theta_Z$ - projection of area on the surface, which is perpendicular to direction of solar radiation.

Flux of radiation or radiation power on the horizontal surface is $E_{S\perp} * S * \cos \Theta_Z$, where $E_{S\perp}$ - density of perpendicular solar radiation per m^2 (W/m^2). $E_{S\perp}$ is maximum in January – $1410W/m^2$ and minimum in June - $1315W/m^2$. Due to the distance between the Sun and the Earth changes all the time. But for energetic calculations constant average value can be used. $E_{S\perp} = 1367 W/m^2$, and it is named solar constant. The same flux of radiation will be on the horizontal area S. Density of radiation of this plane can be calculated:

$$E_{hor}^0 = E_{S\perp} * S * \cos \Theta_Z / S = E_{S\perp} * \cos \Theta_Z \quad \text{Formula 1 /1/}$$

So, it is very necessary to estimate Θ_Z – value, it changes every day of the year. Angle of sight of solar radiation and the length of the day depends on following factors:

1. Geographical coordinates of the surface, geographic latitude first of all;
2. Position of the Earth on the orbit because of the rotation around the Sun;
3. Time of the day depend on Earth spinning motion.

Geographic latitude Φ_M is an angle between the line, which connect point (point M on the figure 2. is a site of interest) on the Earth plane with center of the Earth and it's projection on the equator plane.

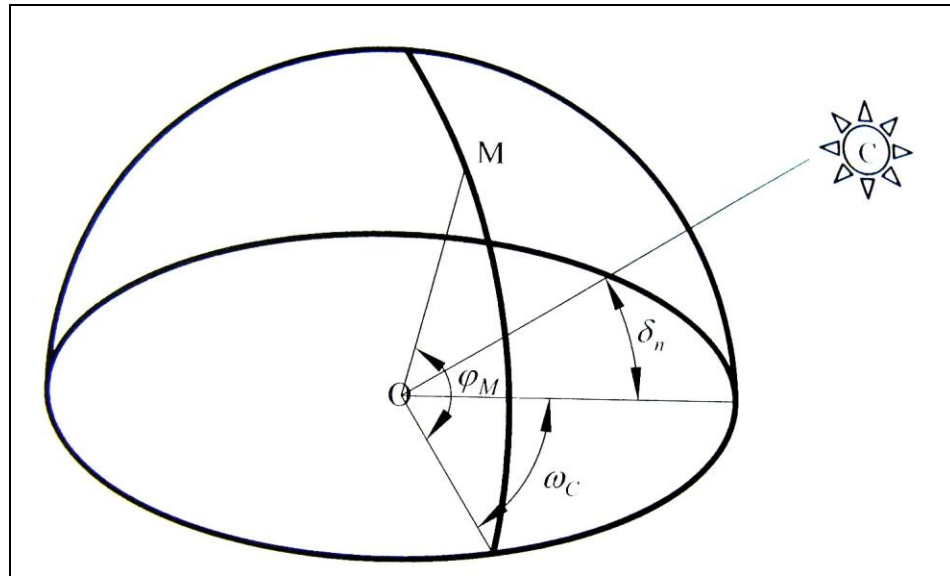


Figure 2. Geographic latitude and angle of pitch of the Sun./1/

Position of Earth on the orbit is characterized by angle δ_n . It is an angle between the line OC (**Figure 2**), which connect centers of the Earth and the Sun and its projection on the equator plane. This angle is called angle of solar declination. We should use it because it takes into account influence of inclination of the Earth axis. The Earth axis is inclined on $66,5^\circ$ for Earth orbit plane. (**Figure 3**)

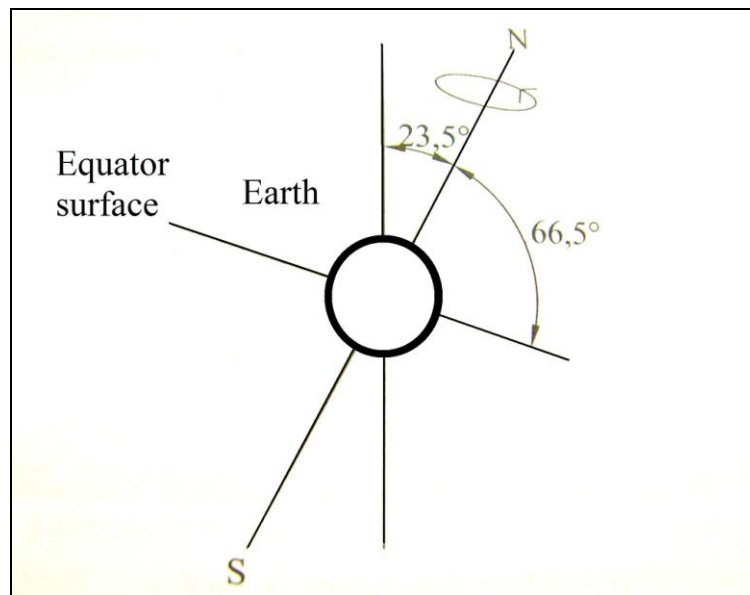


Figure 3. Inclination of the Earth axis. /1/

Angle of solar declination changes all the time from $+23,5^0$ to $-23,5^0$. $+23,5^0$ is on the day of summer solstice, 22 of June. It is the longest day in the year, because Earth axes is inclined by the northern end to the Sun side. $-23,5^0$ is on 22 of December. It is a day of winter solstice, it is the shortest day in the year on the northern hemisphere.

Besides days of summer solstice and winter solstice there are days of autumnal and spring equinox. They are 21 of March and 23 of September. During this days the Earth axes is perpendicular to the line, which connect center of the Earth and center of the Sun. The angle of solar declination during this days is 0.

Position of the Earth on the orbit during the rotation around the Sun is characterized by the angle of solar declination. It has a big influence on the amount of solar radiation on the horizontal plane on the given latitude. Θ_z - angle of sight of solar radiation is minimum on the 22 of June and maximum on the 22 of December. Θ_z is average and the same on 21 of March and on 23 of September.

Angle of pitch of the Sun for every day can be calculated using the following formula:

$$\delta_n = 23,5 * \sin (360^0 * (n-81) / 365), \quad \textbf{Formula 2 /1/}$$

where n is a serial number of the day in the year (reference point is the 1 of January)

Angle of solar declination value is positive in the period from spring equinox to autumnal equinox and negative in other half of the year.

Angle of sight of solar radiation dependence on Earth spinning motion is characterized by solar-hour angle ω_s . It is measured on the equatorial plane between the projection of the lines. First line connects point M with center of the Earth, second connect centers of the Earth and Sun. (it is shown on the **figure 3**. Geographic latitude and angle of pitch of the Sun.)

Solar-hour angle ω_s depends on the time of the day. In the middle of the day it is 0. Every hour it is changed 15^0 . Solar-hour angle can be calculated using formula:

$$\omega_s = k_{\omega_s} * (t_s^r - 12), \quad \textbf{Formula 3 /1/}$$

$k_{\omega_s} = 15^0$ / hour. It is a coefficient of conversion of solar-hour angle into degrees;

t_s^r is a real daylight time in hours.

This formula implies that at the middle of the day $t_s^r = 12$ h solar-hour angle will be 0, $\omega_s = 0$. Before the noon value of solar-hour angle is less than zero, $\omega_s < 0$. After the noon value of solar-hour angle is more than zero, $\omega_s > 0$.

Solar time is differ from the time, which is used on this territory. For example in Russia it is varies over legal time (1 hour for summer period and 2 hours for winter).

Mathematical expression for cosine of angle of sight of solar radiation on the horizontal plane is:

$$\cos \Theta_Z = \cos \delta_n * \cos \varphi_M * \cos \omega_s + \sin \delta_n * \sin \varphi_M \quad \text{Formula 4 /1/}$$

Time of the sunset and sunrise, length of the day, changes of the density of solar radiation on horizontal plane (in the way without atmosphere or if it is transparent) can be calculated according this formula.

Time of the sunset and sunrise, length of the day.

The angle of sight of solar radiation on the horizontal plane is 90^0 in the moment of sunrise and sunset. It means that $\cos \Theta_Z = 0$. Using this result in formula 4 can be achieved:

$$\cos \omega_s^{\text{sunrise,sunset}} * \cos \delta_n * \cos \varphi_M = - \sin \delta_n * \sin \varphi_M \quad \text{Formula 5 /1/}$$

Solar-hour angle for sunrise and sunset can be calculated according following formula:

$$\omega_s^{\text{sunrise,sunset}} = \arccos (- \operatorname{tg} \varphi_M * \operatorname{tg} \delta_n) \quad \text{Formula 6 /1/}$$

Before the noon value of solar-hour angle for sunrise is less than zero, $\omega_s < 0$. After the noon value of solar-hour for sunset angle is more than zero, $\omega_s > 0$. So, absolute values of time of sunrise and sunset are equal. They are opposite in sign:

$$t_s^{\text{sunset}} = \omega_s^{\text{sunset}} / k_{\omega_s} + 12 \quad \textbf{Formula 7 /1/}$$

$$t_s^{\text{sunrise}} = - \omega_{C_s}^{\text{sunrise}} / k_{\omega_s} + 12 \quad \textbf{Formula 8 /1/}$$

Value of the daylight hours is:

$$T_s = t_s^{\text{sunset}} - t_s^{\text{sunrise}} = 2 k_{\omega_s} * \arccos (- \operatorname{tg} \Phi_M * \operatorname{tg} \delta_n) \quad \textbf{Formula 9 /1/}$$

Using this dependents changes of density of radiation on horizontal plane during daylight hours can be calculated (from sunrise to sunset).

Flux of solar radiation in the way of absolutely transparent atmosphere or without atmosphere can be calculated:

$$W_{\text{hor}}^0 = \int_{t_s^{\text{sunrise}}}^{t_s^{\text{sunset}}} E_{\text{hor}}^0(t) \cdot dt \quad \textbf{Formula 10 /1/}$$

W_{hor}^0 - flux of solar radiation.

Connection between local time and real solar time.

In previous calculations t_s^r - real daylight time in hours is used. Real daylight hours – is a time which Sun is needed to go through the meridian where the site of interest is. Value of daylight hours is not a constant. Sun cross the meridians in uncertain time period. It happens because the visual moving of the Sun is determined not only by the Earth spinning motion. It depends also on the rotation of the Earth around the Sun. This motion is not uniform because the orbit of the Earth is elliptic. As a result, some

days of the year value of real daylight hours is more than average, and other days less than average.

Difference between real daylight hours and average daylight hours on the meridian can be determined by equation:

$$t_{\text{time}} = t_s^r - t_s^{\text{av}}, \quad \text{Formula 11 /1/}$$

$$t_s^r = t_s^{\text{av}} + t_{\text{time}}. \quad \text{Formula 12 /1/}$$

t_s^{av} - average daylight hours;

t_{time} - time correction in minutes.

Approximate value of t_{time} - time correction can be found on diagrams or using approximating function:

$$t_{\text{time}} = 229,2 * (0,000075 + 0,001868 * \cos B - 0,032077 * \sin B - 0,014615 * \cos 2B - 0,04089 * \sin 2B. \quad \text{Formula 13 /1/}$$

Where $B = 360^0 * (n - 1) / 365$.

Nowadays zonal time is used. The whole Earth is separated into 24 time zone every 15^0 from Greenwich meridian. In every time zone time is fixed. This time depends on the average position of the Sun in the highest point on middle meridian at 12 o'clock. So, the average solar time and zone time are equal only on the middle meridian in given time zone.

Difference between local average solar time and zone time can be estimated by following formula:

$$t_{\text{SM}}^{\text{av}} = t_{\text{zone}} + (\lambda_M - \lambda_{\text{av}}) / k_{\text{os}} \quad \text{Formula 14 /1/}$$

t_{zone} - zone time,

λ_M - longitude of the site of interest,

λ_{av} - longitude of middle meridian of concerned time zone.

Since on every meridian $t_s^r = t_s^{av} + t_{time}$, therefore:

$$t_s^r = t_{zone} + (\lambda_M - \lambda_{av}) / k_{\omega s} + t_{time} . \quad \text{Formula 15 /1/}$$

Equation 14 shows relation between real solar time and local time in most of the countries. But in Russia legal time is used. It means that 1 hour correction for the winter time and 2 hour correction for summer time must be used. Equation 14 can be modified for Russia:

$$t_s^r = t_M - \Delta t_{leg} + (\lambda_M - \lambda_{av}) / k_{\omega s} + t_{time} , \quad \text{Formula 16 /1/}$$

where Δt_{leg} - correction of legal time.

For calculation of local time on given meridian (when all corrections are taken into account) following formula can be used:

$$t_M = t_s^r + \Delta t_{leg} + (\lambda_M - \lambda_{av}) / k_{\omega s} + t_{time} \quad \text{Formula 17 /1/}$$

According local time of sunset can be calculated:

$$t_M^{\text{sunset}} = 1 / k_{\omega s} * (\arccos(-\text{tg } \Phi_M * \text{tg } \delta_n) + (\lambda_M - \lambda_{av})) + \Delta t_{leg} - t_{time} + 12.$$

Formula 18 /1/

2.2. Influence of physical atmosphere properties

Solar energy absorption and solar radiation dispersion at clear atmosphere.

Direct solar radiation from cosmos is absorbed and dispersed by molecules of atmospheric gases: nitrogen (N₂), oxygen (O₂), carbon dioxide (CO₂), water vapor (H₂O), ozone (O₃).

Absorption is happened when natural-vibration frequency of molecules and radiation frequency of solar spectrum are the same. Radiation absorption in different

part of the solar spectrum by different gaseous vary. For example, N_2 and O_2 do not reduce solar energy too much. They absorb radiation in ultraviolet spectrum, where is small part of solar energy. Ozone influence is much higher. Ozone absorbs photons with highest energy, these photons can be dangerous for nature. CO_2 absorb infrared spectrum in a small amount. Water vapor H_2O can absorb more than 10% of solar radiation.

Dispersion of solar radiation is due to molecules (molecular scattering) and bigger particles like dust, smoke, micro drops of water (aerosol scattering). Because of dispersion, photons don't absorb. They change their direction. Some part of radiation goes back to cosmos; another part comes down to the earth as diffuse radiation.

Decreasing of density and changes in spectrum of solar radiation at the expense of absorption and dispersion depends on length of the trajectory of solar energy.

Scheme for calculation of this length is shown on **figure 4**:

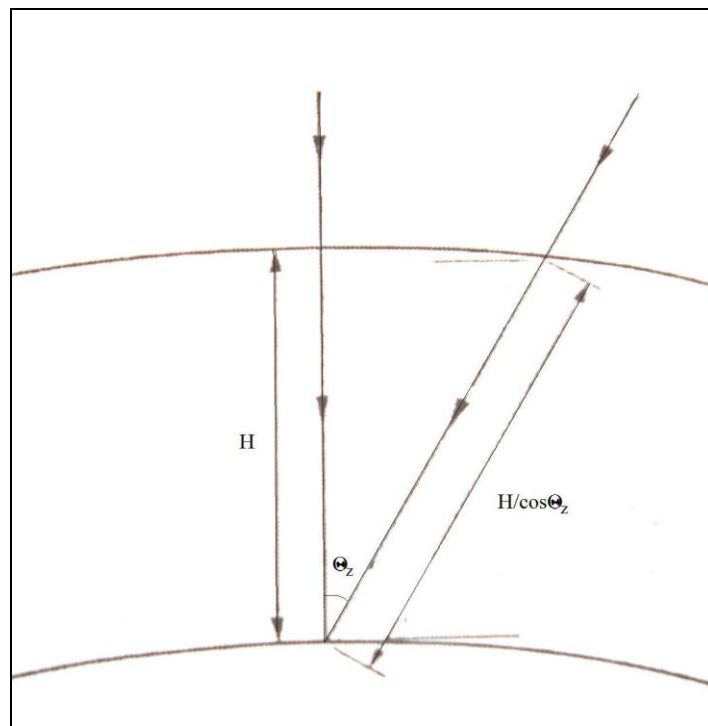


Figure 4. Sunbeam's trajectory in the atmosphere./1/

$$L = \frac{H}{\cos \Theta_Z} . \quad \text{Formula 19 /1/}$$

Thickness of the atmosphere is many times less than radius of the Earth, so we can calculate it as plane-parallel layer. The Earth surface curvature when the Sun is not higher than 10 degrees.

M-atmospheric mass is used to measure length of trajectory of sunbeam. When sunbeams come vertically, M=1.

$$M = \frac{1}{\cos \Theta_Z} . \quad \text{Formula 20 /1/}$$

Density of direct solar radiation on horizontal plane subject to it's absorption and dispersion in a clear atmosphere can be calculated:

$$E_{\text{hor}}^{\text{direct}} = E_{S\perp} * \tau_{\Sigma} * \cos \Theta_Z , \quad \text{Formula 21 /1/}$$

Where τ_{Σ} is a coefficient of direct light transmission. It depends on absorption and dispersion of the atmosphere.

All types of absorption and dispersion of direct solar radiation are determined by coefficients of transmission. Total coefficient of direct light transmission can be calculated:

$$\tau_{\Sigma} = \tau_{\text{absorb}} * \tau_{\text{disp}}, \quad \text{Formula 22 /1/}$$

Where τ_{disp} is a multiplication of coefficients of dispersion of solar radiation in the atmosphere;

τ_{absorb} is a multiplication of coefficients of absorption of solar radiation by ozone, gaseous, water vapor (τ_{O_3} , τ_{gas} , $\tau_{\text{H}_2\text{O}}$):

$$\tau_{\text{absorb}} = \tau_{\text{O}_3} * \tau_{\text{gas}} * \tau_{\text{H}_2\text{O}}. \quad \text{Formula 23 /1/}$$

There are many methodic to determine density of solar radiation on horizontal plane in a clear sky. Bird model is chosen in farther calculations. It includes simplest

equations of transmission coefficient. It takes into account absorption of solar radiation by ozone, gaseous, water vapor, aerosol scattering, rayleigh scattering.

Correcting coefficient for horizontal plane for Russia was found by E. Aronova:

For direct solar radiation: $K^{\text{direct}}=1,14$ – for winter period;

$K^{\text{direct}}=0,91$ – for summer period;

For diffuse solar radiation: $K^{\text{diffuse}}=1,05$.

Subject to these coefficients density of direct solar radiation can be calculated:

$$E_{\text{hor}}^{\text{direct}} = E_{S\perp} * \tau_R * \tau_A * \tau_{O_3} * \tau_{\text{gas}} * \tau_{H_2O} * \cos \Theta_Z * K^{\text{direct}}, \quad \text{Formula 24 /2/}$$

Where τ_R coefficient of Rayleigh scattering is calculated by following formula:

$$\tau_R = \exp(-0,0903 * (M_i^*)^{0,84}, * (1 + M_i^* + M_i^{*1,01})), \quad \text{Formula 25 /2/}$$

τ_A coefficient of aerosol scattering:

$$\tau_A = \exp(-\tau_A'^{0,873} * (1 + \tau_A' - \tau_A'^{0,7088}) * M_i^{*0,9108}), \quad \text{Formula 26 /2/}$$

where $\tau_A' = 1,832 * \alpha$, if $\alpha = 0,0314$ – Angstrom coefficient of spectral turbidity.

τ_{O_3} - coefficient of absorption of solar radiation by ozone:

$$\tau_{O_3} = 1 - 0,1611 * d_{O_3} * M_i^* * (1 + 139,48 * d_{O_3} * M_i^*)^{-0,3035} - 0,002715 * d_{O_3} * M_i^* * (1 + 0,044 * d_{O_3} * M_i^* + 0,0003 * (d_{O_3} * M_i^*)^2)^{-1}, \quad \text{Formula 27 /2/}$$

where d_{O_3} – thickness of ozone layer at normal temperature and pressure. It is 0,32cm for average latitude.

τ_{gas} - coefficient of absorption of solar radiation by gases:

$$\tau_{\text{gas}} = \exp(-0,0127 * M_i^{*0,26}). \quad \text{Formula 28 /2/}$$

τ_{H_2O} - coefficient of absorption of solar radiation by water vapor:

$$\tau_{\text{H}_2\text{O}} = 1 - 2,4959 * d_{\text{H}_2\text{O}} * M_i^* * ((1 + 79,034 * d_{\text{H}_2\text{O}} * M_i^*)^{0,6828} + 6,385 * d_{\text{H}_2\text{O}} * M_i^*)^{-1}, \quad \text{Formula 29 /2/}$$

where $d_{\text{H}_2\text{O}}$ - water content (for winter period $1,3\text{g}/\text{cm}^2$, for summer period $3,0\text{g}/\text{cm}^2$).

M_i^* - atmospheric mass corrected according position over sea level:

$$M_i^* = p * M_i / 1013, \quad \text{Formula 30 /2/}$$

where p = atmospheric pressure at site of interest.

Diffuse solar radiation

Sources of diffuse solar radiation on horizontal surface are:

1. Part of solar radiation, which is dispersed in the atmosphere.
2. Indirect reflection (direct and diffuse solar radiation, which comes back to the atmosphere and is dispersed again).

Reflection qualities of the all surfaces can be characterized by value of albedo. Albedo is a ratio between flux of reflected solar radiation and radiation which come down to the surface. It is a coefficient of reflection. For example, albedo of the ground is about 5-10%, albedo of snow is a maximum 30-90%. It also depends on angle of the sunbeams.

Intensity of that part of solar radiation which is a result of indirect reflection depends also on albedo of the atmosphere.

Density of the diffuse flux of solar radiation on the horizontal surface is determined by:

- Light angle;
- Transparent of the atmosphere, haziness, cloudiness

- Albedo of the Earth surface

Part of the diffuse solar radiation in a total flux of solar radiation increases when M (atmospheric mass) increases too. It happens because losses of solar radiation become less. When there is a haziness diffusing increase and density of diffuse solar radiation increase. The same effect is when the albedo of the Earth surface increase.

Distribution of the diffuse solar radiation is not uniform. There are several models of calculation of diffuse solar radiation. When the sky is not absolutely clear even in fair weather conditions isotropic distribution model can be used. It means that distribution of the diffuse solar radiation is uniform.

Value of the diffuse solar radiation is in proportion to that part of direct solar radiation in atmosphere which does not come down to the Earth like direct solar radiation. So, following formula can be used to calculate diffuse solar radiation:

$$E_{\text{hor}}^{\text{diffuse}} = E_{S\perp} * \cos \Theta_Z * \tau_{AA} * \tau_{O_3} * \tau_{\text{gas}} * \tau_{H_2O} * (0,5 * (1 - \tau_R) + B_a * (1 - \tau_{AS})) / (1 - M_i^* + M_i^{*1,02}) * K_d, \quad \text{Formula 31 /2/}$$

where K_d - empirically determined coefficient. It depends on condition of the atmosphere and time of the year.

B_a - ratio between diffuse solar radiation and total solar radiation:

$$B_a = 0,5 * (1 + \cos \Theta_Z). \quad \text{Formula 32 /2/}$$

τ_{AA} - transmission coefficient, determine absorption of solar radiation by aerosol particles:

$$\tau_{AA} = 1 - K_{\text{dif}} * (1 - M_i^* + M_i^{*1,06}) * (1 - \tau_A), \quad \text{Formula 33 /2/}$$

where $K_{\text{dif}} = 0,1$.

τ_{AS} - transmission coefficient, determine deffusion of solar radiation by aerosol particles:

$$\tau_{AS} = \tau_A / \tau_{AA}.$$

Formula 34 /2/

Total solar radiation

Density of total solar radiation at clear atmosphere can be calculated:

$$E_{hor}^{total} = (E_{hor}^{direct} + E_{hor}^{diffuse}) / (1 - r_e * r_a),$$

Formula 35 /2/

where r_e –albedo of earth surface, r_a - albedo of atmosphere:

$$r_a = 0,0685 + (1 - B_a) * (1 - \tau_{AS}).$$

Formula 35 /2/

2.3. Influence of climate factors.

Next group of factors which influence on solar radiation is climatic factors. It includes real weather conditions (clouds, rains, haziness), anthropogenic pollution (impacts of different factories, traffic). All of these factors have unpredictable character and can be modeled only by difficult probabilistic models and prognosis. At certain time for correct designing solar systems detail initial data of solar radiation per many years is needed. These values at real weather conditions are registered by special equipment. These values are published in climatologically reference book for region; specialized atlas of solar radiation; archives and electronic data bases./3/

3. Example of calculation.

Initial data:

Site of interest is Tyumen city, Russia.

$\varphi_M = 57^{\circ} 09'$ - geographical latitude,

$\lambda_M = 65^{\circ} 32'$ - geographical longitude,

$\lambda_{av} = 60^{\circ}$ - geographical longitude of middle meridian of given time zone,

$\Delta t_{leg} = 1$ hour - correction of legal time during winter time,

$\Delta t_{leg} = 2$ hours - correction of legal time during winter time.

$k_{os} = 15^{\circ}$ / hour. - coefficient of conversation of solar-hour angle into degrees

Number of month	1	2	3	4	5	6	7	8	9	10	11	12
Date	15	15	15	15	15	15	15	15	15	15	15	15
Day number, n	15	46	74	105	135	166	196	227	258	288	319	349

Table 1. Initial data.

Example of calculation for first month, 15 of January:

Calculation of solar inclination:

$$\delta_n = 23,5 * \sin (360^{\circ} * (n-81) / 365) = 23,5 * \sin (360^{\circ} * (15-81) / 365) = -21,31^{\circ}.$$

Calculation of time correction:

$$B = 360^{\circ} * (n - 1) / 365 = 360^{\circ} * (15 - 1) / 365 = 0,24^{\circ}.$$

$$t_{\text{time}} = 229,2 * (0,000075 + 0,001868 * \cos 0,24^0 - 0,032077 * \sin 0,24^0 - 0,014615 * \cos 2*0,24^0 - 0,04089 * \sin 2*0,24^0) = -8,63 \text{ min.}$$

Calculation of sunset time:

$$t_M^{\text{sunset}} = 1 / k_{\omega_s} * (\arccos(- \text{tg } \varphi_M * \text{tg } \delta_n) + (\lambda_M - \lambda_{av})) + \Delta t_{\text{leg}} - t_{\text{time}} + 12 =$$

$$= 1 / 15^0 / \text{h} * (\arccos (-\text{tg}57^0 09') * \text{tg} (-21,31^0)) + (65^0 32' - 60^0) + 1 - (-8,63/60) + 12 = 17,11 \text{ h p.m.}$$

Calculation of daylight hours:

$$T_s = 2 k_{\omega_s} * \arccos (- \text{tg } \varphi_M * \text{tg } \delta_n) = 2 * 15^0 / \text{h} * \arccos (-\text{tg}57^0 09' * \text{tg} (-21,31^0)) = 7,09 \text{ h.}$$

Calculation of sunrise time:

$$t_s^{\text{sunrise}} = t_s^{\text{sunset}} - T_s = 17,11 \text{ h} - 7,09 \text{ h} = 10,02 \text{ h.}$$

Results for other months are shown at the **table 2** and **figure 5**.

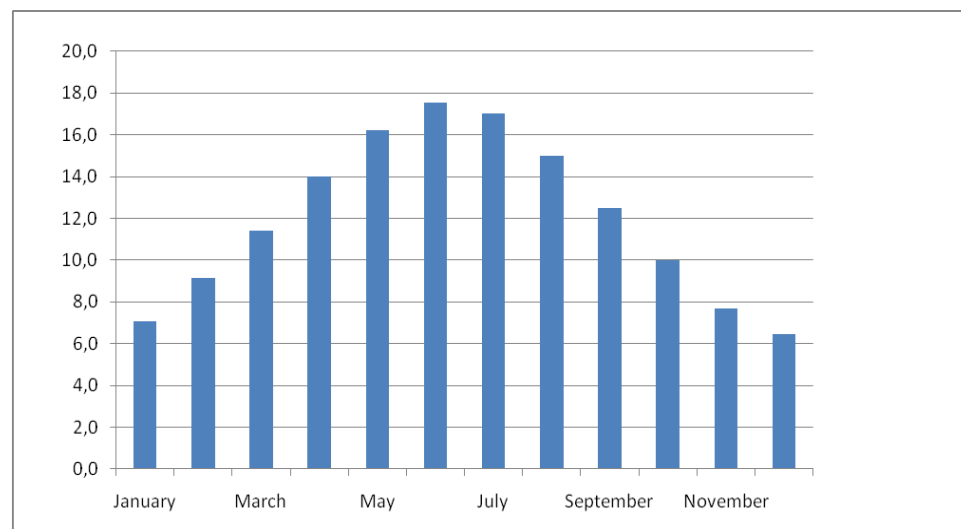


Figure 5. Daylight hours for different month.

Month	January	February	March	April	May	June	July	August	September	October	November	December
Number of month	1	2	3	4	5	6	7	8	9	10	11	12
Date	15	15	15	15	15	15	15	15	15	15	15	15
Day number	15	46	74	105	135	166	196	227	258	288	319	349
Angle of solar declination	-21,3	-13,3	-2,8	9,4	18,8	23,4	21,6	13,8	2,3	-9,6	-19,2	-23,4
t_{time} , min	-8,6	-14,3	-9,7	-0,3	3,9	0,0	-5,8	-4,9	4,6	14,4	15,2	5,0
$t_{\text{M}}^{\text{sunset}}$, h	17,1	18,2	19,2	21,4	22,5	23,3	23,1	22,0	20,5	19,1	17,0	16,6
T_{s} , h	7,1	9,2	11,4	14,0	16,2	17,6	17,0	15,0	12,5	10,0	7,7	6,4
$t_{\text{M}}^{\text{sunrise}}$, h	10,0	9,0	7,8	7,4	6,2	5,7	6,1	7,0	8,0	9,1	9,3	10,1
$W_{\text{hor}}^{\text{O}}$ /day, MJ/m ²	4,54	9,46	17,68	28,52	37,72	42,46	40,54	32,72	22,09	12,21	5,51	3,11
Days in month	31	28	31	30	31	30	31	31	30	31	30	31
W_{hor} /month, MJ/m ²	140,74	264,88	548,08	855,60	1169,32	1273,80	1256,74	1014,32	662,70	378,51	165,30	96,41

Table 2. Calculation of flux of solar radiation per month for Tyumen city, Russia.

Calculation of solar-hour angle for 12 o'clock:

$$\begin{aligned}\omega_s &= k_{\omega_s} * (t_M - \Delta t_{leg} + t_{time} - 12) + (\lambda_M - \lambda_{av}) = \\ &= 15^{\circ}/h * (12 - 1 + (-8,6) - 12) + (65^{\circ} 32' - 60^{\circ}) = -26^{\circ} 66'\end{aligned}$$

Calculation of cosine of angle of sight on the horizontal plane:

$$\begin{aligned}\cos \Theta_Z &= \cos \delta_n * \cos \Phi_M * \cos \omega_s + \sin \delta_n * \sin \Phi_M = \\ &= \cos (-21,31^{\circ}) * \cos 57^{\circ} 09' * \cos (-26^{\circ} 66') + \sin (-21,31^{\circ}) * \sin 57^{\circ} 09' = 0,15\end{aligned}$$

Calculation of density of radiation on the horizontal plane:

$$E_{hor}^0 = E_{S\perp} * \cos \Theta_Z = 1367 \text{ W/m}^2 * 0,15 = 201 \text{ W/m}^2$$

Results for all day are shown at the **table 3**:

Time of the day	ω_s	$\cos \Theta_Z$	E_{hor}^0
10,0	-56,43	-	0,00
11	-41,66	0,07	99,75
12	-26,66	0,15	201,00
13	-11,66	0,19	260,17
14	3,34	0,20	273,25
15	18,34	0,18	239,33
16	33,34	0,12	160,73
17,1	49,94	-	0,00

Table 3. Density of solar radiation on horizontal surface per every hour on 15 of January.

Results for other month are shown at the **Appendix 1**.

Results can be shown graphically on the **figure 6**:

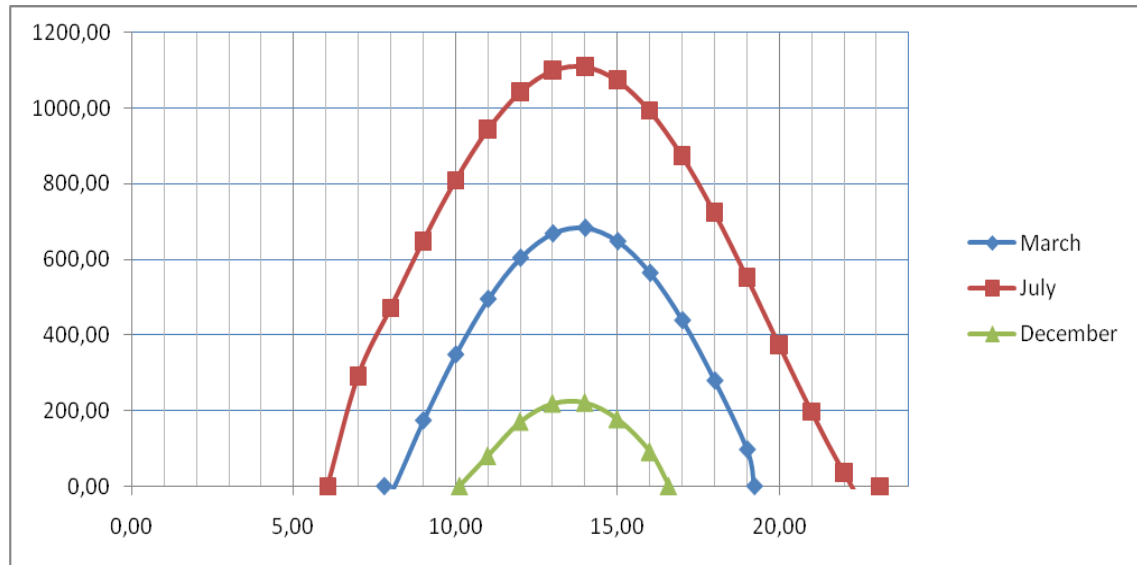


Figure 6. Density of solar radiation on horizontal surface on 15 of December, on 15 of March, on 15 of July.

Calculation of flux of solar radiation per one day in the way of absolutely transparent atmosphere or without atmosphere are done using Mathcad program:

$$W_{\text{hor}}^{\text{o}} = \int_{t_s^{\text{sunrise}}}^{t_s^{\text{sunset}}} E_{\text{hor}}^{\text{o}}(t) \cdot dt = 4,54 \text{ MJ} / \text{m}^2$$

Calculation of flux of solar radiation per month:

$$W_{\text{hor}} = W_{\text{hor}}^{\text{o}} * N_{\text{month}} = 4,54 \text{ MJ} / \text{m}^2 * 31 = 140,74 \text{ MJ} / \text{m}^2.$$

Results of calculation of flux of solar radiation for other month are shown at the **table 2** and **figure 7**:

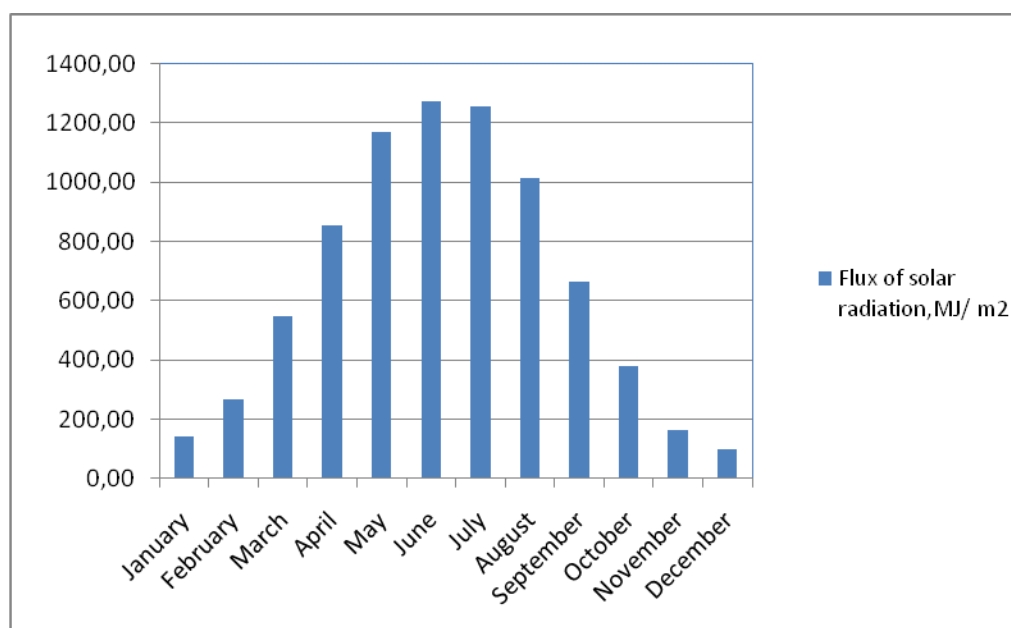


Figure 7. Flux of solar radiation on horizontal surface per month in the way of absolutely transparent atmosphere or without atmosphere.

Calculations of solar radiation in real conditions for day of every month are done using Microsoft Office Excel. Process of calculations is shown in **appendix 1**.

At this example there is no opportunity to calculate real values of influence of climate factors. Climatologically reference books for every Russian region are were established in year 1954 in printed version only. Information from electronic data bases of solar radiation is not free. That is why in further calculations total solar energy is decreased on 40% because of climatic factors. /1/

Calculation of flux of direct solar radiation per one day of every month and per every month with atmosphere and real climatic conditions are done using Mathcad program. Results of calculations are shown at **figure 8** and **table 4**.

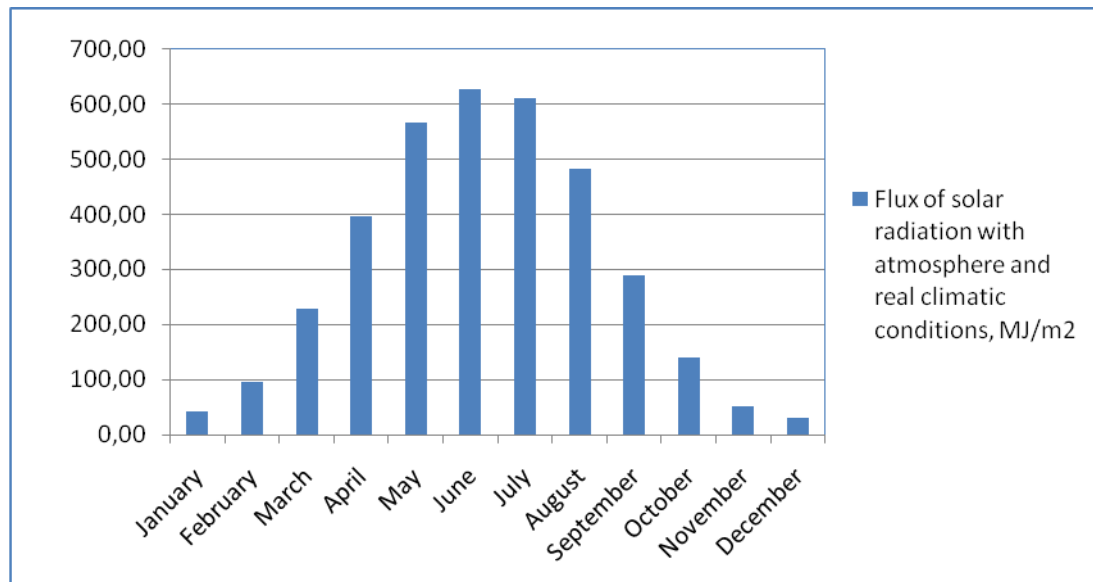


Figure 8. Flux of solar radiation on horizontal surface per month with atmosphere and real climatic conditions.

Month	January	February	March	April	May	June	July	August	September	October	November	December
$W_{\text{hor/day}}^{\text{direct}}$, MJ/m ²	0,04	1,08	5,19	12,55	19,14	22,47	21,14	15,58	8,00	2,21	0,15	0,01
$W_{\text{hor/day}}^{\text{diffuse}}$, MJ/m ²	2,06	4,36	6,81	9,05	10,72	11,65	11,06	9,8	7,63	5,15	2,67	1,5
$W_{\text{hor/day}}^{\text{total}}$, MJ/m ²	2,22	5,75	12,33	22,07	30,44	34,76	32,82	25,91	16,10	7,54	2,93	1,66
$W_{\text{hor/month}}^{\text{direct}}$, MJ/m ²	1,24	30,24	160,89	376,50	593,34	674,10	655,34	482,98	240,00	68,51	4,50	0,31
$W_{\text{hor/month}}^{\text{diffuse}}$, MJ/m ²	63,86	122,08	211,11	271,50	332,32	349,50	342,86	303,80	228,90	159,65	80,10	46,50
$W_{\text{hor/month}}^{\text{total}}$, MJ/m ²	68,82	161,00	382,23	662,10	943,64	1042,80	1017,42	803,21	483,00	233,74	87,90	51,46
$W_{\text{hor/month}}$, MJ/m ²	41,29	96,60	229,34	397,26	566,18	625,68	610,45	481,93	289,80	140,24	52,74	30,88

Table 4. Calculation of flux of solar radiation on horizontal surface

per month with atmosphere and real climatic conditions for Tyumen city, Russia.

4. Heating demand of one family house in Tyumen, Russia.

Site of interest is a one family house which is situated in Tyumen, Russia. Living area is about 600 m². Walls are made of calcium-silicate bricks. Calculations are given for the year 2008. This building is heated by two natural gas boilers. Indoor temperature is 18 °C.

4.1. Calculation of heating demand according to thermotechnical calculation.

Initial data:

$t_{in}=21\text{ }^{\circ}\text{C}$ – indoor air temperature;

$t_{out}=-38\text{ }^{\circ}\text{C}$ – outdoor designing temperature in Tyumen;

$u_w=0,54\text{ W}/(^{\circ}\text{C}\cdot\text{m}^2)$ - thermal conductivity of wall (thickness is 770mm) made of calcium-silicate bricks;

$u_{window}=1,3\text{ W}/(^{\circ}\text{C}\cdot\text{m}^2)$ - thermal conductivity of window;

$u_{floor}=0,22\text{ W}/(^{\circ}\text{C}\cdot\text{m}^2)$ - thermal conductivity of floor;

$u_{roof}=0,11\text{ W}/(^{\circ}\text{C}\cdot\text{m}^2)$ - thermal conductivity of roof.

A_i - total areas of walls, windows, floor, and roof.

$z_{ht} = 225\text{days}$. - duration of heating period;

$t_{av} = -7,2\text{ }^{\circ}\text{C}$ - average outdoor temperature for heating period;

$n=0,5(1/h)$ –air change ratio;

$V=1800\text{m}^3$ - volume of the building.

Calculation:

1) Losses through building envelope:

Degree days D_d is calculated with formula:

$$D_d = (t_{in} - t_{av}) z_{ht} \quad \text{Formula 36 /4/}$$

Annual energy losses through the building envelope can be calculated:

$$Q = H_{cond} * (t_{in} - t_{av}) * \Delta t = \sum H_{cond} * D_d, \quad \text{Formula 37/4/}$$

Where Δt is time of heating period,

H_{cond} - average heat loss of a building components can be calculated by evacuation:

$$H_{cond} = \Phi / (t_{in} - t_{out}), \quad \text{Formula 38 /4/}$$

Where Φ – total heat load of the building:

$$\Phi = \sum H_i * (t_{in} - t_{out}) = \sum (u_i * A_i) * (t_{in} - t_{out}). \quad \text{Formula 39 /4/}$$

A - total areas of walls, windows, floor, and roof are calculated approximately according building plan.

Results of total heat load calculation are shown in **table 5**:

	u-value, W/(°C*m ²)	A, m ²	H, W/°C	Indoor t _{in} , °C	Outdoor t _{out} , °C	Φ, W
wall (west)	0,38	165	89,10	18	-38	3511,2
wall (south)	0,38	165	89,10	18	-38	3511,2
wall (east)	0,38	165	89,10	18	-38	3511,2
wall (nourth)	0,38	165	89,10	18	-38	3511,2
windows	1,3	52,15	39,63	18	-38	2686,8

roof	0,11	600	66,00	18	-38	3696,0
floor	0,22	300	66,00	18	6	792,0
Total						21219,6

Table 5. Heat load through building envelope of one family house in Tyumen, Russia.

Average heat loss of a building components can be calculated:

$$H_{\text{cond}} = 21219,6 \text{ W} / (18^{\circ}\text{C} - (-38^{\circ}\text{C})) = 454,7 \text{ W}/^{\circ}\text{C}.$$

Degree days D_d is according (formula 36):

$$D_d = (18^{\circ}\text{C} - (-7,2^{\circ}\text{C})) \cdot 225 \text{ days} = 5670^{\circ}\text{C} \cdot \text{day}$$

Annual energy losses through the building envelope according (**formula 37**):

$$Q = 454,7 \text{ W}/^{\circ}\text{C} \cdot 5670^{\circ}\text{C} \cdot \text{day} \cdot 24 \text{ h} = 61876 \text{ kWh} = 61,9 \text{ MWh}.$$

2) Heating demand for HDW:

Total cold water demand is measured by water meter. It is 111000 liters. Hot water consumption is about 1/3 of total demand. It is 37000 liters. Heat demand which is needed to heat this amount of water can be calculated:

$$Q = V_{\text{water}} \cdot \rho \cdot c_p \cdot (t_{\text{hot}} - t_{\text{cold}}) \quad \text{Formula 40}$$

$$Q = 37000 \text{ l} \cdot 1 \text{ l/kg} \cdot 4,2 \text{ kJ}/(\text{kg}^{\circ}\text{C}) \cdot (60^{\circ}\text{C} - 5^{\circ}\text{C}) = 8567 \text{ MJ} = 2,4 \text{ MWh}.$$

3) Heat load from ventilation:

$$Q = V * n * \rho * c_p * (t_{\text{supply}} - t_{\text{outdoor}}) * \tau$$

Calculations for heat load of ventilation are given at **table 6**. Average temperatures for every month are taken from “Building rules and norms of Russian Federation” (Building climatology)

Number of month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Total
Average outdoor temperature, °C	-17,4	-16,1	-7,7	3,2	11	15,7	18,2	14,8	9,7	1	-7,9	-13,7	
Days in month	31	28	31	30	31	30	31	31	30	31	30	31	
Heat load, kW	9,0	8,7	6,6	3,8	1,8	0,6	-0,1	0,8	2,1	4,3	6,6	8,1	
Energy consumption, MWh	6,7	5,8	4,9	2,7	1,3	0,4	0,0	0,6	1,5	3,2	4,8	6,0	38,0

Table 6. Heat load of ventilation for one family house in Tyumen, Russia.

Total energy demand is 102,3 MWh per year.

4.2. Calculation of heating demand according to the gas consumption.

Initial data:

Specific combustion heat of natural gas is taken $28\text{MJ}/\text{m}^3$.

Price of the natural gas is $2,15\text{ rub}/\text{m}^3$. ($0,05\text{ €/m}^3$)

Euro rate $43,2\text{ rub}$.

Volume consumption of natural gas is taken from bills for year 2008.

Total energy consumption and costs of fuel are given in table 5:

Month	Consumption of gas, m ³	MJ	MWh	Energy consumption for heating, MWh	Cost of gas, rub	Cost of gas, €
January	2247	62916	17,48	15,77	4831,05	111,83 €
February	2967	83076	23,08	21,37	6379,05	147,66 €
March	1368	38304	10,64	8,93	2941,2	68,08 €
April	1328	37184	10,33	8,62	2855,2	66,09 €
May	927	25956	7,21	5,50	1993,05	46,14 €
June	220	6160	1,71	0,00	473	10,95 €
July	220	6160	1,71	0,00	473	10,95 €
August	220	6160	1,71	0,00	473	10,95 €
September	500	14000	3,89	2,18	1075	24,88 €

October	1300	36400	10,11	8,40	2795	64,70 €
November	1665	46620	12,95	11,24	3579,75	82,86 €
December	2300	64400	17,89	16,18	4945	114,47 €
Total:	15262	427336	118,70	98,17	32813,3	759,57 €

Table 5. Total energy consumption and costs of fuel for
one family house in Tyumen, Russia.

4.3. Total energy demand for heating and HDW

Calculated values of energy demand are not the same. It takes place because:

- Designing U-values of the materials are not realistic;
- Heat losses of ventilation are approximated;
- Heat losses of heating systems are not calculated;
- Heat losses of leakage air are not taken into account.

At further calculations calculation of energy demand according gas consumption must be used. This calculation is more accurate.

At summer period during June, July and August there is no need of heating. All energy is used for hot domestic water. So, energy consumption for hot domestic water is 1,71 MWh per month.

Total energy demand for heating and HDW per every month is shown on the **figure 9**:

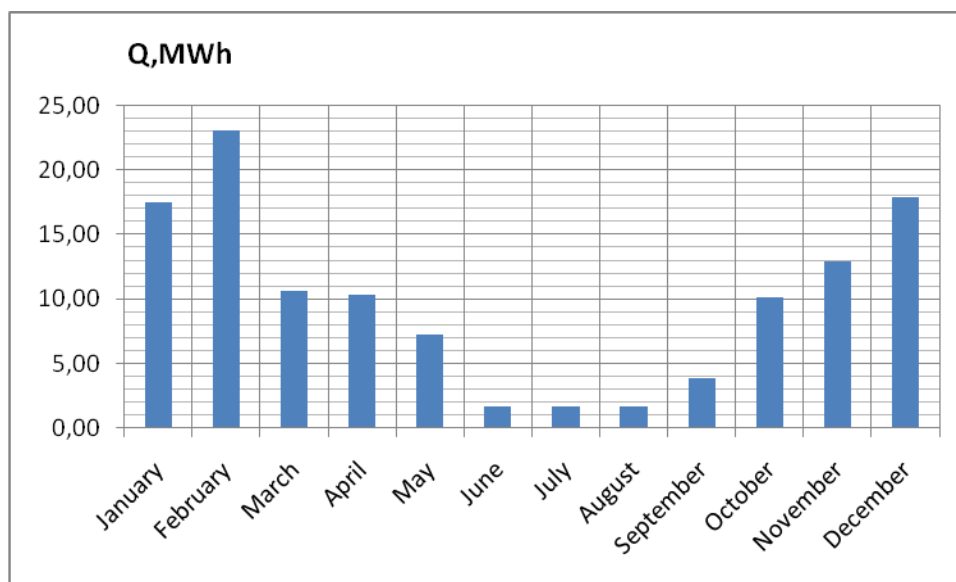


Figure 9. Total energy demand for heating and HDW per every month
for one family house in Tyumen, Russia

5. Usage of solar energy.

5.1. Solar house

Last 15-20 years “solar” houses have become more and more popular. The simplest way is to use solar energy for heating and lighting. In this way the biggest part of energy demand is provide by solar energy. Well designed “solar” house with effective solar heating system can totally meet the demands of heat and light, even without other sources of energy. There will be no need of district system connection, of meters, and storages for fuel.

Main goals of “solar” house are:

- to maximize utilization of solar radiation;
- to transfer solar energy into heat and electricity;
- to store solar energy in the house with minimum of energy losses.

If these goals are achieved, considerable amount of money can be saved. Ecological situation will be better. Because of reducing of usage of other energy sources amount of combustion products (which are dispersed to the atmosphere) becomes lower, roads will be free of heavy transport of million tons of fuel, forests will be saved.

There are two types of energy saving systems for “solar” house:

1. Passive
2. Active

First is based on architectural and constructional methods. For example, house is orientated in axes south-north; there is no shade on the southern wall; minimum of windows on the northern wall; southern wall is a window wall; two or three-glass cover; reinforced thermo-insulation of walls; wind-porches, etc.

“Passive solar design systems usually have one of three designs:

- **Direct gain** (the simplest system) stores and slowly releases heat energy collected from the sun shining directly into the building and warming materials such as tile or concrete. Care must be taken to avoid overheating the space.
- **Indirect gain** (similar to direct gain) uses materials that hold, store, and release heat; the material is located between the sun and living space (typically the wall).
- **Isolated gain** collects solar energy remote from the location of the primary living area. For example, a sunroom attached to a house collects warmer air that flows naturally to the rest of the house. “ /5/

This technical method increases costs of construction by 5-10%. But it reduce 50% of costs of heating.

Active solar energy saving system consists of solar collectors, solar batteries, equipment for control, computer and other high-performance equipment for maximal using of solar energy.

There are two basic active ways of transforming solar energy:

- Thermal
- Photovoltaic

First is simpler. Heat-transfer agent (usually it is water) is heated in the collector (system of tubes, which are collecting and absorbing solar energy). It has high temperature and can be used for heating in buildings. Collector is installed on the roof of the building. Position is chosen to get more energy per day. Part of solar radiation is accumulated in water tanks to provide heat when the sun is not shining.

Solar photovoltaics (PVs) are arrays of cells containing a material that converts solar radiation directly into electricity current. Materials presently used for photovoltaics

include amorphous silicon, polycrystalline silicon, microcrystalline silicon, cadmium telluride, and copper indium selenide/sulfide.

There are many “solar” houses in the world. They can totally or partially be provided by solar energy. They are built not only in southern countries like Egypt, Israel, Turkey, Japan, India, USA. Many countries with moderate climate (France, England, Germany) and northern countries like Sweden, Finland, Canada use solar energy too. Specialized companies produce the equipment and materials for “solar” houses. Big concerns like Concept Construction (Canada) and Enercon Building Corporation (USA) are involved in a building process.

5.2. Types of solar collectors

Solar collectors transform solar radiation into heat and transfer that heat to a medium (water, solar fluid, or air). Then solar heat can be used for heating water, to back up heating systems or for heating swimming pools.

Flat plate collector

Plate collectors (**Figure 10**) consist of elements, which absorb solar radiation, transparent covering and insulated layer. Absorbing layer is called absorber. It is connected to heat distribution system. Transparent element (glass) usually is made of prestressed glass where content of metals is reduced. Flat plate collectors can heat water till 190-200°C.

Efficiency of collector depends on amount of solar energy, which is transformed to a medium. The efficiency can be increased using special optic coverings, which don't radiate heat. Standard decision for increasing efficiency is to use absorber made of flat copper.

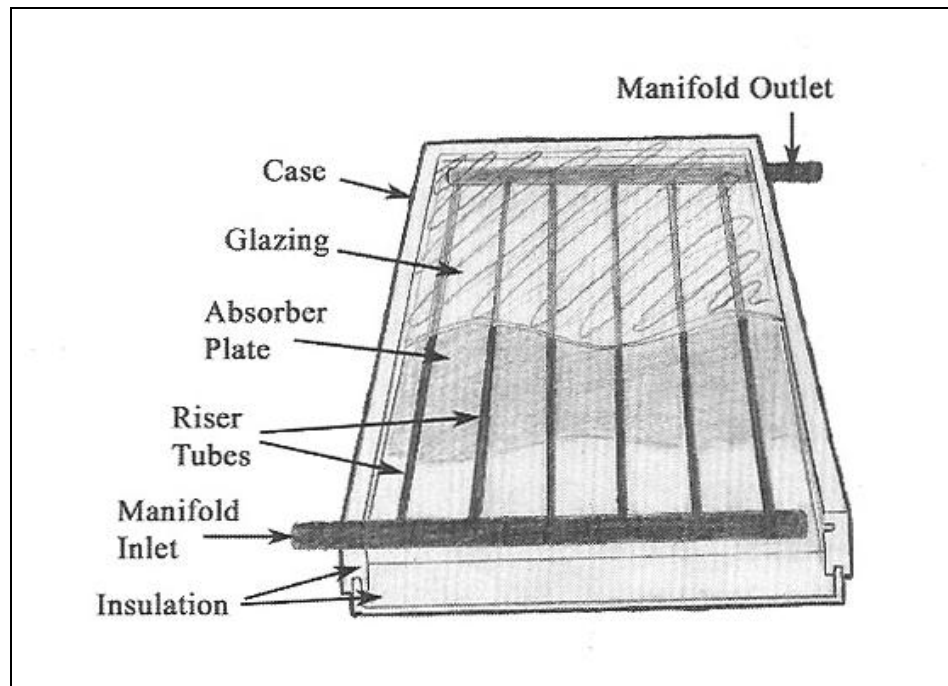


Figure 10. Flat plate collector./6/

Evacuated tube collector

These collectors (**Figure 11**) can heat water till 250-300°C. It happens because heat losses are reduced by multilayer glassing coating and vacuum inside collector.

Principle of evacuated tube collector is the same as thermos. External part of the tube is transparent. Internal plates have highly selective covering which detect solar energy. Vacuum is inside the tube. Vacuum layer is a heat-insulating layer and it gives an opportunity to save 95% of detected solar energy.

Heat pipes with absorber plates (which are inside the glass tube) are thermal conductors. Liquid in these pipes is vaporized. It condensed in the highest part of the tube and transfer heat to the collector.

The highest efficiency can be achieved (in comparison with other types of collectors) in low temperature conditions and low flux of solar radiation.

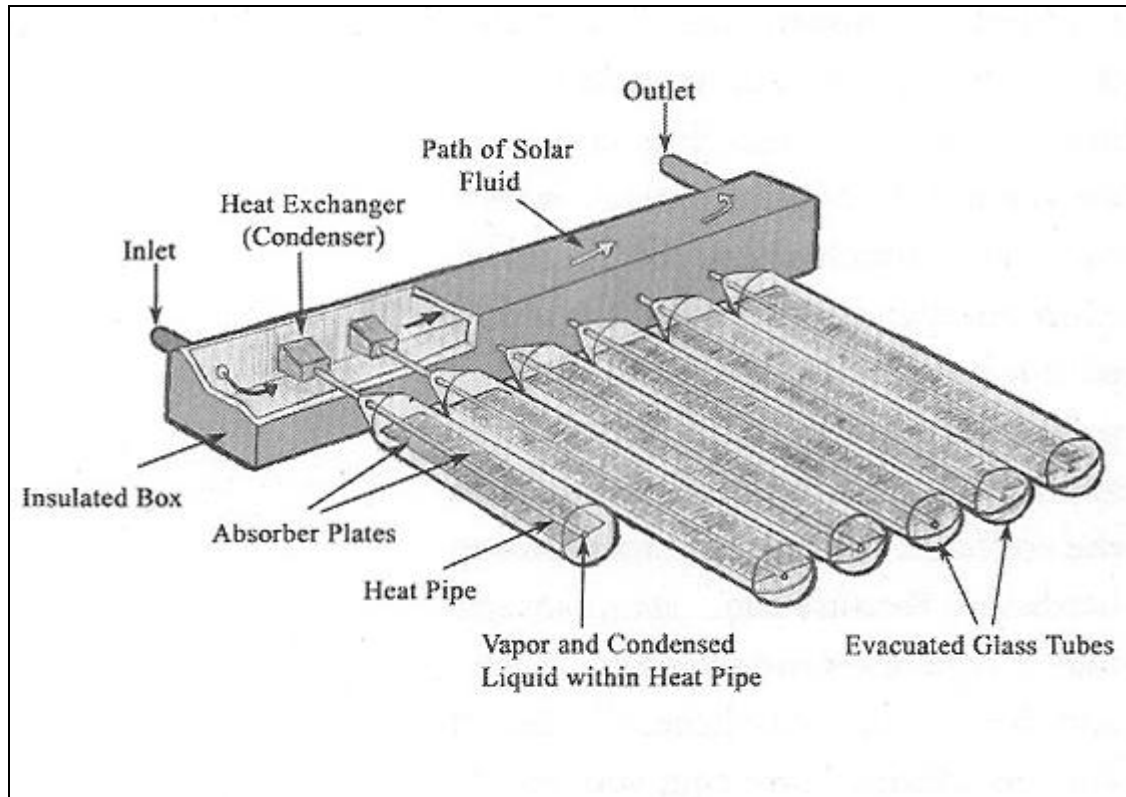


Figure 11. Evacuated tube collector./6/

Concentrating collectors

These collectors (**Figure 12**) can heat water till 120-250°C. It is due to using concentration of solar energy. Cylindrical parabolic concentrators are under absorbing elements. To achieve highest efficiency solar tracer is needed.

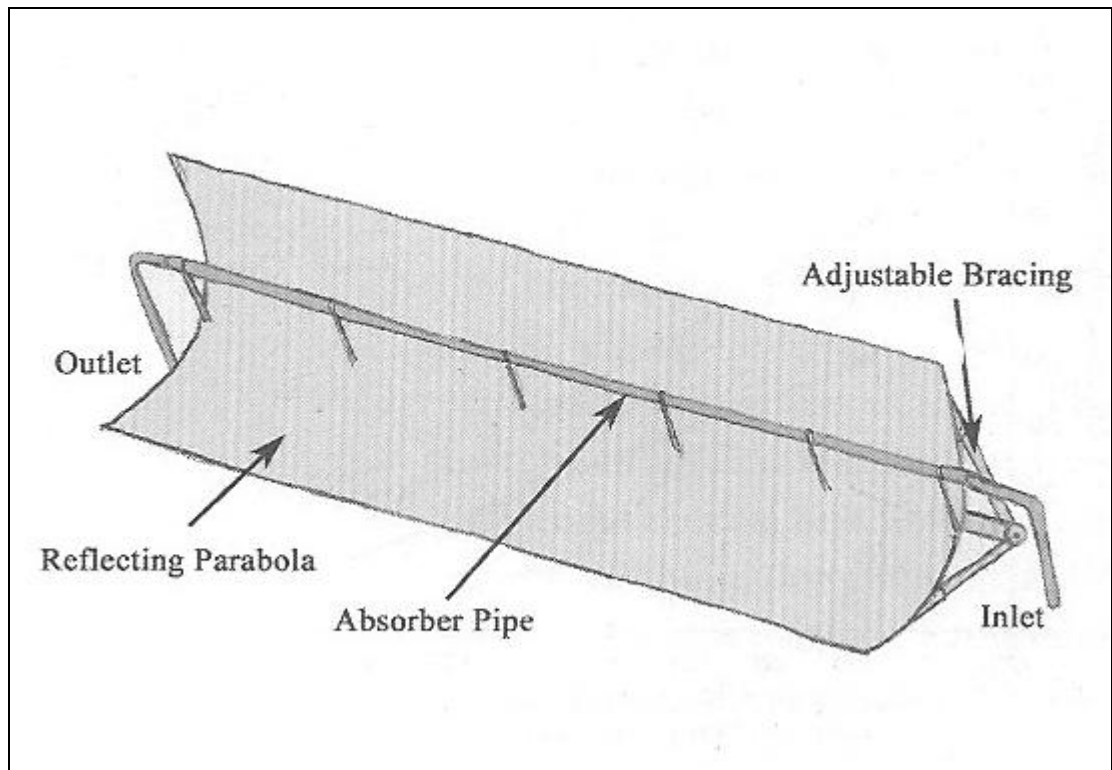


Figure 12. Concentrating collector./6/

Which collector is suitable for which situation?

The desired temperature range of the material to be heated is the most important factor in choosing the correct type of collector. An uncovered absorber is certainly not suitable for producing process heat. The amount of radiation on that spot, exposure to storms, and the amount of space must all be carefully considered when planning a solar array.

Graph of efficiency and temperature ranges of various types of collectors is shown at **figure 13:**

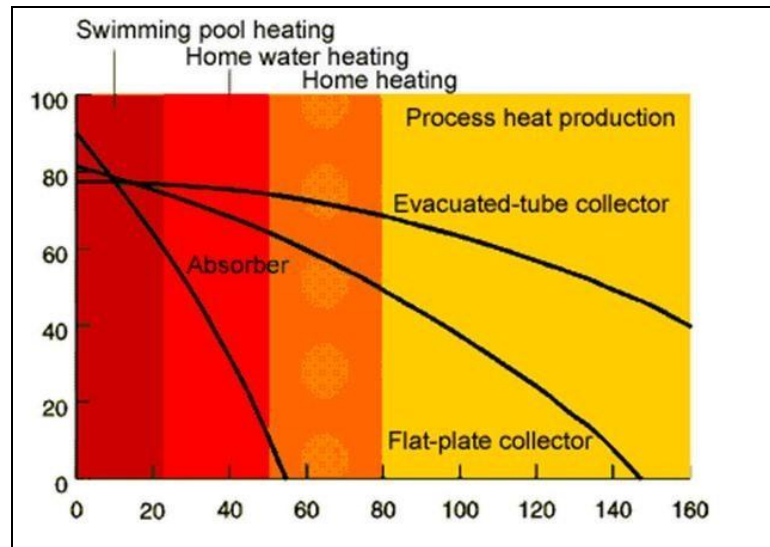


Figure 13. Graph of efficiency and temperature ranges of various types of collectors (radiation: 1000 W/m^2)/6/

5.3. Types of solar water heating systems

All the active solar water heating systems are divided in two general categories: open loop systems and closed loop systems.

Open Loop Systems (figure 14)

These are basic type of systems. They are simple and appeared long time ago. The main principle of the open loop system is the water circulating directly through the solar collectors and then returns to the storage tank. There is special pump controller which is called differential controller. It turns the pump on when collectors have higher temperature than stored water and shut is off when they get the same temperature. This type of system has several benefits such as low cost and easy installation. On the other hand there are significant drawbacks:

1. No totally reliable form of freeze protection

Collectors are drained manually so they can be set only in areas which never freeze

2. No high limit protection

There is possibility that water in the storage tank and solar collector can boil if there won't be daily consumption of hot water

3. In areas of waste water the solar collectors are sensitive to clogging from mineral deposits

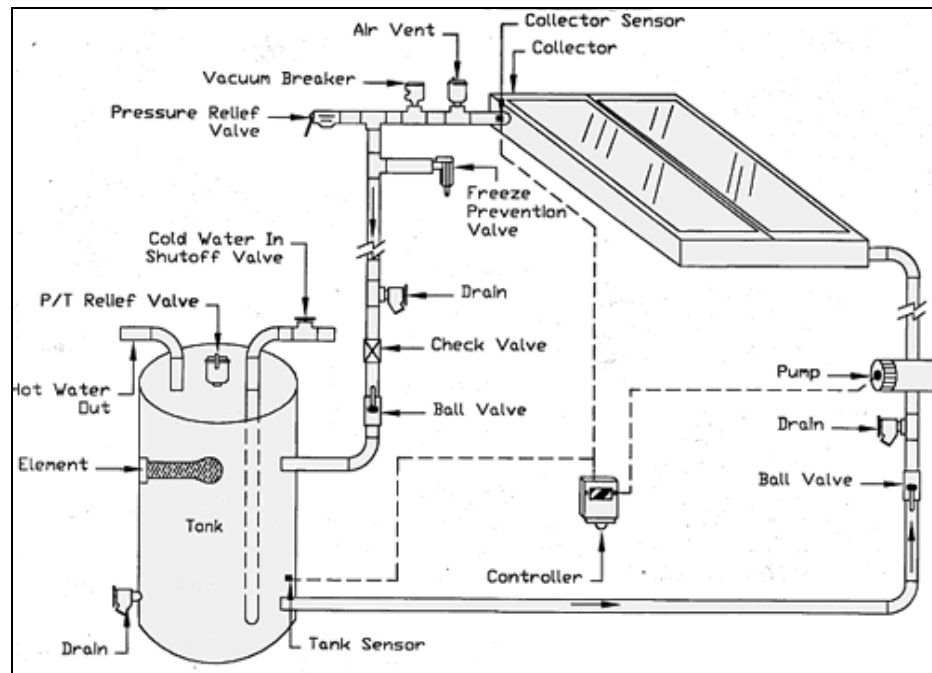


Figure 14. Open loop solar water heating system./7/

Closed Loop Systems

In closed loop system water doesn't circulate directly through the solar collectors. There is special fluid which is separated and circulates through the collectors. Then it goes to heat exchanger which transfers the heat to the water in storage tank. This fluid is often propylene glycol. There is special equipment in closed loop systems such as an expansion tank, pressure gages and fill valves.

There are two types of closed loop systems:

- 1) Glycol Indirect System is shown on the **figure 15**.

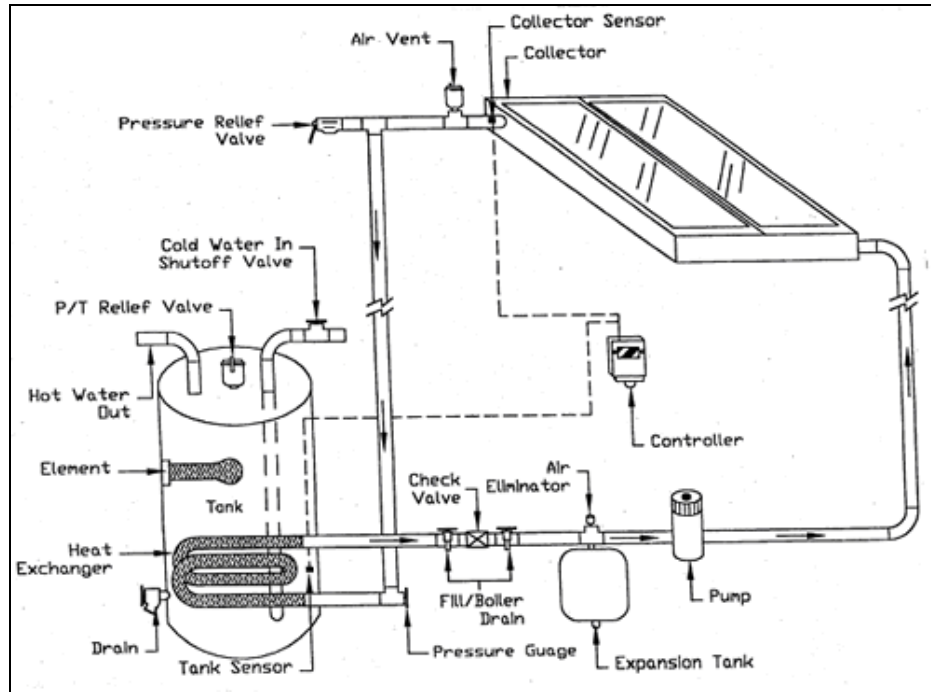


Figure 15. Glycol Indirect solar water heating system./7/

It is used for a long time like the open loop system but with a mixture of glycol and water as the heat transfer fluid the problem of freezing is removed. Nevertheless there are problems of high limit protection and the possibility of failure of the added components such as expansion tank or pressure gages.

- 2) Drainback system (**figure 16**)

This type of system is non-pressurized and uses water as a heat transfer fluid. The solution is a small drainback reservoir which is installed in the collector loop which is located lower than collectors. That is why water reaches only the top of reservoir and collectors stay dry when the pump doesn't work. Pump circulates water in the reservoir through the collectors

where it is heated when collectors are hotter than the water in storage. Also there is a heat exchanger which transfers heat from this water to the heat storage tank. The pump shuts off when collectors reach the same temperature as the water in the storage tank or this water gets a preset temperature. Then all the water drains back to the reservoir. This type of system has several benefits:

- freeze protection is based on gravity
- damage of collectors in hard water areas is almost eliminated
- less components which can failure

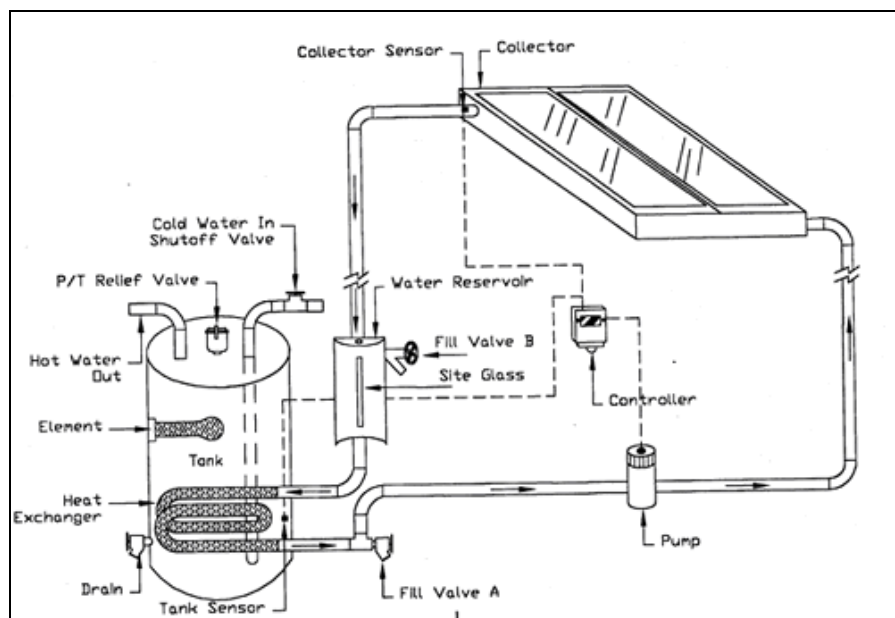


Figure 16. Drainback solar water heating system./7/

5.4. The operating principle of solar water heating system

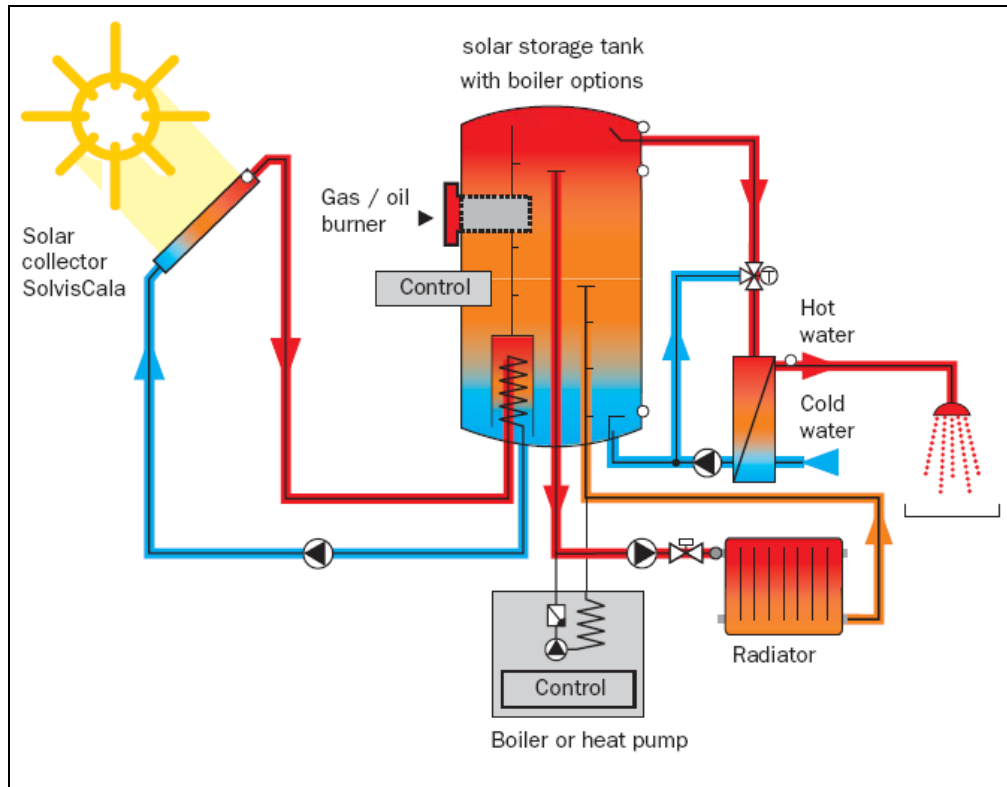


Figure 17. Solar water heating system./8/

Basic working principle of solar water heating system is shown in **figure 17**. The main idea is to maintain maximum temperature difference between heat exchanger and heated water. Efficiency increases when temperature difference is as high as possible. So, solar heat exchanger must be in the coldest place. Cold water is at the lower part of the storage tank. Stratification of water with different temperature (from lowest to highest) is due to gravity. Density of cold water is more than density of hot water.

All connections are carried out in this way to prevent mixing of cold and hot water. Hot domestic water is taken from the highest point, where temperature is high enough. Incoming cold water connection is situated in the lowest place, near solar heat exchanger. Water temperature for heating purposes is taken from highest point (where

temperature is near 80°C.) Returned water connection is in the middle of the tank, where temperature is the same as returned water temperature.

Solar storage tank should be high enough to maintain temperature difference inside. In other case gravity principle will not work. Sometimes thermostable panels are made inside the tank to make a tunnel for water. It helps to prevent water mixing.

When solar energy is not enough oil or gas boiler starts to work. But it must not reduce solar energy efficiency. That is why it is connected upper than solar heat exchanger.

6. Summary

Values of solar energy are very low for winter period. That is why it is decided to use solar energy only for hot domestic water in summer period. Evacuated tube collector is chosen for a system as the most effective. It can transfer into heat more than 95% of incoming solar energy. Potential consumption of solar energy is taken from previous calculations of solar radiation on horizontal surface per month with atmosphere and real climatic conditions. Solar collector where area is 10m^2 will be enough to provide heat for DHW in summer months. As shown in **figure 18**.

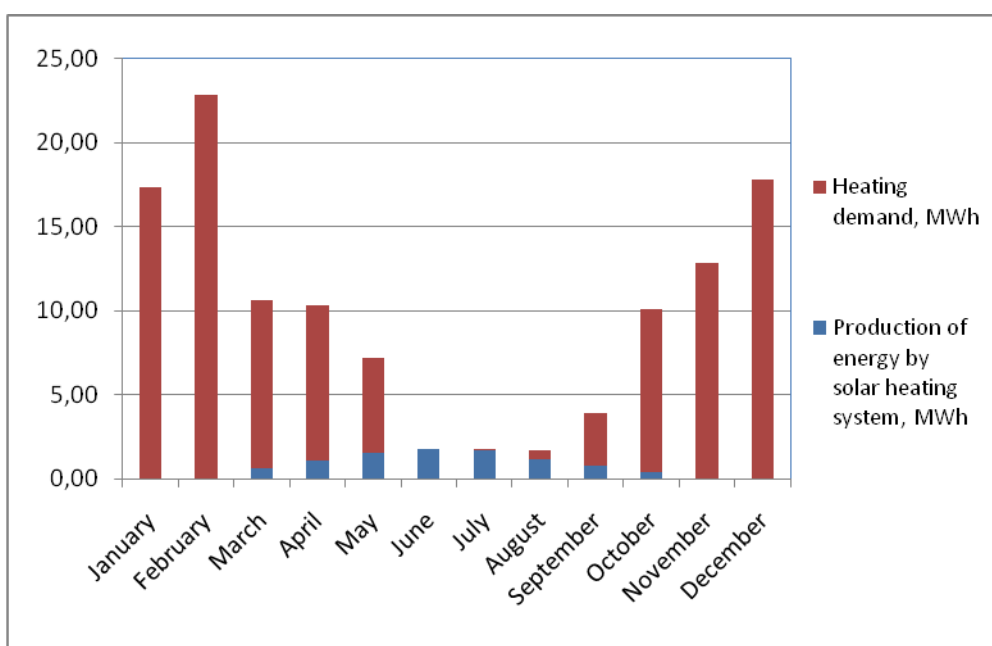


Figure 18. Quantity of solar energy in total energy demand.

Calculation of cost efficiency

Discount cash model is used for cost efficiency calculation.

All amounts of money are corrected with discount factor:

$$D=1/(1+i)^n$$

Formula 41 /9/

where D – discount factor;

i - interest rate;

n - number of the period.

1. Net present value - NPV
2. Payback period - PB
3. Internal rate of return - IRR
4. Profitability index - PI

1. NPV (Net Present Value)

$$NPV = \sum_{n=t1}^{t2} DInflow - \sum_{n=t1}^{t2} DOutflow$$

Formula 42 /9/

where:

n-number of the period;

t1, t2-interval of calculations.

When NPV is negative project is not cost efficient.

2. PP (Payback Period)

During Payback Period all investment costs must be compensated.

$$\sum_{n=t1}^{t2} DInflow - \sum_{n=t1}^{t2} DOutflow = 0$$

Formula 43 /9/

where:

n – number of the period of the project;

t1, t2 - interval of calculations;

D – discount factor.

3. IRR (Internal Rate of Return)

IRR shows maximum investment cost. For example, maximum interest on credit, which can be taken for a project.

$$\sum_{n=t1}^{t2} \frac{Inflow(a)}{\left(1 + \frac{IRR}{100}\right)^n} - \sum_{n=t1}^{t2} \frac{Outflow(a)}{\left(1 + \frac{IRR}{100}\right)^n} = 0$$

Formula 44 /9/

where:

n - number of the period of the project;

t_1, t_2 - interval of calculations;

D – discount factor.

4. PI (Profitability Index)

Profitability Index shows net profit per unit of investment.

$$PI = NPV / I$$

Formula 45 /9/

where:

NPV – Net Present Value;

I - investment.

At this example minimum investment cost of equipment is 90000rub (price is given for year 2009). Minimum operation life of the solar heating system is 20 years.

Inflation in Russia is 14% for year 2009./10/

Interest on credit in Sberbank of Russian Federation is 18%./10/

Rise of gas price at internal market is expected 30%./10/

Calculations of cost efficiency are made in Excel program. Process of calculations is shown at **table 6**.

Results of calculations are:

PP=14,41 year;

IRR=47,02%;

PI=3,33.

Project is cost efficient.

Number of the year	1	2	3	4	5	6	7	8	9	10
Return, because of using solar energy	2687	3493,1	4541,0 3	5903,33 9	7674,3 41	9976,6 43	12969, 64	16860, 53	21918, 68	28494, 29
Deprecation	4500	4500	4500	4500	4500	4500	4500	4500	4500	4500
Credit payment	5310	5310	5310	5310	5310	5310	5310	5310	5310	5310
Inflow	1877	2683	3731	5093	6864	9167	12160	16051	21109	27684
NPV(14%)	1646	2065	2518	3016	3565	4176	4859	5627	6491	7468
NPV(60%)	1173	1048	911	777	655	546	453	374	307	252

Number of the year	11	12	13	14	15	16	17	18	19	20
Return, because of using solar energy	3704 2	48155, 35	62601, 95	81382,5 4	105797 ,3	137536 ,5	178797 ,4	232436 ,7	302167 ,7	392818
Deprecation	4500	4500	4500	4500	4500	4500	4500	4500	4500	4500
Credit payment	5310	5310	5310	5310	5310	5310	5310	5310	5310	5310
Inflow	3623 3	47345	61792	80573	104987	136726	177987	231627	301358	392008
NPV(14%)	8573	9827	11250	12868	14708	16803	19187	21903	24997	28523
NPV(60%)	206	168	137	112	91	74	60	49	40	32

Table 6. Indexes of efficiency of investment project.

Conclusion

Solar water heating systems can be used effectively in cold climate conditions during 6-7 month per year (March/April-September) for domestic hot water, underfloor heating or space heating.

However, solar energy is not very popular in Russia. It has many problems, such as:

- There is no big experience in building solar systems;
- Inclement climate;
- Climatology data bases are rather old;
- Ratio between cost of solar collectors and it's efficiency is not high enough;
- No solar heating association is needed to cooperate with other countries.

Lack of solar radiation is the problem of northern regions. Sometimes even solar collector with large area can not be enough to provide required energy demand. In this case designers must think how to decrease heating demand. This aim could be achieved due to decrease heat losses through building envelope. Passive solar heating should be taken into account at the design phase. Different ways of accumulating energy must be used in buildings.

Investment cost of equipment which transformed solar energy looks to high in comparison with cost of natural gas or light oil. Cost efficiency of this project is not high in conditions of Russian economics. It is due to high level of interest of credit. In given example project is cost efficient. It is no difference for customer to pay for fuel or invest money into solar heating system. Sometimes it is not cost-beneficial to use solar systems, but we must think in perspective way. Fossil fuels are not renewable. New sources of energy must be improved.

However fossil fuel usage has a great influence on the ecology of our planet. And it is an irreversible process. In my view it is governmental problem, so government must stimulate customers to use environmentally-friendly systems for their houses. Our nature needs to be protected by government and by each person.

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Appendix

January

Time of the day	ω_c	$\cos \theta_z$	Ehor	Mi	trayleigh	taerosol	tozone	tgas	TH2O	Edirect	B	taa	tas	Ediffuse	ra	Etot
10,0	-56,43	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-41,66	0,07	99,75	13,70	0,00	-0,29	0,99	0,98	0,80	0,00	0,54	0,57	-0,52	34,64	0,77	40,00
12	-26,66	0,15	201,00	6,80	0,00	0,45	0,99	0,98	0,82	0,23	0,57	0,90	0,50	94,00	0,28	99,00
13	-11,66	0,19	260,17	5,25	0,01	0,59	0,99	0,98	0,83	3,52	0,60	0,94	0,63	125,43	0,22	134,00
14	3,34	0,20	273,25	5,00	0,02	0,61	0,99	0,98	0,83	5,25	0,60	0,94	0,65	131,88	0,21	143,00
15	18,34	0,18	239,33	5,71	0,01	0,55	0,99	0,98	0,83	1,65	0,59	0,93	0,59	114,73	0,24	122,00
16	33,34	0,12	160,73	8,50	0,00	0,29	0,99	0,98	0,81	0,01	0,56	0,85	0,34	71,23	0,36	76,00
17,1	49,94	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-

February

Time of the day	ω_c	$\cos \theta_z$	Ehor	Mi	trayleigh	taerosol	tozone	tgas	TH2O	Edirect	B	taa	tas	Ediffuse	ra	Etot
9,02	-	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-
10,00	72,72	0,09	118,11	11,57	0,00	-0,04	0,99	0,98	0,81	0,00	0,54	0,71	-0,05	46,06	0,55	51,70
11,00	-	0,19	263,60	5,19	0,02	0,59	0,99	0,98	0,83	3,93	0,60	0,94	0,63	127,14	0,22	137,00
12,00	-	0,27	373,15	3,66	0,11	0,72	0,99	0,98	0,84	36,78	0,64	0,96	0,74	172,52	0,16	216,20

	28,07															
	-															
13,00	13,07	0,32	439,30	3,11	0,18	0,76	1,00	0,98	0,85	75,59	0,66	0,97	0,78	190,84	0,14	274,2
14,00	1,93	0,33	457,57	2,99	0,20	0,77	1,00	0,98	0,85	88,40	0,67	0,97	0,79	194,86	0,14	291,3
15,00	16,93	0,31	426,70	3,20	0,17	0,75	1,00	0,98	0,84	67,24	0,66	0,97	0,78	187,82	0,15	262,7
16,00	31,93	0,26	348,79	3,92	0,08	0,70	0,99	0,98	0,84	25,95	0,63	0,96	0,73	164,10	0,17	196,7
17,00	46,93	0,17	229,15	5,97	0,01	0,52	0,99	0,98	0,83	1,07	0,58	0,92	0,57	109,34	0,25	116,1
18,00	61,93	0,06	75,92	18,01	0,00	-0,90	0,98	0,97	0,79	0,00	0,53	0,16	-5,53	18,67	3,15	50,5
18,18	64,69	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-

March

Time of the day	ω_c	$\cos \theta_z$	Ehor	Mi	trayleigh	taerosol	tozone	tgas	TH2O	Edirect	B	taa	tas	Ediffuse	ra	Etot
7,79	-89,99	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-
8,00	-86,91	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-
9,00	-71,91	0,13	174,04	7,85	0,00	0,35	0,99	0,98	0,82	0,03	0,56	0,87	0,40	78,85	0,33	84,4
10,00	-56,91	0,25	348,42	3,92	0,08	0,70	0,99	0,98	0,84	25,80	0,63	0,96	0,73	163,96	0,17	196,4
11,00	-41,91	0,36	495,23	2,76	0,25	0,79	1,00	0,98	0,85	117,18	0,68	0,98	0,81	201,97	0,13	327,6
12,00	-26,91	0,44	604,48	2,26	0,37	0,83	1,00	0,98	0,85	213,98	0,72	0,98	0,84	215,70	0,11	439,5
13,00	-11,91	0,49	668,73	2,04	0,43	0,84	1,00	0,98	0,86	276,98	0,74	0,98	0,86	220,54	0,11	508,2
14,00	3,09	0,50	683,60	2,00	0,44	0,85	1,00	0,98	0,86	291,99	0,75	0,98	0,86	221,43	0,10	524,2
15,00	18,09	0,47	648,09	2,11	0,41	0,84	1,00	0,98	0,86	256,39	0,74	0,98	0,85	219,17	0,11	486,0
16,00	33,09	0,41	564,60	2,42	0,33	0,81	1,00	0,98	0,85	176,80	0,71	0,98	0,83	211,66	0,12	397,8
17,00	48,09	0,32	438,83	3,12	0,18	0,76	1,00	0,98	0,85	75,27	0,66	0,97	0,78	190,73	0,14	273,8

May

Time of the day	ωc	$\cos \theta z$	Ehor	Mi	trayleigh	taerosol	tozone	tgas	TH2O	Edirect	B	taa	tas	Ediffuse	ra	Eto
6,25	-	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-
7,00	109,84	0,20	266,86	5,12	0,02	0,60	0,99	0,98	0,83	4,35	0,60	0,94	0,64	128,76	0,21	139
8,00	-83,52	0,33	450,12	3,04	0,20	0,77	1,00	0,98	0,85	83,08	0,66	0,97	0,79	193,27	0,14	284
9,00	-68,52	0,46	627,94	2,18	0,39	0,83	1,00	0,98	0,86	236,59	0,73	0,98	0,85	217,68	0,11	464
10,00	-53,52	0,58	788,21	1,73	0,53	0,87	1,00	0,99	0,86	400,56	0,79	0,99	0,88	225,98	0,09	638
11,00	-38,52	0,67	920,04	1,49	0,61	0,88	1,00	0,99	0,87	541,74	0,84	0,99	0,89	229,17	0,09	784
12,00	-23,52	0,74	1014,43	1,35	0,65	0,89	1,00	0,99	0,87	644,14	0,87	0,99	0,90	230,63	0,08	889
13,00	-8,52	0,78	1064,98	1,28	0,67	0,90	1,00	0,99	0,87	699,15	0,89	0,99	0,91	231,29	0,08	945
14,00	6,48	0,78	1068,22	1,28	0,67	0,90	1,00	0,99	0,87	702,68	0,89	0,99	0,91	231,33	0,08	948
15,00	21,48	0,75	1023,95	1,34	0,66	0,90	1,00	0,99	0,87	654,49	0,87	0,99	0,91	230,76	0,08	899
16,00	36,48	0,68	935,18	1,46	0,61	0,89	1,00	0,99	0,87	558,12	0,84	0,99	0,90	229,43	0,08	801
17,00	51,48	0,59	807,95	1,69	0,54	0,87	1,00	0,99	0,86	421,48	0,80	0,99	0,88	226,59	0,09	660
18,00	66,48	0,48	650,92	2,10	0,42	0,84	1,00	0,98	0,86	259,20	0,74	0,98	0,85	219,37	0,11	489
19,00	81,48	0,35	474,79	2,88	0,23	0,78	1,00	0,98	0,85	101,19	0,67	0,97	0,80	198,30	0,13	307
20,00	96,48	0,21	291,54	4,69	0,03	0,63	0,99	0,98	0,83	8,52	0,61	0,95	0,67	140,50	0,20	155
21,00	111,48	0,08	113,65	12,03	0,00	-0,09	0,99	0,98	0,80	0,00	0,54	0,68	-0,13	43,33	0,59	49
22,00	126,48	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-
22,5	133,50	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-

June

September

Time of the day	ωc	$\cos \theta z$	Ehor	Mi	trayleigh	taerosol	tozone	tgas	TH2O	Edirect	B	taa	tas	Ediffuse	ra	Etot
8,04	-82,79	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-
9,00	-68,35	0,23	319,17	4,28	0,05	0,67	0,99	0,98	0,84	15,52	0,62	0,95	0,70	152,55	0,18	174,00
10,00	-53,35	0,36	488,10	2,80	0,24	0,78	1,00	0,98	0,85	111,51	0,68	0,97	0,80	200,74	0,13	320,00
11,00	-38,35	0,46	626,87	2,18	0,39	0,83	1,00	0,98	0,86	235,56	0,73	0,98	0,85	217,59	0,11	460,00
12,00	-23,35	0,53	726,05	1,88	0,48	0,85	1,00	0,99	0,86	335,49	0,77	0,98	0,87	223,59	0,10	570,00
13,00	-8,35	0,57	778,87	1,76	0,52	0,86	1,00	0,99	0,86	390,70	0,78	0,99	0,88	225,67	0,10	620,00
14,00	6,65	0,57	781,75	1,75	0,52	0,86	1,00	0,99	0,86	393,73	0,79	0,99	0,88	225,77	0,09	630,00
15,00	21,65	0,54	734,48	1,86	0,49	0,86	1,00	0,99	0,86	344,23	0,77	0,98	0,87	223,96	0,10	570,00
16,00	36,65	0,47	640,28	2,13	0,41	0,84	1,00	0,98	0,86	248,69	0,73	0,98	0,85	218,62	0,11	470,00
17,00	51,65	0,37	505,58	2,70	0,26	0,79	1,00	0,98	0,85	125,57	0,68	0,98	0,81	203,67	0,13	330,00
18,00	66,65	0,25	339,53	4,03	0,07	0,69	0,99	0,98	0,84	22,36	0,62	0,96	0,72	160,64	0,17	180,00
19,00	81,65	0,11	153,44	8,91	0,00	0,25	0,99	0,98	0,81	0,00	0,56	0,83	0,30	67,02	0,38	70,00
20,00	96,65	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-
20,51	104,25	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-

October

Time of the day	ωc	$\cos \theta z$	Ehor	Mi	trayleigh	taerosol	tozone	tgas	TH2O	Edirect	B	taa	tas	Ediffuse	ra	Etot
9,12	-64,17	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-
10,00	-	0,20	270,72	5,05	0,02	0,60	0,99	0,98	0,83	4,88	0,60	0,94	0,64	130,65	0,21	141,54

	50,91															
11,00	-															
	35,91	0,29	401,86	3,40	0,14	0,74	0,99	0,98	0,84	52,05	0,65	0,97	0,76	181,25	0,15	240,63
12,00	-															
	20,91	0,36	492,65	2,77	0,25	0,79	1,00	0,98	0,85	115,11	0,68	0,97	0,81	201,53	0,13	325,12
13,00	-5,91	0,39	536,89	2,55	0,30	0,80	1,00	0,98	0,85	152,10	0,70	0,98	0,82	208,25	0,12	369,40
14,00	9,09	0,39	531,58	2,57	0,29	0,80	1,00	0,98	0,85	147,49	0,69	0,98	0,82	207,53	0,12	364,00
15,00	24,09	0,35	477,08	2,87	0,23	0,78	1,00	0,98	0,85	102,94	0,67	0,97	0,80	198,73	0,13	309,95
16,00	39,09	0,28	377,09	3,63	0,11	0,72	0,99	0,98	0,84	38,73	0,64	0,96	0,75	173,79	0,16	219,55
17,00	54,09	0,17	238,43	5,73	0,01	0,54	0,99	0,98	0,83	1,59	0,59	0,93	0,59	114,26	0,24	121,66
18,00	69,09	0,05	70,54	19,38	0,00	-1,12	0,98	0,97	0,79	0,00	0,53	-0,01	91,82	14,73	-43,00	1,53
19,00	84,09	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-
19,12	85,82	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-

November

Time of the day	ω_c	$\cos \theta_z$	Ehor	Mi	trayleigh	taerosol	tozone	tgas	TH2O	Edirect	B	taa	tas	Ediffuse	ra	Etot
9,30	-															
	61,28	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-
10,00	-															
	50,70	0,05	67,60	20,22	0,00	-1,26	0,98	0,97	0,79	0,00	0,52	-0,13	9,60	12,50	-4,02	6,
11,00	-															
	35,70	0,14	192,78	7,09	0,00	0,42	0,99	0,98	0,82	0,13	0,57	0,89	0,47	89,42	0,29	95,

