SOLAR AND TERRESTRIAL RADIATION WITH MEASURING INSTRUMENTS OVERVIEW

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Abstract: The Earth receives more energy from the sun in one hour than human population uses in one year. Total solar energy absorbed in Earth's atmosphere, oceans and land is about 3.850.000 EJ per year. The amount of solar energy that reaches the surface is enormous, such that, in one year, it is two times greater than all Earth's non-renewable sources of energy.

Keywords: solar energy, measuring instruments, radiation.

1. INTRODUCTION

The Sun is an open fusion reactor, which turns about 600 million tons of hydrogen into helium each second (proton – proton chain), with the release of the enormous amount of energy that is sent to space [1].

From a total 3.8×10^{26} W that the Sun radiates into space, the Earth receives 1.75×10^{17} W**.** About 30 % of received energy the Earth reflects back into space, about 47% is retained in the form of heat, about 23% is used in the process of water circulation in nature while the rest is „spent“ to photosynthesis. Fossil fuels are a form of accumulated solar energy: oil, gas, coal.

The Earth receives more energy from the Sun in one hour than human population uses in one year. Total solar energy absorbed in Earth's atmosphere, oceans and land is about 3,850,000 EJ per year. The amount of solar energy that reaches the surface is enormous, such that, in one year, it is two times greater than all Earth's non-renewable sources of energy [2].

2. SOLAR RADIATION

Sun, as the closest star, irradiates the surface of planet Earth with an enormous amount of the sun or, in other words, solar energy. It is responsible for all movements of matter and energy on our planet. For that reason, being familiar with radiation structure is very important in order to understand that movement [2].

Temperature of the surface of the Sun is 5,778 K, where the waves are irradiated from gamma to radio spectrum. 99% of radiation falls within the range of 0.2-5.6 µm, 80% within 0.4-1.5 µm and maximum is at 0.48 µm. Radiation from Earth is 160,000 times less in intensity that the solar and it is in the field of infrared radiation in the range 4-25 µm with a maximum of 9.7 µm. The largest source of radiation for the planet Earth is the Sun, where a direct incoming solar radiation to the Earth's surface is called direct solar irradiation. Radiation that

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reaches the outer edges of atmosphere is called extraterrestrial radiation. Its spectral distribution is shown in Figure 1.

Planet Earth changes the distance from the Sun by moving in elliptical orbit. Nature of the Sun is such that it has activities that are reflected in the change of radiation intensity. For that reason, solar constant S_0 is defined as the average energy of extraterrestrial radiation that amounts to 1,367 W/m^2.

In Figure 1, it can be seen in which part of incoming spectrum does the visible light fall, i.e. to what extent is the optical system of a man limited. Figure 2 shows the ratio between extraterrestrial radiation, direct (that reached the Earth's surface itself, sea level altitude) and global radiation (includes both direct and diffuse radiation). Spectral distribution of direct and global radiation has a „rural" character. It is due to the absorption that occurs by passing of light through the atmosphere.

The second largest radiation source is full Moon. In that case, it is about a reflected extraterrestrial radiation weakened due to diffusion and absorption in the atmosphere by night. Figure 3 shows Moon's spectral „radiation" (it is actually about Moon's albedo).

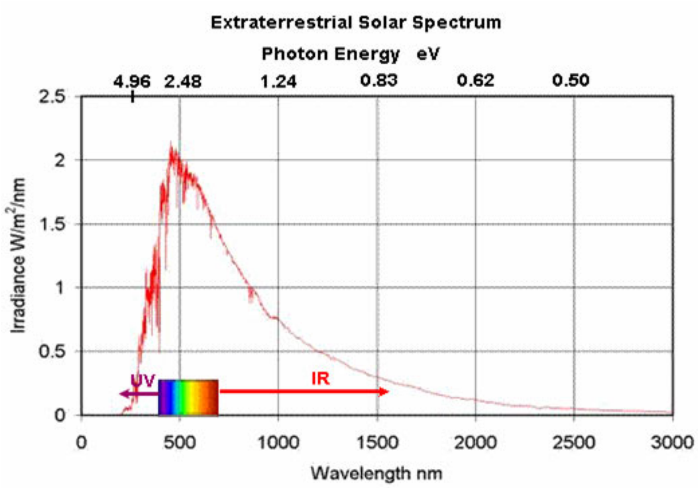

Fig. 1. Spectral distribution of extraterrestrial radiation [2].

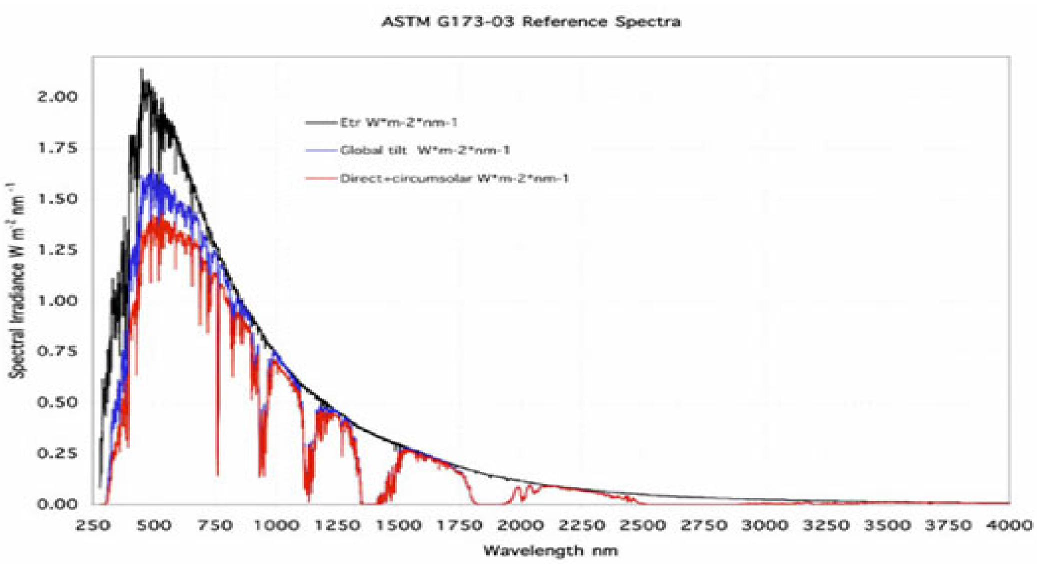

Fig. 2. Ratio between extraterrestrial radiation, direct and global radiation [2].

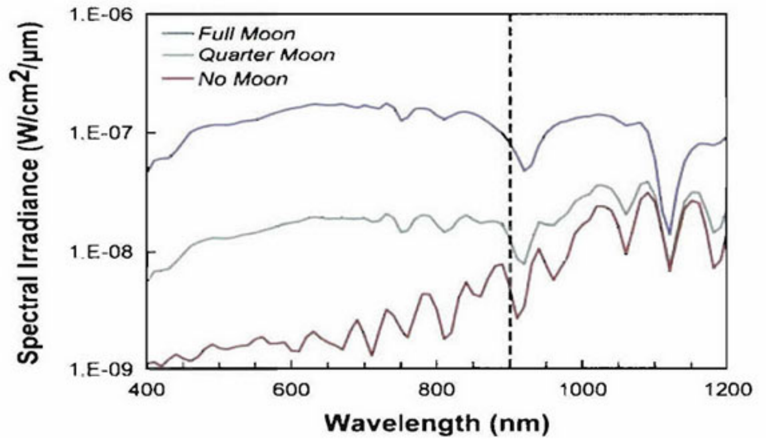

Fig. 3. Lunar spectral „radiation“ [2].

Extraterrestrial radiation can be absorbed, reflected or transmitted once it reaches the surface of atmosphere. What will happen depends on physical parameters of medium, as well as their distribution, the wavelength of incident-incoming light, angle under which it falls on surface. Transmission changes the speed and wavelength of the waves but not the frequencies. In case of reflection, we distinguish angular reflection and ray scattering reflection in all directions (Figure 4). In the first case (reflection), the reflection-rejection of light angle is known (equals the incidence angle), while in the second case (scattering), it is about numerous reflection angles. However, neither wavelength nor radiation speed are changing, because it does not go through the medium. Absorption makes a medium opaque for a given wavelength. The absorption itself is followed by repeated radiation and increase of atmosphere's temperature [2].

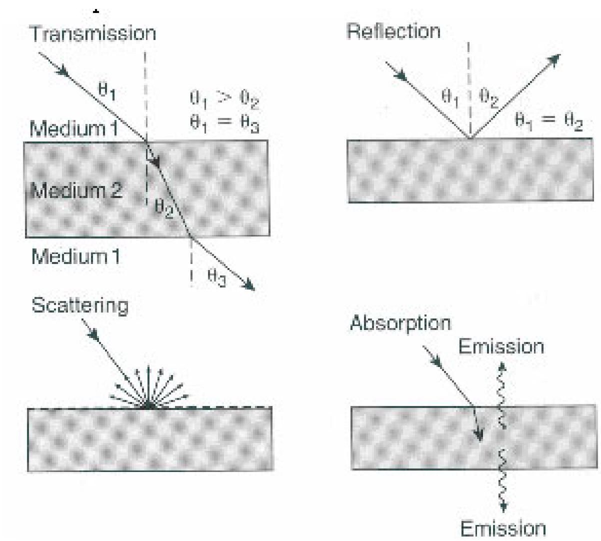

Fig. 4. Angular reflection and ray scattering reflection in all directions [2].

Interaction with atmosphere determines the amount of energy that will be received on surface itself and additional interaction with the surface determines the amount that will, summary, be returned to space. In Figure 5, it can be seen which percentage of incoming light falls on the surface, which is reflected and from which it is determined in relation to total radiation, as well as Earth's radiation (terrestrial), also in the overview of effects share on it (with the error of about 2%). Otherwise, this is already known figure from the paper [3]. Red colour refers to direct light that can be seen during sunrise or sunset, when there is no light diffusion. The second colour figuratively marks the blue sky. Even in that way, it is pointed out to the participation and significance of direct and diffusion light.

The most important absorbers in the atmosphere are: ozone, carbon dioxide, water vapour, oxygen, nitrogen.

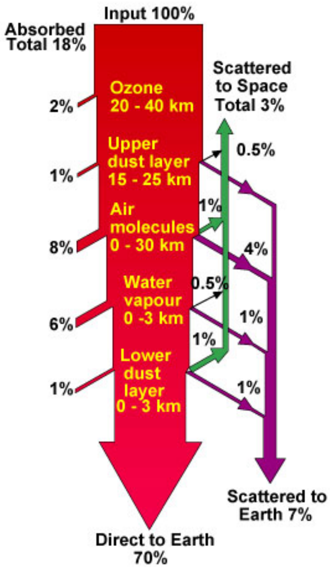

Fig. 5. Percentage of incoming light that fall on the surface [3].

About 16 % of intensity is absorbed in atmosphere gases, integrally observed, while 2% is absorbed in clouds. Gamma rays and X-rays are absorbed by oxygen and nitrogen, ozone absorbed wavelengths 0.2-0.3 μm, 0.9-2.7 μm water vapour and carbon dioxide. Furthermore, 5-8 μm and 20-1,000 μm water vapour, 14-20 μm carbon dioxide, ozone 9-10 μm.

In case of scattering, it comes to light scattering in all directions, so that agents that affect this phenomenon are the following: gas molecules, aerosols (small particles), clouds. There three types of dispersion [2].

The first is Rayleigh (molecularly, particle diameter is ten times smaller than wavelength), the dispersal that mainly occurs with oxygen and nitrogen at heights above 4.5 km. The intensity decreases with the fourth degree of wavelength. It needs to be mentioned that blue light disperses 5 times more intensively that red light. That is the reason for the emergence of blue light on the sunny sky. Looking at the sky in any direction, blue colour-wavelength that has the most intensive diffusion in the atmosphere can be seen. However, during sunrise/sunset only those wavelengths above red light pass through the atmosphere so the colour of the sky is reddish, due to the scattering.

The second dispersion (Mie or non-molecular) occurs on particles from 0.1 to 10 times larger than wavelength. Those are water vapour particles, smog (smaller particles), dust, volcanic ash, salt crystals obtained by evaporation of small drops in the air that come from the sea. This occurs at altitudes less than 4.5 km. Lawfulness is inversely proportional to wavelength. Both dispersals are significant in case of the clear sky.

Finally, the third is indiscriminate scattering, almost even by the intensity for all radiation wavelengths and it occurs on particles larger than ten times wavelength of incident ray: aerosols, clouds, fog, ice crystals. Even dispersion is precisely the reason for purely white edges of clouds.

Incoming radiation on Earth's surface interacts unevenly with the surface due to both the nature itself and human activities that affect the change of surface. Intensity of the light varies from 50% to 70% of initial extraterrestrial radiation and about 7% to 10% of diffusion radiation. Incident rays are either absorbed or reflected on the surface. About 5% of the energy absorbed, the Earth radiates in long wave infrared range, although that also depends on surface temperature. In case of reflection, there is a big dependence of the reflection intensity on surface type. For that reason, the Albedo is defined as incident light reflection ratio. Thanks to the Albedo, planet Earth is visible from space.

2.1. Global solar radiation

Light or electromagnetic radiation that reaches the Earth's surface is partially absorbed on the surface, while the other part is reflected back to the atmosphere. Incoming light, apart from the component that comes directly from the Sun (it means that the light has not encountered obstacles, direction of direct radiation can be determined in each point of Earth's surface), there is also a part of the light that diffusely refracts due to the particles in atmosphere itself (e.g. clouds, dust, smog and other aerosols), in that way it changes the spectral distribution of incident light. Apart from that, the planet Earth itself radiates electromagnetic radiation (Figure 6). Total radiation that falls on the flat horizontal surface is called global radiation [2].

Global or total radiation consists of three components:

- direct;
- diffused or scattered;
- reflected or albedo surfaces.

Many papers, only the first two are mentioned as global radiation components, although sometimes the reflection from surrounding area is significant so it can noticeably change the total light intensity that reaches the plane of solar collector or panel. Due to the revolution and rotation of Earth, only extraterrestrial radiation changes over time, global radiation also changes on horizontal surface so that annual course in radiation occurs. It is the highest at summer and the least at winter, when it is cloudy or foggy, the value is smaller.

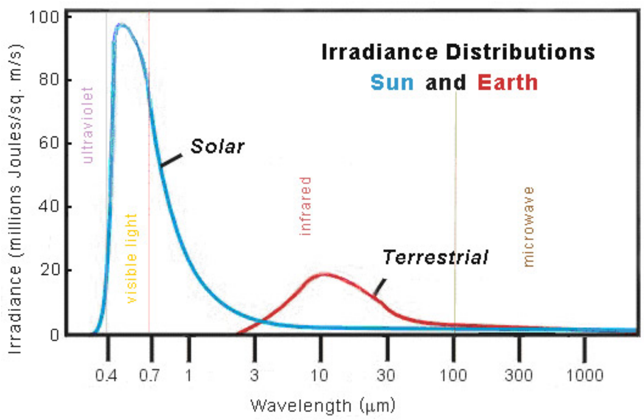

Fig. 6. Sun and Earth irradiation [2].

For that reason, there are maps that show the average total radiation for each month in a particular area. Intensity, quantity and quality (distribution of wavelengths in spectrum) are influenced by: astronomical, physical, meteorological, geometric and geographic factors. Figure 7 shows that global radiation depends on solar time both in intensity and in quality (only a part of spectrum is shown). Dashed line shows the light during sunrise and sunset.

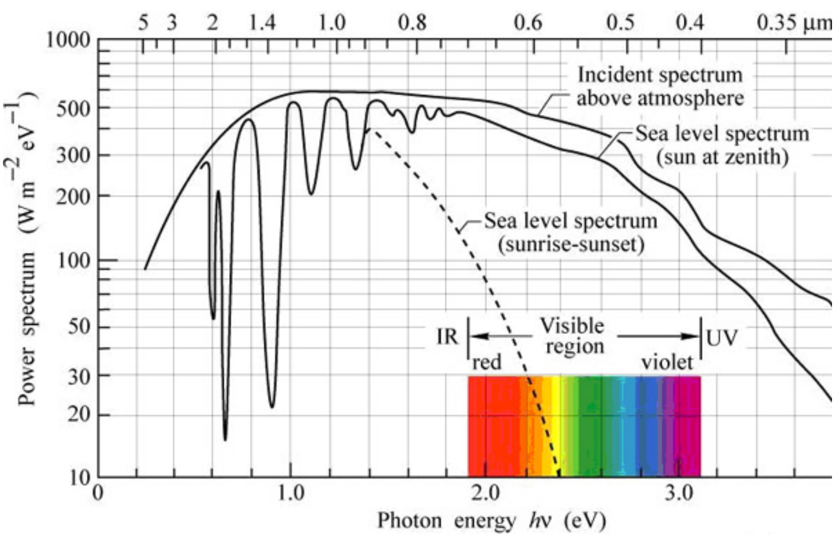

Fig. 7. Dependence of global radiation during the day [2].

When direct light falls at the angle other than 90^0, then the light flux on horizontal plate decreases, by which the light intensity is reduced (Figure 8) [4].

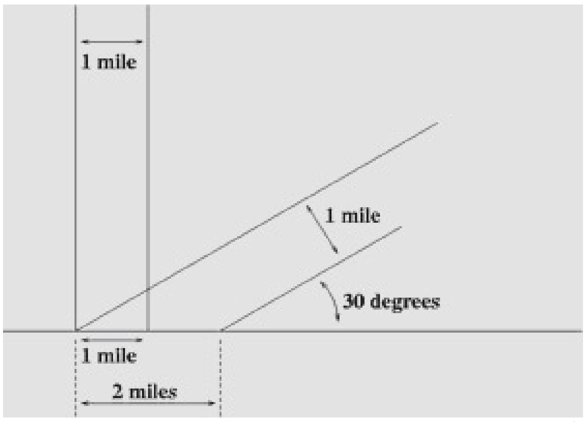

Fig. 8. Difference of direct radiation flux for incident angle of 90^o and 30^o [4].

3. MEASURING INSTRUMENTS FOR SOLAR AND TERRESTRIAL RADIATION

As a need for clear and precise description of conditions in which solar panels are planned and implemented, the knowledge of intensity and duration of solar insolation (total and diffusion) appear. Scientific discipline actinometry was developed within meteorology and it „deals with studying solar, terrestrial and other radiations in the atmosphere". In order to obtain as much data as possible, various measuring instruments were developed. Since ancient times, we are trying to measure the light amount that falls on Earth's surface and one of the oldest is the method of thermal conversion of light. Instrument that performs such measurements is actinometer, although many measuring instruments of solar radiation are called the same. Let's mention the instrument types and their names [1, 4, 5]:

- *actinometer and pyrheliometer* – for measuring direct solar radiation;
- *pyranometer and pyranograph* – for measuring dispersion and direct solar radiation;
- *pyrgeometer* – measuring the effective terrestrial radiation;
- *albedometer* – measuring reflected radiation;
- *bolometer* – measuring general radiation energy;
- *photometer* – measuring the intensity of solar radiation;
- *spectrobolometer and spectroheliograph* – determining the characteristics of light.
- *radiometer* – for measuring the radiation balance.

Actinometer measures total solar radiation (Figure 9) by converting the light into thermal energy (bimetallic strips are heated) or into chemical energy. It can be chemical, optical and electric. They are most frequently used in ultraviolet and visible part of spectrum, although there are also the applications in medical radiology, or even for measuring the exposure duration in photography.

Fig. 9. Actinometer from 1903 [6].

Pyrheliometer measures the amount of energy that the Sun radiates on Earth's surface (Figure 10), i.e. it measures total flux of solar radiation. Main part of the apparatus is a collimator tube in which thermo-cells and thermometer are found. Previous solutions, and the first was made in 1908 (having this shape), were the tubes-black chambers that have absorbed all incoming radiation, while the walls have continuously been moistened with liquid water. It was used for measuring solar constant with the error smaller than 1%. Today, it is used for measuring *direct solar radiation*. Back in 1825, a spherical pyrheliometer was made and it had two concentric and hollow spheres and water between them, while the inner sphere represents black body in which the light is released (although it can be found that this measuring instrument often referred to as actinometer, but due to conversion mechanism, it is better to call it pyrheliometer).

Fig. 10. DN5 Pyrheliometer [5].

Pyranometer measures diffuse and direct radiation in spatial angle 2π srad in wavelength range from 0.285 μm to 2.8 μm (Figure 11). Pyranometer can have thermoelectric, photoelectric, pyroelectric or bimetallic elements as sensors. Thermoelectric pyranometers that use thermal detectors, which produce the voltage on the principle of thermoelectric effect in the function of incident solar radiation, are most frequently used. They are used for accurate meteorological measurements.

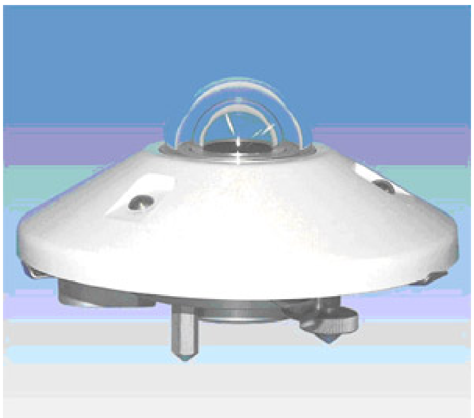

Fig. 11. CMP 21 Kipp & Zonen Pyranometer [5].

Pyranograph provides a continuous recording of the intensity of global solar radiation (direct and diffuse) in a longer period (Figure 12). It consists of light-sensitive (bimetallic strip) part and mechanical (clockwork) part by which the recording of measured insolation is done. It is one of the oldest instruments, which are rarely used today, mostly as backup or comparative measuring system.

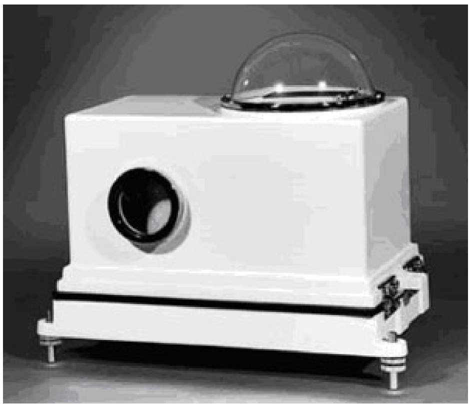

Fig. 12. Pyranograph [7].

Pyrgeometer is an instrument that measures the radiation in the field of *infra-red spectrum* (4.5 μm-100 μm) (Figure 13), for example, from Earth's surface into the atmosphere. The presented pyrgeometer measures the range 4.5 μm-42 μm. It contains thermoelectric detector that is protected with semi-sphere filter transparent for large wavelength, while it does not pass the visible part of spectrum (silicon window). The radiation of clouds, CO_2 and other gases that can be found in atmosphere is observed by it.

Fig. 13. CGR 3 Kipp & Zonen Pyrgeometer [5].

Albedometer is an instrument for measuring the reflected light, i.e. the albedo from the surface in the wavelengths range 0.3 μm-2.8 μm (Figure 14). It is important to provide a protective cover for this device that prevents the Sun from irradiating the dome of lower pyranometer at sunrise and sunset. It is necessary to prevent the overheating of instruments as well as the constant height from the ground (especially during winter). Albedometer represents two pyranometers, where one is adjusted to record reflected radiation. It includes the angle of 2π srad.

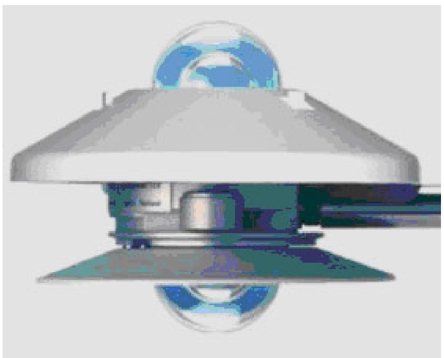

Fig. 14. Albedometer [5].

Bolometer or air thermometer measures the temperature with very high accuracy on the basis of infra-red or thermal radiation of the body (Figure 15). At first, it served for measuring incident total radiation. It can be used for measuring radiation energy of any frequency, and it has appeared to be the most sensitive instrument for wavelengths from 200 μm to 1 μm. For that reason, it is referred to as a very sensitive thermometer and it can measure the *temperatures of distant celestial bodies*, Moon through the telescope. On the other hand, it can be modified for the research of ionizing and non-ionizing particles, and even in the research of the dark matter. However, one important parameter is the temperature of apparatus during its exploitation. It is necessary to be cooled to 50 mK-300 mK, so that it would react slowly and return slowly into thermodynamic balance. It is applied in satellite measurements.

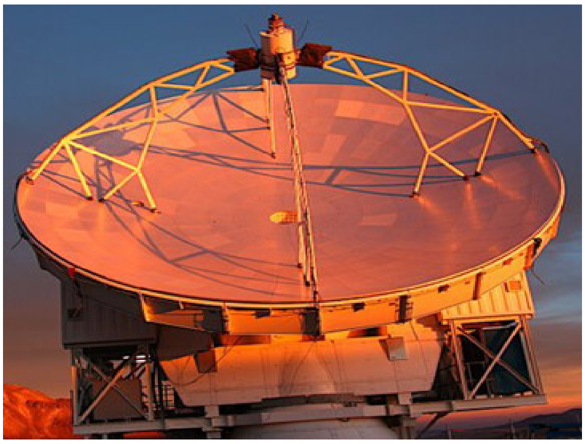

Fig. 15. APEX telescope with ArTeMiS bolometer camera [8].

Photometer measures the light intensity, i.e. the amount of light emitted from light source (lighting near the source, light intensity when the source is remote) received on the surface (lightings) or in the total amount of emitted light (light flux) (Figure 16). They are used in medicine, water analysis, analysis of optical characteristics of surfaces and solutions. By using various filters, the light intensity of a particular wavelength can also be measured. Today, it is used for measuring the intensity of *star radiation* or the radiation of other celestial bodies.

Fig. 16. AERONET Photometer [5].

Spectroheliograph (Figure 17) is an instrument for photographing the Sun’s surface in one light wavelength, usually the one that corresponds with an element that is found on the Sun. As a monochrome photo is obtained, the other name for it is monochromator. It was made in 1890. The downside is that small surfaces can be recorded so that several minutes are necessary for obtaining the entire image. However, a five-minute oscillation of the Sun was recorded by it. One modification of spectroheliograph is adapted for measuring the Doppler shift of solar spectral lines. It is also used for recording circular polarization of the spectral radiation line.

Fig. 17. Spectroheliograph [5].

Spectrobolometer is a combination of spectrometer and bolometer for determining the distribution of wavelengths of radiation emitted by the body, primarily in the solar spectrum. It is applied in satellite measuring devices or on antennas for cosmic recordings. Figure 18 shows 3D design of Microbolometer Spectrometer designed to record Earth's atmosphere and radiation in 2012.

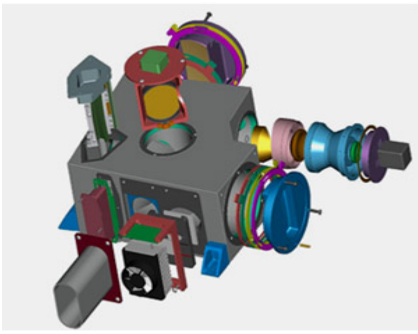

Fig. 18. TNO TPD 3D project of the future Spectrobolometer [2].

Radiometer (Figure 19) serves for measuring the radiation balance, i.e. the difference between incoming and outgoing radiation. The best known thermoelectric is *Yanishevsky radiometer*. It measures the difference in light intensity between upper and bottom measuring surface, „upper“ light and „bottom“ light. The difference in temperatures of these surfaces appears. Through the colder plate, the current is released until the equal temperature is established. By measuring the current, the size of difference in radiation is measured.

Fig. 19. Kipp & Zonen Net Radiometer [5].

4. CONCLUSION

The world needs more and more energy. Constant population growth is followed by constantly greater needs for energy and the humanity is continuously looking for energy sources that would appropriately meet energy needs. There are times when demand for energy is temporarily reduced (global financial crises and global recessions), but such events and transient and after they are ended, the hunger for energy gets greater and greater all over again. In the long run, demand for energy is increasing all the time [9].

At the moment, the world mostly covers its energy needs by non-renewable energy sources, mostly fossil fuels – coal, oil and natural gas. As the name suggests, these energy sources are not renewable, and that implies that they cannot last forever and that in one moment they will be spent. Fossil fuels are very harmful to the environment due to the emission of the large amount of carbon dioxide (CO_2), environmental pollution in the form of oil spills at sea, causing smog that is very harmful to health. At the moment, perhaps the most stressed negative effect of fossil fuels is *global warming* – perhaps the greatest challenge which the mankind has encountered in its short history [9].

Life on Earth was created and survived for millions of years due to favourable climate conditions. Climate can be observed as a renewable resource whose energy component is solar energy and material component are oceans, as water reservoirs. Solar energy stimulates the water circulation on Earth and thus it enables life. When there is no water, there is not quality life, such as in deserts. Climate changes on Earth have reached such a level that we can speak about climate crisis [10].

Vision of exiting the crisis is very clear, and that is the return to the less harmful energy sources.

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