ISSN 2712-0562
**Sustainable Engineering and Innovation**
*Review Article*
Vol. 4, No. 1, March 2022, pp.42-52
https://doi.org/10.37868/sei.v4i1.id82

# Sustainable heating system by infrared radiators

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Received Nov. 13, 2021
Revised Feb. 6, 2022
Accepted Feb. 28, 2022

**Abstract**
Maintaining the optimum temperature in the living quarters is the key to a comfortable stay. Due to the lack of a central heating system or in the event of its insufficiency, they resort to the installation of additional heat sources. There is a wide range of devices on the market with different operating principles, hence the difficulty of which is better - a convector or infrared heater. A comparative analysis of devices will help you make the right choice. Asking the question of which is better a convection heater or an infrared heater, one must decide on its role in heating the house. It is better to use them as additional equipment with an existing heating system. One of the effective sources of additional heating are infrared radiators. Its principle of operation is based on infrared radiation, which provides a quick and qualitative increase in temperature in any part of your apartment. Today, more and more people prefer infrared radiators. From the usual electric convector, they differ in that they heat not the air in the room, but hard surfaces (floors, walls) and objects, and these, in turn, leak heat into the surrounding space. So, the entire room is heated up unnoticeably.



*Keywords*: Infrared Radiators, Solar energy, Thermal performance, Life cycle assessment

## 1. Introduction

Once Isaac Newton extracted electromagnetic light energy from the sun by putting white light thru a glass prism that divided up the beam into rainbow hues, he discovered infrared radiation. William Herschel found energy beyond the sight in the 1800s. Planck, Stefan, Boltzmann, and Wien described the electromagnetic spectrum's activity and established formulas to determine IR energy in the 1900s. This study allows for the definition of IR energy that use the fundamental blackbody (a perfect Radiator), which states that an object with a temp higher than -273 degrees Centigrade releases radiant energy proportionate to the fourth power of its temp. Infrared heating is now widely employed in industry for a range of purposes, including comfort heating [1]–[3].

Infrared energy becomes a kind of heat that may be used for a variety of purposes, including heat processing, drying, finishing, and manufacturing. Here's a quick rundown of what infrared radiation could achieve and where it can or can't be utilized to its full potential. Infrared is a kind of electromagnetic radiation that is measured in wavelengths (m = microns). Conduction takes over once electromagnetic energy particles assault the surface of the materials to be treated. To effectively employ infrared energy, we must first comprehend this process. Materials have the ability to transmit heat well (instance: copper, gold). Nevertheless, in several

circumstances, the conductivity may be less than ideal, resulting in heat absorption and retardation. Some of the materials might potentially be used as insulators. (For instance, ceramic and foam) [4]–[12].

The choice of infrared heater seems critical to success. There are generally three kinds of densities in the infrared spectrum: long waves, medium waves, and short waves. It is indeed critical to remember that infrared energy seems to be a surface phenomenon. Processing foam, for instance, seems to be a poor radiant energy conductor and must be radiated from both sides. Furthermore, if the surface is bright (for example, metal), the infrared radiation might reflect and bounce back and forth, resulting in a delayed heating effect. Objects with energy-absorbing surfaces generally provide good outcomes [13].

The most important thing to know about industrial heating is that being processed and at what pace. Essentially, every product has its unique infrared response. This is referred to as the "heat absorption factor." Every sort of substance may be classified according to its wavelength. That, of course, may be converted into degrees of temp. As a consequence, we can get the quickest response from materials when they are subjected to an infrared radiation peaking that corresponds to their absorption factor. Infrared seems to be a hotter source of energy than convection heating in all instances. Infrared heat is usually applied to materials directly. To avoid overheating and destroying the material, the exposure to this direct source of heat must be timed [14].

Infrared is a kind of electromagnetic radiation, and therefore its radiant heating is perhaps the earliest source of warmth well-known to man. Heat sources have used this mechanism to certain degree or another since the start of civilization, whether it was heat from the sun, the light of a bonfire, or even the warmth provided by our typical home radiators. Infrared heat is emitted by all heaters in some form or another, and our bodies are no exception. Thermal images cameras function fully on this premise, since we all continually generate and absorb radiant heat. Warm living items generate infrared radiation that appears as orange, red, or white in thermal imaging. Inanimate things that collect and release less infrared radiation, on the other hand, will seem purple or blue [15].

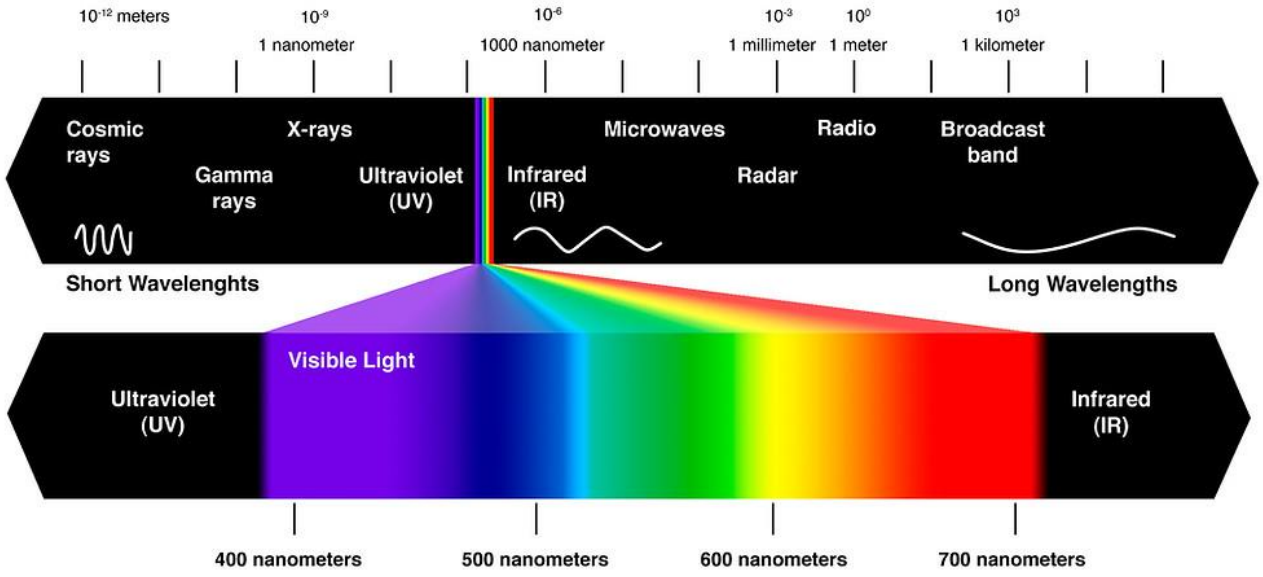


Figure 1. Infrared radiation ranges [16]

### 1.1. Radiators

Radiators seem to be heat exchangers that utilized to transmit thermal energy from one medium to another for cooling and heating purposes. The greater part of radiators has been designed to work in electronics, buildings, and automobiles. A radiator might be a source of heating to its surroundings, whether for the purpose of cooling

or heating the coolant or fluid provided to it, as is the case with vehicle cooling system and HVAC dry cooling towers. Even through their name, most radiators transport heating mostly by convection rather than thermal radiation [17].

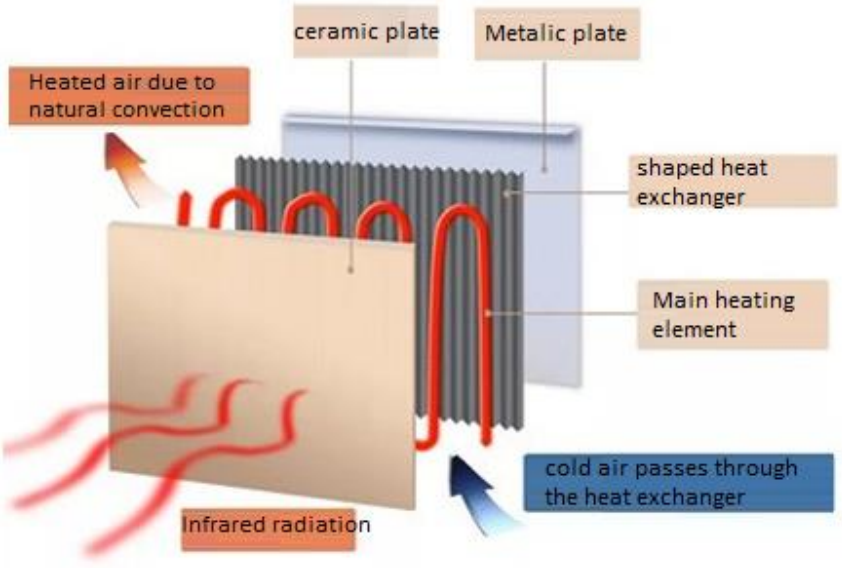


Figure 2. The components of interfered radiation [18]

Consider stepping outdoors on a bright day; the ambient air temp may only be 13 degrees centigrade, however the warmth from the sun's rays may make it seem as warm as the early summer days. Once the clouds roll in, it will seem considerably colder than it did before since all of the radiant heat produced by the sun's rays will have been blotted away. Infrared radiation does not depend on air movement to work; instead, it goes straight through it until it hits a solid object. This eliminates the requirement for an intermediary between the source and the object, allowing for a continuous transmission of heating from the source to the item. Convection heaters, on the other hand, rely on the movement of heated air to function as a middleman in the transmission of heat from the source to things inside the room. Even though this is a wasteful process in and of itself, but it's also susceptible to draughts and winds, which may swiftly disperse whatever heat that has built up. Infrared heaters fill a need in the marketplace that is hard to fill with conventional heaters. They provide direct heating, discrete product housings, and a variety of types suitable for both outdoor and indoor uses.

Infrared room heating is a revolutionary method that does not treat the air itself as much as it treats the things in the room. An infrared source in space acts like the Sun on our planet. All other heating methods (batteries, oil heaters, etc.) work on the principle of convection heating of air masses. That is, cold (unheated) air flows around the heated surface, receiving heat from it. An increase in temperature leads to a decrease in density, as a result of which, according to the law of physics, the air rushes upward. But we do not live in the ceiling. It is important for us that the air temperature is comfortable in the middle and lower third of the room [19].

There is nothing complicated about the device of infrared panels - it's amazing how humans have not thought of their invention before! The infrared heat emitted by heaters is similar in strength and structure to sunlight.

## 2. The difference between traditional and infrared heating

However, miracles do not happen and the provision of heating will only be for heating a house in which heat loss is reduced. Under these conditions, of course, all heating costs will be lower, including the costs of any electric heating. But with infrared heating, the temperature really needs to be lower. The second reason for conservation is the presence of a thermostat. In the case of processing, the heaters operate for a short period of time when the room temperature drops below the set temperature. Otherwise, the heaters are on all the time, the room is hot, you have to open the windows, and the electric bills are big (to say the least).


Figure 3. Differences between traditional and infrared heating [20]

Infrared heating can be used as the main heating, or it can be used as additional heating to create more comfortable conditions in a specific place - near the desktop, in the recreation area, etc.

## 3. Infrared heating panels

All people are familiar with infrared, in fact, it is it that occupies most of the spectral radiation of the sun. Infrared radiation is invisible to the eye and occupies the area between the red end of the spectrum and the emission of radio waves. A person can feel infrared rays like warmth. Infrared waves are emitted by each object and the more heated it is, the shorter the waves.

The first infrared heaters appeared in Switzerland in the 60s of the last century, and therefore the history of infrared heating goes back more than half a century. The principle of operation of a heating system with infrared Radiators is very similar to the "working" of our star. The only difference is that infrared Radiators do not work from a thermonuclear reaction, but from an energy source. In addition, unlike the sun, infrared heaters may not have visible radiation or have faint glare. This does not affect the quality of heating, since the heat transferred to the surfaces is the result of invisible radiation [21].

Reviews of many users about heating with infrared heaters are generally positive. Perhaps the only drawback is the cost of electricity. However, in the long run, as well as as an alternative heat source. This equipment is out of competition. The prospects for installing infrared heaters for home heating are highly appreciated abroad. Often, outdoor cafes, verandas, verandas and all kinds of open areas in gardens or on the decks of ships are heated with gas or electric infrared heaters. In our country, infrared heating equipment is not very popular, but gradually, with the development of technology, it is becoming more and more popular. Consider a variety of Radiators such as infrared panels.

An important factor when choosing infrared heating systems is their healing effect on the human body. This is an excellent way to prevent influenza and acute respiratory infections. In winter, the panels compensate for the lack of sunlight. Infrared rays completely destroy harmful and pathogenic microorganisms, without harming the person himself or pieces of furniture. Any infrared panels have a positive effect on human health. The heater does not emit any odors, does not burn oxygen during operation - this is an excellent guarantee of the absence of headaches and other unpleasant sensations, especially in winter [22].

### 3.1. Pros and cons of heating with infrared radiators

Like all inventions in the world, infrared equipment has its advantages and disadvantages. The choice depends on the ratio between them and the quality of the equipment, which is a priority for the consumer at the moment. We list the main features of heating with infrared heaters, perhaps this will help you choose [23]:

- infrared devices do not directly affect the air, which means that they do not dry it and do not change the microclimate in the room;
- For the same reason, convective flows and drafts are not generated, and dust particles are not transmitted;

- Air heats up from all surfaces affected by the device, and does not accumulate under the ceiling as with conventional heating;
- The system is completely fireproof, all devices have overload sensors and will turn off the system in an emergency;
- The compact dimensions of infrared devices allow them to be installed even in small rooms, often completely hidden under the decorative coating of walls, floors or ceilings;
- The device is easy to install and connect even without special skills;
- All equipment has a sufficiently long service life, since there are no parts in it that could malfunction as a result of wear. And in the event of a malfunction, it is possible to replace an individual element or unit;
- The infrared heating system can be fully automated, and each device is programmed for its own mode of operation;
- perfect compatibility with the environment: no noise, dust and emissions of combustion products;

### 3.2. Disadvantages

- The cost of devices can be very different and depends on the specific model;
- Operating costs depend on the choice of equipment operating mode;
- It can use infrared equipment in any room, provided that the equipment is located correctly.

## 4. Devices and types of infrared panels

### 4.1. Infrared heating panels wall-mounted

- Heating element: or rather the heat Radiator in each infrared heating source, is a special lamp. In principle, a well-known incandescent lamp is also a source of infrared radiation. After all, less than 10% of the energy is converted into light, and the rest (90%) is infrared radiation. Various types of lamps can be used in modern infrared heating panels. The most common source of energy is electricity, but it can also be gas. The reflective surface is another essential component of an infrared radiator. It is a mirror-polished steel plate, curved to focus the lamp's radiation in a specific place. The radiator radius and coverage area are the main characteristics when choosing heating equipment.
- Design of infrared heaters: most often these are simple wall panels of strict geometric shape and small thickness, or ceiling equipment. It should also be noted that the characteristics of the device depend on the shape of the reflecting element: the greater the size and convexity of the reflector, the greater the area of focus and coverage [24].

### 4.2. Infrared heating as an alternative to traditional heating

Compared with infrared heating, convection heating. Perhaps gas or solid fuel will occupy a leading position in Russia. But that's only in terms of prevalence. This can be explained by both habit and insufficient information about this high-tech heating method. If we compare the efficiency, then infrared heating is the undoubted leader among other methods of heating the house. Moreover, infrared equipment is superior to conventional heating devices (stoves, heating boilers, electric convectors, etc.) in several parameters at once [25]:

- Ease of installation;
- Low noise
- Lack of combustion products
- Environmental hygiene and many more

### 4.3. Benefits of infrared radiators panels

Modern heating methods are based on more advanced technologies, and therefore have more advantages over traditional devices [26]:

Rapid heating of the room: the required heating time of 10-15 minutes will be enough to warm the room. They can serve as the main source of heat, and can be used for local heating of individual areas (for example, you

can only heat your workplace or sleeping area with a bed). To organize autonomous heating of a house or apartment with infrared panels, permits are not required.

Quick installation: It only takes a day to install the panels in a standard two-room apartment. for an alternative. If you don't want to drill holes in the walls, mount the panels to legs or stands.

Simple controls: select the temperature that suits you, and the device will take care of itself to constantly maintain it in the room. individual settings. There is an opportunity in each room to set the optimum temperature. thermostat It will not only save finances, but also prevent overheating of the air.

Does not dry out: suitable for installation in rooms where children live as well as people with allergies and asthma. The infrared panel heater does not dry the air and does not burn oxygen and dust particles that provoke the appearance of toxic gases. Moreover, infrared rays are used in the treatment of asthma.

Safety: The outside of the panel does not heat up and cannot cause burns when touched. The heating element is located inside the device, so it cannot cause any inconvenience if you accidentally touch the panel. It can also be calm parents of young children, who, having played, will touch the “battery” more than once. Heating with infrared panels can be organized not only in the living room and bedroom, but also in the children's room.

Profitability: According to the assurances of manufacturers, new generation heating plates consume 30-50% less electricity than classic ones, with the same heat output. Also, additional devices (boiler), a separate room (boiler room) and a communication system (ventilation) are not required.

Long service life: The average life of the IR panel is 30 years, and some manufacturers give a 50-year warranty. Fire safety. The device does not contain components that could catch fire or cause a fire. Unusual design. You can choose a palette for a painting with a thematic image that will fit into the room - children's for the nursery, exotic flowers for the living room, soothing and calming pictures for the bedroom.

## 5. Infrared radiators

### 5.1. The device and principle of operation

Convectors and infrared radiators differ fundamentally in the way they are heated. To select the most effective and most suitable device for use in certain conditions, it is necessary to study the device and the features of each variety. The principle of operation of the convector is based on the circulation of air in the room. The device consists of a housing and a heating element located inside. The heater is usually installed on the floor. Cold air is heavier than hot air, so it falls to the bottom of the room. It enters through the air intake network inside the device, where it is heated, and passes through the radiator of the heating element. The masses rise according to the laws of physics. During the cooling process, air descends and enters the heater again [27].

The device provides constant air circulation in the room: the main difference between this type of device is the almost complete absence of direct heating of objects. The room creates a cozy atmosphere, which is quite comfortable to be in. However, this is not enough for difficult conditions. As an additional source of heating : convectors are a good solution, and therefore are well suited for premises in apartment buildings with central heating. If there is a need to heat a cold room in a country house, then the features of such devices will not allow to create the necessary microclimate. The sensation of warm air is deceptive. Cold walls and furnishings can cause colds.

The design of the heating device includes two main elements: a housing and a radiator. Convection occurs naturally without forced air movement. The absence of a fan provides an important advantage of convection - complete noiseless operation [28]. Modern models can also be equipped with a temperature controller. Some of them allow you to set not only the heating power, but also the required air temperature. With the help of controllers, you can combine several devices into one group and control the microclimate in the house together. As additional options, the devices can be equipped with timers that determine the operating time, remote controls, and air humidifiers

## 6. The differences between Interfered radiators and heater radiators

The main elements of the device are an infrared Radiator and a reflector, which focuses and directs the beams in the desired direction. Radiators are often of the following three types [29]:

- Quartz and carbon models emit almost no light, so most of the energy is spent on heating. This saves in electricity, but devices with such Radiators are more expensive than halogen ones.
- The reflector is made of brushed steel or aluminum profile. The radius of curvature of the reflector affects the radiation scattering and heating area.
- The heater is equipped with a safety device that stops heating when the device is dropped or the set temperature is exceeded. This allows you to ensure fire safety during operation.

## 7. Design and technology

Infrared radiators were being used to tackle a wide range of heat and dry problems. Heating regions with a great power density and selective energy application may be produced in the material to be heated using established modular systems. The ability to adjust the heat output with sophisticated digital temperature controls and theorist switch units provides the most efficient use of energy, lowering running costs and helping to safeguard the environment.

The phrase "infrared radiation" refers to the production and transmission (reproduction) of electromagnetic waves in the spectral region above visible light, which extends from 0.7 m to roughly 80 m. The generation and transmission of electromagnetic waves is linked to energy transfer in a particular, directed direction. Energy transmission seems to be achievable in a vacuum because it does not need a trasport medium.

Long, medium, and Short-waves infrared radiators were categorised depending on the wavelength max of spectral radiation emitted. The max becomes less than 1.5 m in shortwave infrared radiators. Long-wave infrared radiators have a max wavelength of more than 3 m. The medium-waves infrared radiators have been located between them. The spectral energy distribution of various example radiators in such categories is shown in Figure 3. The shorter wavelength of light, the greater the temp of the radiators.

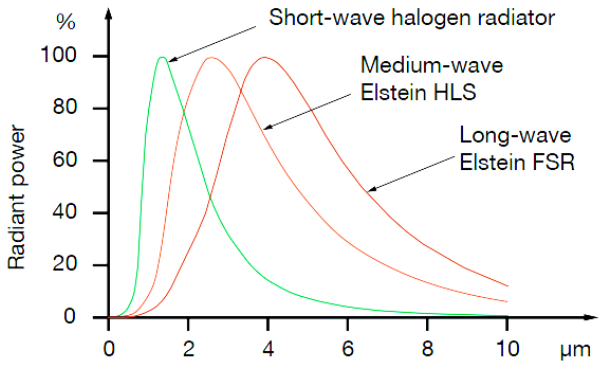


Figure 4. Spectral radiant power [30]

Because they partially reflect the radiation or, in the case of glass, allow it flow thru, all materials have various radiation values. Figure 5 displays the absorption of brilliant aluminum and ceramic, for instance. Only approximately 15percent of the light is absorbed by aluminum; the rest was reflected. On the other hand, ceramic absorbs around 90percent of the radiation. Because absorption and emission in each body have been caused by the same physical processes, ceramic is an excellent material for infrared radiator.

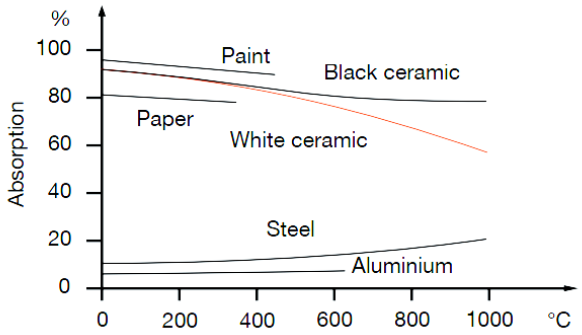


Figure 5. Absorption of various materials [31]

Radiator power is typically proportional to the fourth power of the absolute temp. So as to attain high efficiency, infrared radiators are often operated at temps over 300 degree centigrade. In practice, it's important to remember that heated materials generate infrared radiation as well. As a result, simply the variation in radiant powers between the two warms the material [32].

The absorption spectra of several materials in the medium and longwave infrared region are quite similar, save from a few minor changes (Figure 6). Plastics with modest layer thicknesses display typical absorption bands, but metal oxides and minerals materials absorbed continuously well enough from roughly 300 cm. The absorption of energy is especially favorable in these wavelength bands. Other wavelength ranges of radiation are reflected or transmitted. This is especially important once heating thin plastic foils, in which modest quantities of pigments may significantly increase the absorption qualities. In the real world,

On the other hand, once brilliant or polished metals are heated, the absorption is hardly perceptible. The majority of infrared radiation is reflected. The reflectance of a metal is governed by its electrical conductivity and surface condition. In these circumstances, little modifications in the surface quality, such as higher roughnesses, oxide coatings (Figure 6) or paint layers, permit infrared radiation heating. The infrared radiators' use for material drying is very important. Water has a wide absorption spectrum there in medium to longwave range, as seen in Figure 6. As a result, infrared radiators may also be used to tackle drying and evaporation problems. Infrared radiators are useful for a variety of practical circumstances, not only because of their high emissivity, but also because of the optimal wavelength range for heating that is suited for the material concerned. The limit temps to be respected are listed on the data sheets and on the radiators themselves. These temperature limits must not be exceeded since the ceramic will be damaged [33].

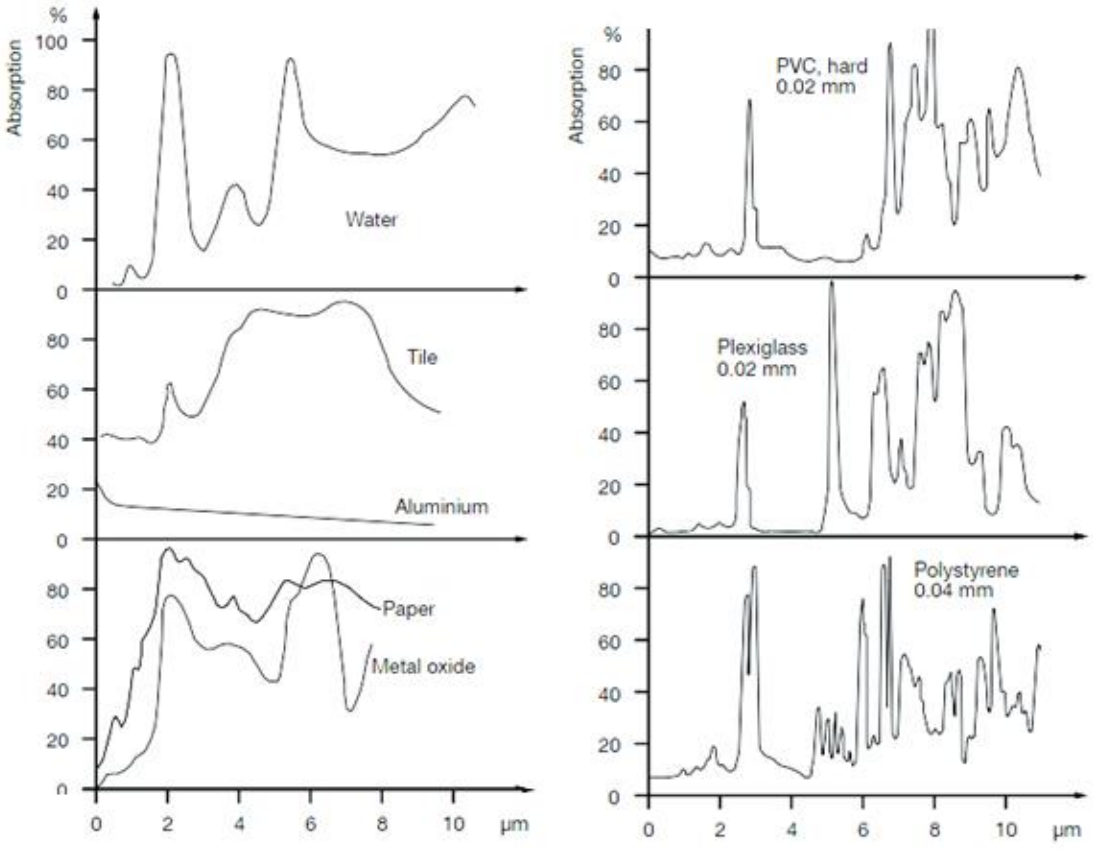


Figure 6. Spectral absorption of various materials [31]

Application examples for the use of infrared radiators

- Heating plastic foils and sheets in thermoforming machines
- Production of shrink foils and films

- Gelling PVC pasty coats on fabrics
- Heating GRP parts during production
- Thermofixation of nylon and perlon threads
- Activating glues and hot seal coats
- Drying plastic emulsions
- Heating laminated materials before punching
- Drying raw and printed papers, cardboards and wallpapers
- Drying skins, hides and paint sprayed leather
- Quick-drying gummed papers
- Drying glazes on ceramic tiles
- Soldering printed circuit boards
- Pre-heating weld seams in pipe construction [34].

## 8. Performance

Keep in mind that the heat sensitivity of the skin, rather than the eye, is a better indicator of an infrared radiator's cooling and heating capabilities. When a halogen spotlight gets turned off, for example, the light goes out in a flash. However, the heated glass tube continues to disperse its stored heat to the surrounding region in the form of infrared radiation for many minutes.

Reflected, transmitted, and absorbed infrared energy. The three impacts appear in varying amounts based on the IR-radiation source employed and the qualities of the substance to be heated. Absorption is the desired action that warms the substance, thus this portion of the radiation must be as great as feasible. The radiator's efficacy is reduced due to grear levels of transmission and reflection. Figure 7 depicts an example of three distinct radiation sources heating a clear foil: the ceramic IRradiator's long-wave infrared radiation is the most efficient. The restriction temperatures listed on each infrared radiator must be recognized and followed while utilizing them. It is possible that the heating and ceramic conductor will be damaged if this limit is exceeded. Ensure that the radiators be protected from moisture, impact, and knocks, impact, and while they are cold when installing them. The radiators may be operated in any position due to the permanent installation of the heating coil [35].

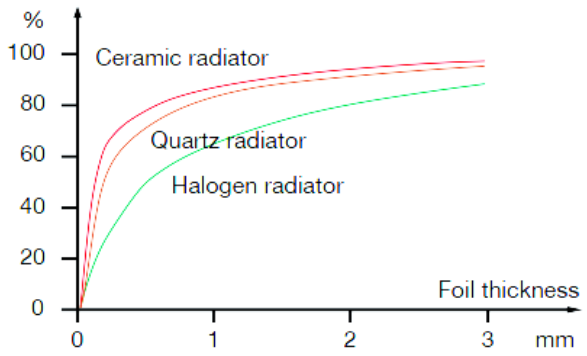


Figure 7. Absorption in transparent foils [31]

## 9. Conclusion

In conclusion, we can say that the market for solar energy technology currently offers a variety of equipment. And most importantly, given the affordable cost of solar panels for the home, reviews of their high quality and a long reliable operation period, we can conclude that the use of such equipment has become more convenient and allows you to participate in a wide range of environmental projects and programs.

Both convectors and infrared heaters are small and compact and thus fit easily into any environment in the room. These portable devices are also lightweight. It is made of lightweight materials such as copper and aluminum. It is not difficult to disassemble or rearrange the devices.

The main advantages of this type of heater are also reliability and durability. Branded equipment is able to work without major repairs for decades, and is backed by a large warranty period. And most importantly, the devices are safe to use, of course, subject to the basic rules for working with them.

The choice of the heater is an individual matter. Some people like the quiet operation of the infrared device, while others feel some discomfort in the presence of radiation. Many users note that convectors dry the air and have to moisten it additionally. So when choosing, you should focus on your feelings, needs and abilities.

Modern technologies have combined two types of heaters - efficient convectors and economical infrared radiators.

## 10. Recommendations

The rapid penetration of new technologies into our lives for the use of alternative sources of electricity and heat directs our choice to increase the purchase of solar power plants, solar collectors (heating plants), wind and hydropower home plants, as well as the use of heat pumps and a variety of electric generators. So in recent years, much experience has been gained in the application of photovoltaic power supply systems in many areas of management. This applies to the use of solar panels and solar collectors in domestic conditions: in private homes and summer cottages.

The use of solar energy is the ideal solution for homes and summer homes.

## Acknowledgments

The authors would like to thank Al-Mustaqbal University College for providing technical support for this research.

## Declaration of competing interest

The authors declare that they have no any known financial or non-financial competing interests in any material discussed in this paper.

## References

[1] F. E. Barton, *Near infrared equipment through the ages and into the future*, NIR news, (2016).

[2] A. Shubbar, M. Nasr, M. Falah, and Z. Al-Khafaji, *Towards net zero carbon economy: Improving the sustainability of existing industrial infrastructures in the UK*, Energies, (2021).

[3] M. A. Hamad *et al.*, *Production of Ultra-High-Performance Concrete with Low Energy Consumption and Carbon Footprint Using Supplementary Cementitious Materials Instead of Silica Fume: A Review*, Energies, (2021).

[4] L. S. Rothman, *Infrared energy levels and intensities of carbon dioxide. Part 3*, Appl Opt, (1986).

[5] Q. S. R. Marshdi, S. A. Hussien, B. M. Mareai, Z. S. Al-Khafaji, and A. A. Shubbar, *Applying of No-fines concretes as a porous concrete in different construction application*, Period Eng Nat Sci, (2021).

[6] A. Z. S. A.-K. Dr. Abdullah Jabar Hussain, *The Fields of Applying the Recycled and Used Oils by the Internal Combustion Engines for Purposes of Protecting the Environment against Pollutions*, J Adv Res Dyn Control Syst, (2020).

[7] A. J. Hussain and Z. S. Al-Khafaji, *The fields of applying the recycled and used oils by the internal combustion engines for purposes of protecting the environment against pollutions*, J Adv Res Dyn Control Syst, (2020).

[8] Z. S. Al-Khafaji *et al.*, *The Impact of Using Different Ratios of Latex Rubber on the Characteristics of Mortars Made with GGBS and Portland Cement*, IOP Conf Ser Mater Sci Eng, (2021).

[9] W. K. Tuama, M. M. Kadhum, N. A. Alwash, Z. S. Al-Khafaji, and M. S. Abdulraheem, *RPC Effect of Crude Oil Products on the Mechanical Characteristics of Reactive-Powder and Normal-Strength Concrete*, Period Polytech Civ Eng, (2020).

[10] Z. S. Al Khafaji and F. Ruddock, *Study the retardant effect of using different sugar's types on setting time and temperature of cement paste*, Int J Civ Eng Technol, (2018).

[11] Z. S. Al-Khafaji *et al.*, *Impact of high volume GGBS replacement and steel bar length on flexural behaviour of reinforced concrete beams*, in *IOP Conference Series: Materials Science and Engineering*, 2021.

[12] G. Zhang *et al.*, *Reinforced concrete deep beam shear strength capacity modelling using an integrative bio-inspired algorithm with an artificial intelligence model*, Eng Comput, (2020).

[13] Z. S. Al-Khafaji and M. W. Falah, *Applications of high density concrete in preventing the impact of radiation on human health*, J Adv Res Dyn Control Syst, (2020).

[14] D. Deming, S. Seager, L. J. Richardson, and J. Harrington, *Infrared radiation from an extrasolar planet*, Nature, (2005).

[15] R. H. Kingston, *Detection of optical and infrared radiation*. Springer, 2013.

[16] S. M. Schieke, P. Schroeder, and J. Krutmann, *Cutaneous effects of infrared radiation: from clinical observations to molecular response mechanisms*, Photodermatol Photoimmunol Photomed, (2003).

[17] R. J. Naumann, *Optimizing the design of space radiators*, Int J Thermophys, (2004).

[18] D. Dregely, K. Lindfors, M. Lippitz, N. Engheta, M. Totzeck, and H. Giessen, *Imaging and steering an optical wireless nanoantenna link*, Nat Commun, (2014).

[19] Z. Pan, R. Khir, L. D. Godfrey, R. Lewis, J. F. Thompson, and A. Salim, *Feasibility of simultaneous rough rice drying and disinfestations by infrared radiation heating and rice milling quality*, J Food Eng, (2008).

[20] A. Kavga, T. Panidis, V. Bontozoglou, and S. Pantelakis, *Infrared heating of greenhouses revisited: An experimental and modeling study*, Trans ASABE, (2009).

[21] P. Kic, *Electric infrared heating panels as an alternative source of heating for greenhouses*, (2020).

[22] A. J. H. Corsten, *A comparative performance assessment of infrared heating panels and conventional heating solutions in Dutch residential buildings*.

[23] V. A. Hemadri, A. Gupta, and S. Khandekar, *Thermal radiators with embedded pulsating heat pipes: Infra-red thermography and simulations*, Appl Therm Eng, (2011).

[24] C. D'Alessandro *et al.*, *Performance analysis of evacuated solar thermal panels with an infrared mirror*, Appl Energy, (2021).

[25] C. Dmitry, *Infrared heating as an alternative to traditional heating systems in a singlefamily home in Russia*. Bachelor's Thesis Building Services Engineering, MAMK University of applied …, (2015).

[26] I. Das and S. K. Das, *Emitters and Infrared heating system design*, Infrared Heat Food Agric Process Z Pan GG Atungulu, Eds, (2010).

[27] R. Stroop, S. Ch, and G. Th, *Efficacy of an Infrared Radiator for Hypothermia Prevention in a Simulated Setup of Entrapped Vehicle Accident Victims*, Injury, (2021).

[28] M. M. A. AbdurakhmonovSultonaliMukaramovichd, *Increasing the Thermostability of Optoelectronic Devices on Semiconductor Radiators*, Turkish J Comput Math Educ Vol, (2021).

[29] D. Li *et al.*, *Experimental research on vibration-enhanced heat transfer of fin-tube vehicle radiator*, Appl Therm Eng, (2020).

[30] H. Z. and P. Blackborow, *Technical note Understanding Radiance (Brightness), Irradiance and Radiant Flux*, (2018).

[31] M. Aalizadeh, A. Khavasi, A. E. Serebryannikov, G. A. E. Vandenbosch, and E. Ozbay, *A Route to Unusually Broadband Absorption Spanning from Visible to Mid-Infrared*, arXiv Prepr arXiv181007139, (2018).

[32] B. Zohuri, *Heat pipe design and technology: Modern applications for practical thermal management*. Springer, 2016.

[33] J. Meiguni *et al.*, *EMI prediction of multiple radiators*, IEEE Trans Electromagn Compat, (2019).

[34] N. Prieto, R. Roehe, P. Lavín, G. Batten, and S. Andrés, *Application of near infrared reflectance spectroscopy to predict meat and meat products quality: A review*, Meat Sci, (2009).

[35] E. Ptitsyna, D. Ptitsyn, and A. Kuvaldin, *Performance Indicators of Dark Infrared Radiators of Various Type*, in *2020 International Multi-Conference on Industrial Engineering and Modern Technologies (FarEastCon)*, 2020.