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Importance of Form and Placement of Heating Elements from the Aspect of Comfort, Enviroment, Health and Economy

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Subject review

People want to have good conditions in their living and existing places. Therefore heating and cooling methods are developed according to different application areas, different heat transfer principles. When we heat a place, the suitability of the placement of heating element and applied heating method need to be examined from the aspect of factors such as effect on human health, comfort conditions and economics etc. according to design and operation cost. In this paper, heating methods were evaluated on selection of heating systems and heating elements to take into consideration such factors as heating area, energy economy, environment, health, comfort and economics.

Važnost oblika i smještaja ogrjevnih elemenata s aspekta komfora, okoliša, zdravlja i ekonomičnosti

Pregledni članak

Ljudi žele imati dobre uvjete u boravišnim prostorijama. Stoga su razvijene adekvatne metode grijanja i hlađenja prostorija za različite primjene, što dakako zahtijeva korištenje i adekvatnog načina prijenosa topline. Za zagrijavanu prostoriju mora se ispitati položaj grijaćeg elementa i način prijenosa topline s aspekta nekoliko čimbenika, kao što su: ljudsko zdravlje, uvjeti komfora, ekonomičnosti itd., u odnosu na njihov dizajn i cijenu. U ovom su radu opisani sustavi grijanja, grijaćih elemenata uzevši pri tome u razmatranje utjecaje čimbenika kao što su: mjesto zagrijavanja, ekonomiziranje energijom, okoliš, ljudsko zdravlje, komfor i ekonomičnost.

1. Introduction

Energy generation is one of the most important factors for communities to maintain their lives. It is becoming more and more important the means by which energy is obtained, used and increase in the expenses on energy in the global meaning. The most economical way of using limited sources which exist on the earth and the conscious way of consumption of energy must be done. From this point of view, heating has the greatest ratio in energy consumption. Applications like heating of places through the surfaces of structure elements like floor, ceiling and wall were carried out in ancient times. The first time in history, the oldest remains are left from the South Western Anatolian civilization from 1200 B.C. it is known that at those times in China and Tibet, about the year 80 B.C. in Rome, much later than that in Russia and in many of the North European countries, heating was used. An old application about floor heating "Hypokaustenheizung des Römerkastells Saalsburg" is shown in Figure 1 [1]. Heating is carried out by distribution of the chimney gases of the fireplace or a furnace through the walls and the floor of the location until the help of cannelo.

There are three basic reasons to consider and study about heating. The first one is that the most important energy-containers coal, oil and natural gas will be exhausted in a short time. The second one is that carbon dioxide left in the atmosphere after consumption and combustion has been reduced by the protocol of Kyoto and the need to protect the natural climate, and obligation the third one is the ongoing increase in consumption of energy due to an increase in the world's population. New technologies are being developed in order to have the best benefit from energy used in heating and to have comfort conditions in the cheapest way.

The methods and materials used for heating should be evaluated due to comfort, health and their interaction with the environment. The role that is played in each

Symbols/Oznake

A - area, m^2
- površina

k - overall heat transfer coefficient, $W/(m^2K)$
- ukupni koeficijent prolaza topline

T - temperature, K; °C

α - convection heat transfer coefficient, $W/(m^2K)$
- konvekcijski koeficijent prijenosa topline

ε - emissivity ($0 \leq \varepsilon \leq 1$)
- emisijski faktor

λ - thermal conductivity, W/(mK)
- toplinska provodnost

σ - Stefan-Boltzmann, $= 5{,}67 \cdot 10^{-8} W/(m^2K^4)$
- Štefan-Baltzmannova konstanta

φ - relative humidity, l
- relativna vlažnost

$\dot{Q}$ - heat flow rate, W
- toplinski tok

$\dot{q}$ - heat flux W/m^2
- gustoća toplinskog toka

Indices/ indeksi

b - steam
- para

bd - saturated steam
- zasićena para

cd - cold
- hladno

conpo - condensation point
- temperatura kondenzacije

ht - hot
- toplo

inns - inner surface
- unutarnja površina

outs - outside surface
- vanjska površina

∞ - outer medium
- vanjska radna tvar

x - toward of x axis
- uzduž osi x

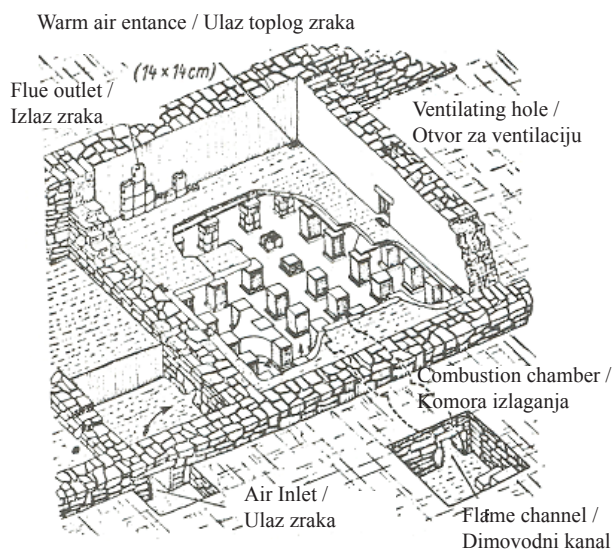


Figure 1. An application on heating, Old Roman Age

Slika 1. Sustav grijanja u staroj rimskoj vili

of the expenses during investment and operation will show us whether it is applicable or not by decreasing the energy used in heating and the heating element of the method. On the other hand, the shape of the volume that will be heated, is also important. As examples, we can give houses, which are continuously used, hospitals and schools, which contain a big number of people in them, places in ice-skating centers where audience sits and airplane hangars and factories which have a really high roof.

Heating is, as everybody knows, keeping the temperature of the inside of the volume, between some certain values where a certain amount of comfort is necessary against the natural conditions where it is impossible for man to live. Also the shape of the activity that people show is important for heating comfort. Whether due to the height in the volume or the temperature difference which is between the inner and the outer mediums and which is constant, are the elements that affect the heating comfort and also economical usage of energy. Heat transfer is carried out in three ways due to their usage in the heating systems [2,3]: 1) Conduction heat transfer, 2) Convection heat transfer 3) Radiation heat transfer.

2. Heating systems

The heating systems which are used today are classified into three groups according to heating types.

2.1. Traditional Systems

Heating is carried out by convection. The hot air, steam or hot water gained by a central pipes/channel. First purpose here is to heat air of medium. And for the second, the people and the machines etc get heated. For heat generation, there must be heating central or boiler house. It is so hard to do a local or a regional heating.

2.2. Radiation heating systems

All objects radiate rays due to their surface temperatures. Those waves are infrared waves, when they hit the objects or the heating surfaces, the molecules in discharged the objects are set in motion and then heat is got out. The infrared waves can't be seen with the naked eye and move directly through the air without heating it. The energy in the waves is absorbed by cold surfaces. While some of the waves are absorbed by the surfaces and objects, some are reflected back. In that heating system, heat transfer is carried out by radiation.

The approximate ratios of the heat transfer types which are effective in the heating systems are shown in Figure 2.

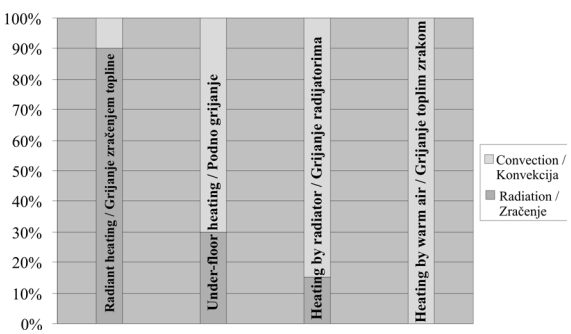


Figure 2. The approximate ratios of the heat transfer types in heating systems

Slika 2. Aproksimacijski omjeri načina prijenosa topline grijaćih sustava

In general, radiant heating systems are used in museums, big bazaars and shopping centers, schools, factories, industrial centers and complexes, workshops, auto services and showrooms, gyms, mosques, supply depots, plane hangars, greenhouses, animal farms.

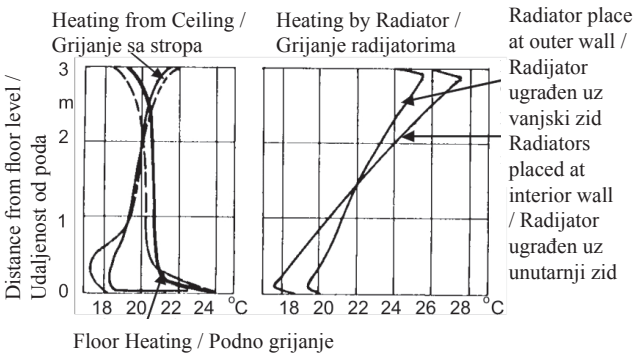
3. Heat transfer mechanism and temperature gradient in volume

Heat transfer mechanism is fulfilled by direct convection from radiators with an approximate temperature of 80 °C to volume in the heating systems with traditional radiators and in the floor heating systems by convection from the floor with temperatures between 25-80 °C to the volume. From the radiators to the volume the radiation ratio which can be neglected, becomes about 50 % of the total heat transfer in the floor heating. As a result of this; the temperature difference between the inner walls and inner surfaces of the outer walls can be kept about 1-2 °C. In Radiator heating systems, this temperature difference is about 6-7 °C. The heated air moves to the upper sides of the volume. The areas volume with the highest temperature in the floor heating systems are the surface of the floor. The relocating hot air from the floor will get colder and colder and there will be a decrease in the movements of the air particles in the upper sides of the volume. The heat gradient volume cross- section for different heating systems is shown in Figure 3, [4].

Table 1. Heating systems

Tablica 1. Sustavi za grijanje

Heating Systems According to Heating Types / Sustavi grijanja prema vrsti instalacije		
Central Heating / Centralno grijanje	Local Heating / Lokalno grijanje	Regional Heating / Daljinsko grijanje
Hot Water Heating (Between 90 °C- 110 °C) / Toplovodno grijanje (između 90 °C- 110 °C) Superheated Water Heating (Between 110 °C-190 °C) / Vrelovodno grijanje (između 110 °C- 190 °C) Low Pressure Steam Heating (1,5 bar, 110 °C) / Niskotlačno parno grijanje High Pressure Steam Heating (>1,5 bar, >110 °C) / Visokotlačno parno grijanje Vacuum Steam Heating (0,05 bar – 0,75 bar,>110 °C) / Grijanje s parom u potlaku Hot air / Topli zrak	Heating is carried out by direct heating equipments / Grijanje sustavima neposredne termotehničke opreme	More than one building are heated by a single heating centre / Više od jedne zgrade je grijano iz jedne kotlovnice
Heating Systems According to Their Heat Sources / Sustavi grijanja prema vrsti toplinskog izvora		
Solid Fuelled / Kruto gorivo	Liquid Fuelled / Tekuće gorivo	Gas Fuelled / Plinovito gorivo
Wood / Drvo Coal (mine- lignite) / Ugljen (lignit)	Fuel-oil / Lož-ulje Diesel / Extra lož-ulje	Natural Gas / Prirodni plin LPG / UNP NPG / Prirodni plin
Heating Systems According to Heat Transfer Type / Sustavi grijanja prema vrsti prelaza topline		
Traditional Heating Systems / Konvekcijalni sustavi grijanja		Radiation Heating Systems / Sustavi grijanja zračenjem topline
Convectors, hot air fans, air conditioning units / Radijatori, ventilo-konvektori, kaloriferi, klima komore		Low density radiant heating systems / Sustavi grijanja niskog intenziteta zračenja Medium density radiant heating systems / Sustavi grijanja srednjeg intenziteta zračenja High density radiant heating systems / Sustavi grijanja visokog intenziteta zračenja



Note: Dot line is given for near window / Isprekidana linija odnosi se na susjedni prozor

Figure 3. Vertical temperature distribution for a heating volume

Slika 3. Vertikalna temperaturna distribucija zagrijavane prostorije

Heating from the floor and ceiling gives theoretical temperature distribution that is accepted as ideal.

3.1. The position of heating elements in volume

While choosing heating systems and a heating method, facts such as volume, type, heating volume function, health, energy economy and comfort are taken into consideration. The positions of the heating elements in the volume can be hanged on the walls, or positioned in the ceiling from the inner and outer sides.

In the radiator, the air comes from downside and goes upward while getting heated. As shown in Figure 4, the air flow is carried out only by convection. So the efficiency of the heating radiator just depends on the air flow. Thermal efficiency of the radiators is carried out due to the European control norm EN 442 and when the radiator is 110mm high from the floor. But, in the real applications according to the application locations and aesthetic choices, those measurements that are advised at the standard are not applied in practice.

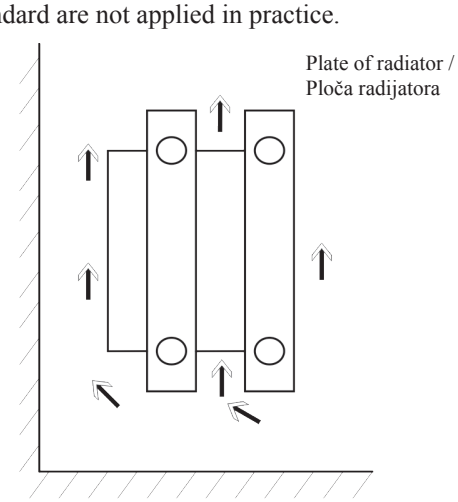


Figure 4. Operation principle of the radiator core

Slika 4. Princip rada radijatora

Çopur et al.[5] have carried our some research into the efects on the energy economy, protection of the environment, thermal comfort and have compared the temperatures of the waters in the heating systems by doing the necessary calculations; they have also determined the temperatures of the installations which are required. Dağsöz et al. [6] have made research into the problems and deficiencies in central heating systems and have decided that in order to do some economic measures, some new corrections should be made. Tiryaki [7] and Inam [8] have researched factors like, the wavelengths of devices according to temperature, length of device, losses in chimneys, efficiency of device and properties of the device while making a choice in devices and how economic the radiant systems is, projecting the radiant heating systems and have shown that it is so important that care should be taken in choosing the radiant, and the advantages which can be obtained when the radiant heating systems are used in high buildings like factories and hangars.[7,8,9]. Seifer and Richter [10] have taken the room of a house with low energy, whose thermal need is 485 W, and have made an energy analysis of how to position heating devices according to the positions of the walls and research into the efects on thermal comfort; they have determined that when the heating device is located in front of the windows, at the outer and inner walls, and the rates of air-exchange is important in determining the quality of the heaters, the heaters which are located at the outer walls can provide the lowest heat capacity.

In order to determine the efect of the distance between the radiators of the central heating system and the floor on the ratio of convection, Gu [11] has improved two methods, so he planned to give the convection ratios of radiators the most suitable shape. He determined that if the distance between the radiator and the floor is small then the heating capacity of the radiators will be small and after a certain distance he found out that the value becomes constant.

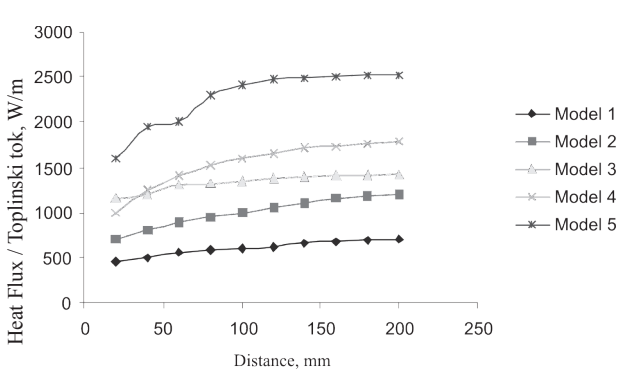


Figure 5. The influence of distance between the radiator and the floor on heat flux

Slika 5. Utjecaj razmaka radijatora od poda na iznos gustoće toplinskog toka

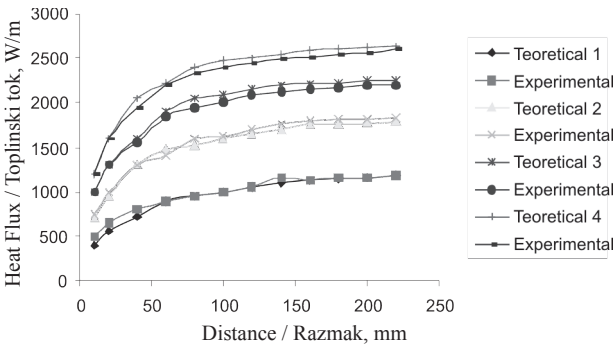


Figure 6. Theoretical and Experimental Results of Effect of Floor Distance on Radiator Core

Slika 6. Teorijski i eksperimentalni rezultati utjecaja udaljenosti radijatora od poda na iznos gustoće toplinskog toka

In radiant heaters in which the heat is transformed by radiation, the temperature change can be about 1-2 °C due to the floor height in the design where the 20 °C inner temperature was taken as the essential point.

The only difference between the models is the distance from the floor. Model height decreases from small to big. There is no difference on model form. The smallest height model is number 4. By increasing the height of the radiator from the floor, its heat flux increases. However, this increment is limited with heat flux value of model number 1. The reason for this, is that heat flux with natural convection does not change much by taking radiator to higher place due to less height of model.

In the systems operating with a radiator which is working with air and hot water from the traditional heating systems, a temperature difference of 5 °C on the floor whose volume height is 8-10 m in the same design temperature can be like 15-25 °C through the ceiling. These sort of conditions affect the increment on energy consumption and it also causes discomfort in living medium.

The purpose of this study is to determine the main factors in designating a heating style while choosing the heating system, by taking into consideration points like, usage style of the volume, heating volume function, health, energy economy and comfort. The situations of the heating elements in the volume can be hanged on the walls, put on the ceiling from inside to outside or hidden in the floor etc.

4. Comparison of heating systems

In the heating by traditional radiators, volume air is heated primarily. Then this air is separated in the volume by convection. In the traditional heating systems, the floor temperature is lower than the comfort temperature. In Figure 7, the traditional heating systems and radiant heating systems are compared due to their energy economy and temperature layering.

The temperature in the regions near the ceiling is higher because of the upward movement of heated air. This causes an increase in thermal losses that occur with air circulation in the volume and heating unnecessary space which is not used.

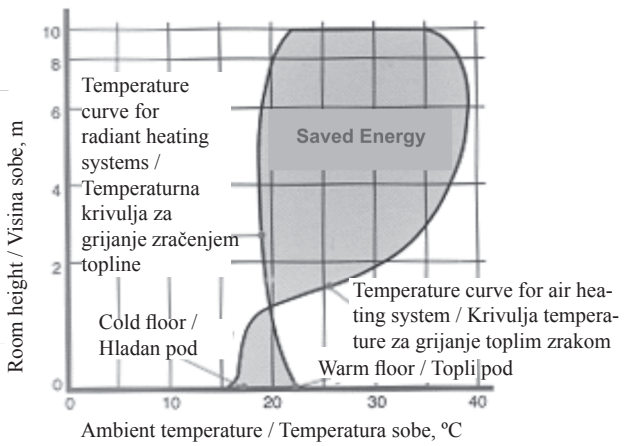


Figure 7. Comparison between traditional heating systems and the radiant heating systems

Slika 7. Usporedba temperaturnog profila prostorije između tradicijskih grijaćih sustava i grijaćih sustava zračenjem

But in the radiant heating the floor temperature is higher than the comfort temperature and on the other hand in the regions near to the ceiling the temperature value is dramatically lower than the value in the traditional heating systems. For this reason this causes a significant energy economy.

4.1. The forming and positioning condition of the heating elements

Opinions about positioning the heating elements at the inner sides of the volumes are becoming widespread [12]. Energy circumstances like physiological ones are being evaluated by making research and based on a computer simulation program. Due to the results obtained, suggestions for ratios having different air changes are listed in literature.

4.1.1. The heating regions of the radiant heaters

In the heating system applications, it is possible to heat all the sections or a part of them in the region by positioning the heaters in a suitable way. As important and economical as production of heat is, so also is the homogeneity of hear separated into the region.

As the heated air will rise by having a lower density, the places where the temperature is high are the places which are close to the ceiling and as the temperature is low in the places with low height which should be heated,

there are energy losses. So as the height of the ceiling and the change in air flow has a significant importance on energy economy, so does the positioning of the heaters in a suitable way.

If a radiator gives the same amount of heat in the same conditions with small surface, then its thermal efficiency is higher. Because of their aesthetic outlook, panel radiators are widely preferred. Steel radiators with smooth surfaces are preferred because of their properties like dust catching and are easy to clean.

4.1.2. The Air Conditioner Modules

The air conditioner modules used over the past last years have the principle of heat transmission caused by the radiation which occurs between hot and cold surfaces. Here, heat moves from hot surfaces to cold surfaces. The cold object gets warmer by receiving heat. With the air conditioner modules, the air is heated up directly, especially under the modules of the air conditioner, the upper surfaces of the floor, walls, tables and furniture. But in counterpart to that, in the event of "cooling" the process operates just in the opposite way. The air conditioner module has the duty of energy supply. The basic assumption is to have a constant inner volume temperature and to obtain a volume air conditioner. It is possible to evaluate the advantages of the air conditioner in some parts such as their effects on health, economy and environment.

In evaluation of them due to health, we can list the entries below:

- Maximum hygiene conditions are obtained.
- Much more high temperatures of wall and floor can be obtained.
- Maximum rate of comfort should be reached.
- As there is no air flow, a very healthy medium can be formed.
- There is no noise at all which can be called "disturbing"
- The best physical conditions can be obtained.

Table 2. Comparison between traditional heating and radiant heating methods

Tabica 2. Usporedba tradicijskih sustava zagrijavanja sa sustavima zagrijavanja zračenjem

Traditional heating methods / Konvekcionalni načini grijanja	**Radiant heating methods / Grijanje zračenjem topline**
When the heating system is on the floor, there can be losses from surfaces / Kod podnog grijanja mogu biti površinski gubici	All the surfaces that provide heating participate in heat transfer / Sve grijaće površine koje su uključene u prijelaz topline
Heat transfer is carried out by convection and conduction / Prijelaz topline je konvekcijom i provođenjem	Heat transfer is just carried out by radiation / Prijelaz topline isključivo zračenjem topline
Especially in the heating systems working with hot air, as fans are used, circumstances for comfort cannot be obtained / Posebno kod sustava toplozračnog grijanja, kao ventilatorima, slučaj kad uvijeti lagodnosti boravka u prostoru ne mogu biti postignuti	In the dusty regions, no movement of dust exist which can ruin comfort / U okolišu koji sadrži prašinu nema prenošenja prašine koja utiče na lagodnost
System works on the heating of the volume / Sustav radi na zagrijavanju volumena	System works on the heating of the surface / Sustav grije od površine
Heating is dense in the regions near to ceiling / Grijanje je izraženije pod stropom	Heating can be done for required place. / Grijanje na traženom mjestu
In order to reach the comfort condition, a long time should pass / Da bi se postigli uvijeti lagodnosti boravka u prostoru, potrebno je dugo vremena	Comfortable conditions are obtained in a short time / Uvijeti lagodnosti boravka u prostoru postižu se u kratkom vremenu
Because of transportation of the heat, many thermal losses exist / Zbog prijelaza topline, veliki su gubitci topline	As transportation of the heat is carried out by direct radiation, there are no thermal losses at all / Prijelaz topline je neposrednim zračenjem, pa nema toplinskih gubitaka
Cannot adapt to improvements or changes in the regions which will be heated / Nije moguće dati poboljšanje ili promjenu u području koje će se grijati	Can be reassembled due to improvements or changes in the regions which will be heated, the present system elements can be removed / Moguće je dati poboljšanje ili promjenu u područjima koja se griju, postojeći sustav se može ukloniti
Heating system and elements cannot be disassembled and used in another heating region / Sustav grijanja i elementi ne mogu se demontirati i primijeniti u drugom području grijanja	Radiant heaters obtained from different volumes can be used in the regions which need to be heated / Grijači zračenja dobiveni od različitih prostora mogu se primijeniti u područjima koja treba grijati
Because of the mechanical parts like pup, hot air or water devices, cauldron and burner; maintenance is often necessary, there can be dangers like leaks, dirt and fire / Zbog mehaničkih dijelova, naprave toplozračnog ili vodenog grijanja, plamenici, održavanje je često potrebno, problem je propuštanja, prljavštine i požari	There are no mechanical parts at all. Operation and maintenance is not often necessary / Nema mehaničkih dijelova. Posluživanje i održavanje nije potrebno
Its general efficiency is about 80 % / Općenito, učinkovitost je oko 80 %	Its general efficiency is about 50 % / Općenito, učinkovitost je oko 50 %

The following advantages can be listed due to their economical direction:

- It is possible to use the volume economically and also gain space.
- It is possible to have homogenous heat dispersion in the volume.
- Energy economy can be made.
- Less material expenses are used.
- Less operation expenses are used.
- It is possible to have the cooling and the heating in the same system.
- Has a short time period of amortization.

And the environmental advantages can be listed as

- Energy economy can be made.
- With energy possession made, the environment can be much less polluted.
- The natural energy sources are consumed with protection.

The comparison made between traditional heating systems where heat is transferred by convection and conduction and heating systems where heat is transferred by radiation due to economy, interaction with environment and comfort, is given in Table 1 [13].

4.2. Conditions related to insulation

The results of isolation applications can be evaluated in three directions. The first one is that it makes increments on the energy transformation efficiency and energy economy. Because of this, heat losses can be lowered and the amount of the material that will be used for heating and capacity of radiator and cauldron will decrease. The expenses for the first investment of the installation will decrease and besides that, as much less fuel will be consumed, there will be economy on spending. Secondly, there will be a decrease in the environmental pollution. Thirdly is thermal comfort obtained by application.

Windows and doors with glass are structural elements which have the highest value of thermal loss. But besides that, on sunny days, there can be a thermal gain through the windows. By using a window with double glasing, thermal loss can be decreased to a minimum. In order to decrease the thermal losses that happen throug it an air leak through the opening parts of the doors and the windows, some applications like gasket and thermal loss is also decreased when the shutters of the windows are closed in the evenings, and by placing self-closing mechanisms on the outer doors or positioning revolving doors, decreasing the time period of the door.

The isolation of rear side of radiator which is the thermal source in the room has a significant importance in decreasing the thermal losses. When the room temperature is 20 °C, the back of the radiator can be 45 °C. Because of aesthetic reasons, when the front of the radiators is covered, that temperature value is much more increased. Due to the laws of thermodynamics, when the temperature difference between two mediums is so high, then the heat transfer is that big. That means, the most and the fastest heat transfer from the volume is carried out in the back of the radiators. The most suitable way is to put an isolating material in the walls that are located at the back of the radiators. But in the buildings which were not constructed like that at the construction period, the isolation for the back of the radiator can easily be carried out by aluminum covered polyethylene sheets. Besides their property as good isolators, it is again a big advantage that they can reflect the heat into the volume. After realizing those applications, in the residences heated with individual heating or central heating by holding the volume temperature the same, there can be a decrease in the fuel consumption by 5 %. In the central heating system, the expense for the heating does not change when an isolation made for a single residence is carried out but a higher level of comfort in heating can be obtained with a temperature increase of 3 %.

Condensation on the inner surfaces of the volume walls, arises if the inner surface temperature which is in touch with the medium air which is a mixture of dry air and steam, becomes lower than the condensation temperature of the steam. The heat transfer coefficient k^* which will prevent the structure material from facing a condensation is detected by the formula below.

$$k^* = \alpha_{\text{inn}} \frac{T_{\text{inn}} - T_{\text{con}}}{T_{\text{inn}} - T_{\text{out}}}. \tag{1}$$

From here, the total heat transfer coefficient k for the wall between the inner medium and outer medium can be found.

$$k = \frac{1}{\frac{1}{k^*} - \left(\frac{1}{\alpha_{\text{inn}}} - \frac{1}{\alpha_{\text{out}}} \right)}. \tag{2}$$

Condensation temperature T_{con} can be designated due to the relative humidity value and the T_{in}, the inner temperature of the air in the heating volume.

$$\varphi = \frac{P_{\text{b}}}{P_{\text{bD}}}. \tag{3}$$

For this, the saturated steam pressure value P_{bD} which matches the inner temperature value is read from the table and the partial steam pressure in the mixture of dry air and water in the medium is obtained by multiplying it by the relative humidity value φ. The saturation value (dew point) which matches that designated pressure value is read from the table. If there is a different humidity

percentage between the outer and inner mediums of the outer walls or because of the formation of condensation in the wall material, there can be a humidity transfer which is similar to heat transfer. In order to prevent that, a steam-prevented with isolation material is suggested.

Due to the international and national standards of thermal losses in the buildings, the thicknesses for isolation are determined. According to that, the approximate value should be less than 60 kWh/ (m^2 year) for the unit area of the building.

5. Conclusion

Every single day, it is becoming more and more important to live in a cheaper way and in better comfort. For this, some new alternative systems have been developed and the problems in the present system are being solved.

We want the mediums where we are in to be suitable to our physiological situation. If the weather temperature, the velocity and humidity of the air, air change rate, the pureness of the air (odour and the hanging particles in it) and control of the air motions in the volumes used, disturb people, the properties of the used heating system should be revised and defects in the application should be corrected. For example, the extreme high and extreme low air temperatures in the place where we live, affect our lives directly.

On the other hand, the heating system should be economical by means of low consumption rate, and economical use of energy. The savings made for fuel and energy can contribute to the home and national economy. It is important to give an answer to the questions as between which temperatures and in what kind of a place work will be carried out, which heat transfer type will be suitable to that type, and besides suitable types, which heating system will be used, and the points where the heating elements will be located in the heating system. Because by making a good decision in choosing a heating system and locating system elements in the place in a correct way, comfortable life and life quality increase and the costs on investment expenses will decrease and energy and savings will be made.

Savings energy and lowering heat losses should be considered and should be related to building a new power plant with the way of making a large economy.

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