Evaluation of Working Parameters of Radiant Heating Systems

Yelena Pshenichnaya[1], Baiba Gaujena[2] [1-2]*Institute of Heat, Gas and Water Technology, Riga Technical University*

Abstract. **The basic benefit of low-temperature radiant heating systems is thermal comfort. Additional sound insulation and high inertia factor that provide heating of the surfaces, even without initial phase of energy consumption, can be regarded as an advantage. This paper discusses benefits of low temperature systems installed under the floor or wall surfaces. This study is aimed to demonstrate the influence of heating system elements on indoor air parameters especially on internal surface of building envelope. The model described in this paper offers to optimize building energy performance with low temperature pipes built in the construction.**

Keywords: **low-temperature radiant heating, thermal comfort, indoor air, envelope.**

INTRODUCTION

This paper describes the systems that use water as the heat-carrier and where the heat exchange within the space is more than 50% radiant and based on the technique of the heat exchange between the pipe and the emitting surface.

The majority of heating systems is equipped with distribution systems operating at high temperatures (90 - 70°C). The main sources of heating used in Latvia are derived from non-renewable natural resources and wood-pulp or its derivatives. The use of more environment friendly technologies, which allow minimization of energy consumption, should play a significant role in Latvia's future civil engineering systems; nevertheless, the wider community is lacking trust and confidence in new technologies and understanding of the positive aspects of their use. [1]

The installation of low-temperature heating systems is one of prospective ways to save energy and to reduce emissions. This kind of systems can be used for both: commercial and residential buildings. Low temperature heating system can be installed in a wall or floor construction. This type can be preferable for building with high percentage of façade windowing, where the usage of traditional heating system radiators is inconvenient from the indoor design point of view. In this case blocks with heating systems installed into vertical or horizontal elements of the building envelope can be acceptable.

Low-temperature heating systems insure lower air temperature and dust level in rooms. In addition, exploitation of such systems provides lower temperature of heating surfaces, decreases risk of mould grow and minimizes radiant heat asymmetry. [2]

HEAT EXCHANGE BETWEEN SURFACE AND SPACE

The actual operation mode of the radiant surface systems depends on the heat carrier temperature. Surface is able to emit heat.

Table 1.

	Total heat exchange coefficient [W/m²K]	Acceptable surface temperature [°C]	Maximum capacity [W/m²]
Floor occupied zone	10.8	29	99
Floor peripheral area	10.8	35	165
Walls	8	~40	160
Ceiling	6.5	~27	42

Total heat exchange coefficient between surface and space for heating, acceptable surface temperature and capacity at 20°C room temperature.

The relationship between heat flow density and mean surface temperature, so-called Characteristic Curve (figure 1), depends on the type of heat emitting surface (floor, wall, ceiling) and whether the temperature of the surface is higher than the space temperature. Heat exchange coefficient is the parameter that affects the amount of heat transfer between the surface and the space.[3]

Floor heating:

$$q = 8.92(\theta_{S,m} - \theta_i)^{1.1} \quad (1.1)$$

Wall heating:

$$q = 8(\theta_{S,m} - \theta_i) \quad (1.2)$$

Ceiling heating:

$$q = 6(\theta_{S,m} - \theta_i) \quad (1.3)$$

q - heat flow density at the surface (W/m2)

θ_i – temperature of the area indoor air (°C);

$\theta_{S,m}$ – temperature of the area indoor air (°C);

The heat exchange coefficient depends on the position of the surface and the surface temperature in relation to the room temperature. The heating capacity depends on the heat exchange coefficient and the temperature difference between surface and space. Acceptable surface temperature is determined based on comfort considerations (Table 1).

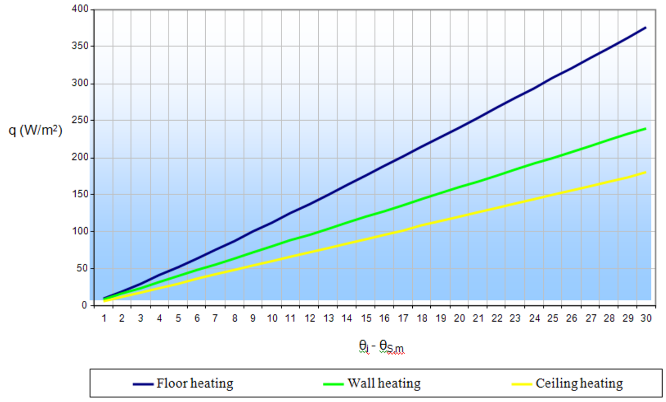

Figure 1. - Basic characteristic curve for floor, wall and ceiling heating.

Heat carrier pipes are installed in system plates which function as the thermal insulation layer. The horizontal (for floor) heat transfer (from pipe to pipe) is limited by the system plates. For the improved temperature distribution heat conducting elements are used. The conducting plates operate efficiently when there is a good connection between pipes and conductive devices. The important attribute of the system is to minimize thermal coupling of the emitting element with the main building structures such as ceilings or walls.

Heat conduction takes place between the heating pipes and the surfaces. Heat conduction takes place between the heat carrier and the heat emitting surface. This is influenced by the type of pipe (diameter, wall thickness and material), pipe spacing, water flow (velocity) and resistance of the additional conducting layer. Heat convection implies transfer of energy between the air and surface. The temperature or density difference causes free convection. The heat radiation represents the energy, which is transferred from one surface to another through electromagnetic waves in a range of 0.8-400µm.

Thermal resistance of the convection heat transfer; construction – indoor, m2K/W

$$R_0 = \frac{1}{a} + R_{\lambda,B} + \frac{S_U}{\lambda_U} \quad (1.4)$$

S_U - thickness of the layer above pipes, m

λ_U - thermal conductivity of the screed, W/(m*K)

$R_{\lambda,B}$ - thermal resistance of heating surface covering, m2K/W

a - heat exchange coefficient of the system construction (Table 1)

Thermal resistance of the convection heat transfer; construction - outdoor, m2K/W

$$R_U = R_{\lambda,iz} + R_{\lambda,kon} + R_{\lambda,ap} + R_{a,kon} \quad (1.5)$$

where

$R_{\lambda,iz}$ - thermal resistance of the heat insulation, m2K/W

$R_{\lambda,kon}$ - thermal resistance of the construction m2K/W

$R_{\lambda,ap}$ - thermal resistance of outdoor plaster (lime sand mixture) layer, m2K/W

$R_{a,kon}$ - construction surface heat thermal resistance:

floor surface - 0.17, m2K/W

wall surface - 0.13 if there is a neighbor room, 0.04 out wall, m2K/W

ceiling surfaces - 0.10, m2K/W.

EMBEDDED SURFACE HEATING SYSTEMS

A significant feature of this system is to minimize thermal coupling of the emitting element (e.g. pipe coil and screed) with the main building structure (ceiling or wall). A separating layer of the thermal insulation is placed between the building structure and the pipe layer to reduce the heat exchange on the backside.

This type of radiant system is increasingly being used mostly in Central Europe and Nordic countries, especially in new buildings (but also in refurbished buildings), because it does not require more work on the structure and is more aesthetic.

System types with pipes insulated from the main building structure are:

in the screed or concrete

outside the screed (e.g. in the thermal insulation layer)

plane section system

in the wood construction.

SYSTEM WITH PIPES EMBEDDED OUTSIDE THE SCREED (E.G. IN THE THERMAL INSULATION LAYER, "DRY„ SYSTEMS)

When you see or read the term “dry system” in association with radiant heating, this means that the radiant heat system was installed beneath a finished floor without concrete or gypsum material poured over the radiant heat tubing. Dry systems are usually installed in circumstances where concrete or flooring materials cannot be poured. Dry radiant systems can be installed either with the radiant floor tubing above the floor, which happens when it is placed between two layers of plywood, or below the floor where it is placed under the subfloor. The heat carrier pipes are embedded in system plates, which function as the thermal insulation layer. The horizontal (for floor and ceiling systems) heat transfer (from pipe to pipe) is limited by the system plates. For the improved temperature distribution heat conducting elements are used. The conducting plates operate efficiently when there is a good connection between pipes and heat conductive devices.[3]

This type of system uses thin aluminum heat transfer plates that are stapled up with radiant tubing under the sub-floor. The plates are highly conductive and provide a large surface area that will absorb heat more quickly and keep the space warm much longer.
Using heat transfer plates will disburse heat more evenly throughout the floor than the other under-floor methods.

Heat transfer plates perform three important functions:

They help to carry heat away from the tubing and distribute it through the joist space and along the floor. (Heat transfer)

They support the plastic heat exchanger tubing.

They greatly reduce heat loss in the downward direction (back loss).

The construction method with heat conducting devices that most effectively transfers and spreads the heat evenly through the subfloor with the least resistance produces the best results.

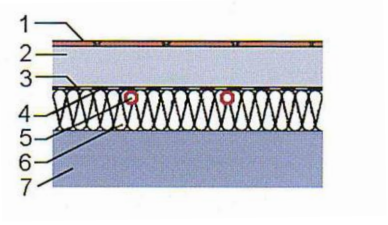

Figure 2 a. floor structure type B1 – floor covering, 2 – weight bearing and thermal diffusion layer (screed), 3 – polyethylene foil, 4 – heat conducting plate (device) 5 – pipe coil, 6 – thermal insulation,7 – building structure.

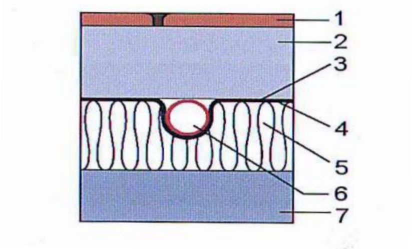

Figure 2 b. Dry floor structure type B 1 – floor covering, 2 – weight bearing and thermal diffusion layer (screed), 3 – splitting foil layer (vapour barrier), 4 – heat conducting plate (device) 5 – thermal insulation, 6 – pipe coil, 7 – building structure.

CALCULATION

The heat flux between embedded pipes and the space is calculated by general equitation method (Single Power Function according to EN 1264-2) [2] and can be applied in various types of embedded surface heating systems.

$$q = B * \prod_i (a_i^{m_i}) * \Delta\theta_H \quad (1.6)$$

The power product links the table parameters of the structure (surface covering a_b, pipe spacing a_T, pipe diameter a_D, screed covering a_U, a presence of heat contact device a_{wl} and contact a_k and the factors expressing the pipe spacing m_T covering thickness m_U and pipe diameter m_D.

Universal single power function for system type B, with pipes embedded outside the screed:

$$q = B * a_B * a_T^{m_T} * a_U * a_{WL} * a_K * \Delta\theta_H \quad (1.7)$$

The heat flow density q is proportional to the heating medium differential temperature $\Delta\theta_H$:

Where:

$$\Delta\theta_H = \left| \frac{\theta_V - \theta_R}{\ln \dfrac{\theta_V - \theta_i}{\theta_R - \theta_i}} \right| \quad (1.8)$$

θ_V – supply of the heat carrier (°C);

θ_R – output of the heat carrier (°C);

θ_i – the temperature of the area indoor air (20 °C);

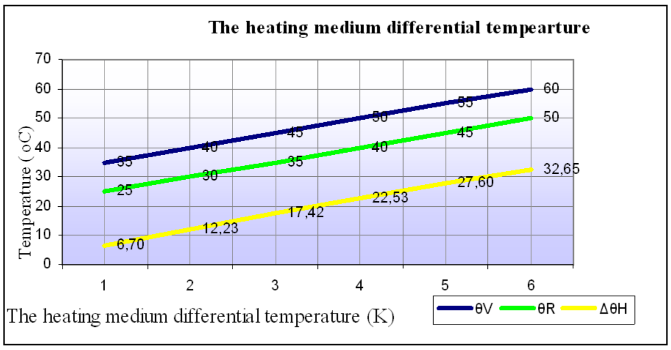

Figure 2. The heat flow density is proportional.

The heat flow density q at a surface is determinate by the following heating system parameters:

- Pipe spacing T
- Thickness S_U and thermal conductivity $\lambda_U = \lambda_E$ of the layer inward of the pipe
- Thermal conductivity resistance $R_{\lambda,B}$ of covering
- Pipe external diameter $D = d_a$, including sheeting ($D = d_m$), if necessary and the thermal conductivity of the pipe λ_R and/or tile sheeting λ_m
- Heat conducting devices, characterized by the value K_{WL}
- Contact between the pipes and the conducting devices or screed characterizes by factor a_K

” Dry” systems heat flow density calculation:

$$q = B * a_B * a_T^{m_T} * a_U * a_{WL} * a_K * \Delta\theta_H \quad (1.9)$$

Where a_U – surface covering factor:

$$\alpha_U = \frac{\dfrac{1}{\alpha} + \dfrac{S_{U,0}}{\lambda_{U,0}}}{\dfrac{1}{a} + \dfrac{S_U}{\lambda_E}} \quad (1.10.)$$

where B = 6.5 W/(m2K)

α = 10.8 W/(m2K) – (depending on the surface position, Table 1)

a_T - pipe spacing factor; $\alpha_T = f(S_U, \lambda_E)$

$\lambda_{U,0}$ = 1 W/(m*K)

λ_E - thermal conductivity of the screed, W/(m*K)

$S_{U,0}$ = 0.045 m

S_U –thickness of the layer above pipes, m

α_{WL} -heat conduction device factor;

$$\alpha_{WL} = f(K_{WL,}T, D)$$

Heat conducting devices, characterized by the value:

$$K_{WL} = \frac{S_{WL} * \lambda_{WL} + b_U * S_U * \lambda_E}{0.125} \quad (1.11)$$

Where $b_U = f(T)$

S_{WL} - thickness of heat conducting device, m

λ_{WL} - thermal conductivity of heat conducting device, W/(m*K)

α_K - correction factor for the contact; $\alpha_K = f(T)$

α_B heating surface covering factor:

$$a_B = \frac{1}{1 + B * a_U * a_T^{m_T} * a_{WL} * R_{\lambda,B} * f(T)} \quad (1.12)$$

Where $f(T) = 1+0.44\sqrt{T}$
(1.13)

$R_{\lambda,B}$ - thermal resistance of surface covering, m2K/W

$$m_T = 1 - \frac{T}{0.075} \quad (1.14)$$

$$m_U = 100(0.045 - S_U) \quad (1.15)$$

$$m_D = 250(D - 0.020) \quad (1.16)$$

Where
T – pipe spacing, m
D – pipe external diameter, m.

„Dry” system parameter is determinate:

B, $S_{U,0}$, α, $\lambda_{U,0}$ - values, according with LVS EN 1264

$R_{\lambda,B}$, λ_E, λ_{WL}, α_T, α_K, α_{WL}, b_U - table data according with LVS EN 1264

S_U, S_{WL}, T, D – selected for the systems parameters

α_B, α_U, m_T, K_{WL} - calculated values depending on systems parameters. Results of calculations are shown in Table 2. [3]

Table 2.

Quantity	Unit	Symbol	Value
Coefficient of the system	W/(m²K)	B	6.5
Factor depending on system construction	W/(m²K)	a	10.80
Surface covering factor	-	a_B	1.00
Correction factor for the contact	-	a_K	0.95
Spacing factor (f (S_U / λ_U))	-	a_T	1.093
Covering factor	-	a_U	1.058
Heat conduction device factor	-	a_{WL}	1.04
B System coefficient (f (T))	-	b_U	0.7
Heat conducting device value	-	K_{WL}	0.72
Thermal conductivity of the screed	W/(m*K)	$\lambda_{U,0}$	1.00
Thermal conductivity of the screed	W/(m*K)	λ_U	1.20
Thermal conductivity of heat conducting device	W/(m*K)	λ_{WL}	52
pipe spacing factor	m	m_T	-1.000
thermal resistance of surface covering	m²K/W	$R_{\lambda,B}$	0.000
thickness of the layer above pipes	m	$S_{U,0}$	0.045
thickness of the layer above pipes	m	S_U	0.045
thickness of heat conducting device	m²K/W	S_{WL}	0.001
Pipe spacing	m	T	0.15
	m	$f(T)$	1.170
Pipe diameter	m	D	0.016
Equivalent heat transmission coefficient	W/(m^{2}K)	K_H	6.21
Heating medium differential temperature	K	$\Delta\theta_H$	5.00
Heat flow density at the surface	(W/m²)	q	31.07

It must be mentioned that the system capacity is always restricted so as not to exceed the hygienic and comfort criteria for surface temperature listed in relevant standards. Boundary conditions are $0.05 \le T \le 0.045$m $0.014 \le d \le 0.022$ $0.01 \le Su/\lambda e \le 0.18$

Heat flow depending on the heat conductive device, surface covering and pipe spacing.

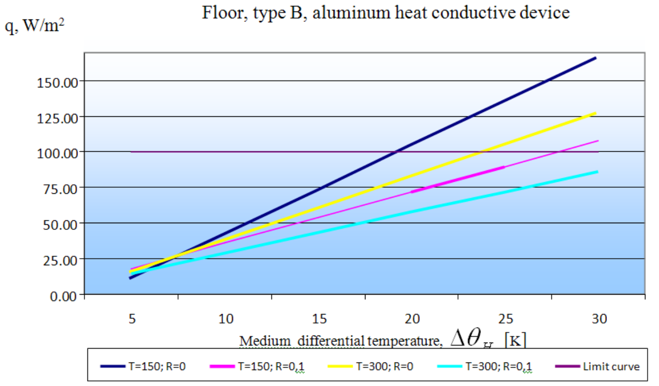

Figure 3.a Heat Exchange for floor systems with aluminium heat conductive device.

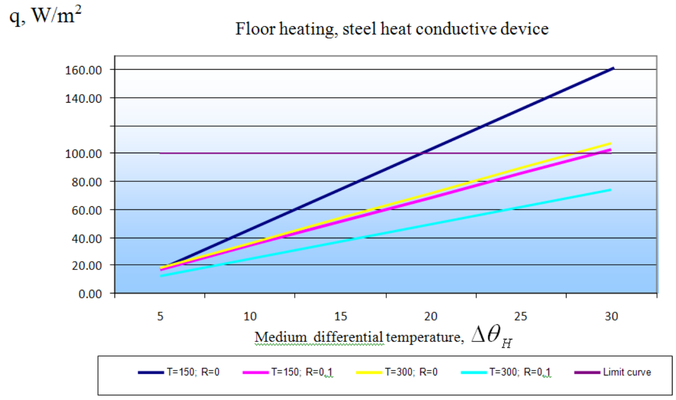

Figure 3.b Heat Exchange for floor systems with steel heat conductive device.

CONCLUSIONS

The calculations of heat flow density allow finding optimal rate for heating system choice, when it is rational and economically efficient. The heat flow density is proportional to ΔθH – the medium differential temperature of the heat carrier (°C) K.

The following calculated values mostly influence the efficiency of the system. Thickness of the layer above pipes enhance form surface covering factor a_U, which properly influence the thermal conductivity of the screed.

Choice of the thickness and thermal conductivity of heat conducting device forms value of the heat conducting device. Systems with pipes embedded in the building structure, which are operated at heat carrier temperatures very close to room temperature, take advantage of the thermal storage capacity of the building structure.

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Yelena Psenicnaja, Civil Engineer, *Mg.sc.ing.* (2007), Scientific assistant, RTU Faculty of Building and Civil Engineering (2011). Institute of Heat, Gas and Water Technology. Publications: ~ 5 scientific and methodological works. Adress: P.O.Box 526, Riga, LV-1010, Latvia. E-mail: jelena.psenicnaja@inbox.lv.

Baiba Gaujena, Civil Engineer, *Mg.sc.ing.* (2008), Scientific assistant, RTU Faculty of Building and Civil Engineering (2010). Institute of Heat, Gas and Water Technology. Publications: ~ 10 scientific and methodological works. Adress: P.O.Box 526, Riga, LV-1010, Latvia. E-mail: baiba.gaujena@rtu.lv.

Jelena Psenicnaja, Baiba Gaujēna. Darba parametru analīze starojuma apkures sistēmām
Zemas temperatūras apkures sistēmu izmantošanas pamata priekšrocības ir siltuma komforts un papildus skaņas izolācija, kā arī svarīgs ir inerces faktors, tas nodrošina virsmu apsildi bez tieša enerģijas patēriņa. Tiek demonstrēta dotās apkures sistēmas elementu ietekme uz iekšējā gaisa kvalitāti un uz telpu iekšējo virsmu temperatūru, atkarībā no izvēlētās konstrukcijas. Dotais modelis piedāvā optimizēt ēkas energoefektivitāti, pielietojot iebūvētās zemas temperatūras apkures sistēmas. Kā sistēmas energoefektivitātes pozitīvie momenti var būt tas, ka sistēma var būt pielietota ar atjaunojamiem energoresursiem kā siltuma avots, piemērām, siltumsūkņu sistēma efektīvi darbotos ar doto apkures sistēmu, jo siltumnesēja piesilde dotajā gadījumā ir minimāla, salīdzinājumā ar tradicionālo radiatoru apkures sistēmu. Vēl viena sistēmas priekšrocība ir, ka sistēma lietderīgi strādā pārējas gada laikos, kad ārējā gaisa temperatūras svārstības ir ievērojamas īsā laika periodā un apkures sistēmas darbība uz pilno jaudu nav lietderīga.
Darbs iekļauj sevī sekojošus posmus:
- ēkas sienu un pārsegumu elementos iebūvētu sistēmu teorētiskais aprēķins;
- siltuma plūsmas blīvuma grafisks attēlojums atkarībā no temperatūras režīma izvēles; siltuma vadāmības koeficienta grafisks attēlojums atkarībā no iebūvēto sistēmu materiālu tipa konstrukcijas un slāņu biezuma.

Pētījumu rezultātā ir pierādīts, ka ir sistēmām, kuram caurules ir iestrādātas būvkonstrukcijās un siltumnesēja temperatūra ir tuvu istabas temperatūrai, ir paaugstināta siltumakumulējoša spēja.

Елена Пшеничная, Байба Гауйена. Анализ рабочих характеристик систем лучистого отопления

Основные преимущества использования низкотемпературных систем лучистого типа – тепловой комфорт и дополнительная звуковая изоляция, также важен фактор инерции, который обеспечивает обогрев поверхностей даже без прямого энергопотребления. Демонстрируется влияние элементов систем отопления на качество воздуха внутри помещений, а также на температуру внутренних поверхностей помещений, в зависимости от их конструкций. Данная модель предлагает оптимизировать энергоэффективность здания, используя низкотемпературные системы отопления встроенные в конструкцию здания. Как положительный момент энегроэффективности упоминается следующее: система может работать с возобновляемыми энергоресурсами, например выбор такой системы эффективен в комбинации с системой тепловых насосов, так как подогрев теплоносителя минимален в сравнении с традиционными радиаторными системами. Ещё одно достоинство системы, – эффективное использование в периоды смены отопительных сезонов, когда изменения наружной температуры воздуха значительные, и нет необходимости работы традиционной системы отопления на полную мощность. Работа включает в себя следующие этапы:

- теоретический расчёт встроенных систем отопления в элементы стен и перекрытий здания;
- демонстрация графических зависимости плотности теплового потока от температурных режимов, также зависимость коэффициента теплопроводности от выбора типа материалов и размеров конструкции со встроенной системой отопления.

В результате исследования показано, что низкотемпературные системы отопления со встроенными в строительные конструкции трубами имеют повышенную теплоаккумулирующую способность.