Ekaterina Bazhenova

T6616KA

Comparison of convective and radiant heating system for office building with transparent facade system

Bachelor's Thesis
Building Services Engineering

January 2017

XAMK
Ammattikorkeakoulu

DESCRIPTION

Ammattikorkeakoulu	**Date of the bachelor's thesis** January 2017
Author(s) Ekaterina Bazhenova	**Degree programme and option** Double Degree Programme in Building Services Engineering

Name of the bachelor's thesis

Comparison of convective and radiant heating system for office building with transparent facade system

Abstract

Today's architectural decisions for office buildings often include open plan of the space and transparent facade systems. It creates a lot of challenges for HVAC-engineers while designing the heating system. The most common approach nowadays is in-floor convectors near external walls around the perimeter. But it has certain disadvantages in terms of indoor climate conditions. Another possibility is to design a system with radiant ceiling panels which are widely applied nowadays in large halls, but not so widely in office buildings with normal heights.

The aim of this bachelor's thesis is to find out which one of two of heating systems for office building with transparent facade system is preferable from the point of their advantages and disadvantages, created indoor climate conditions and cost-efficiency.

The methods used in the paper are the following. Firstly, literature research of the information about modern transparent facade system technologies, radiant and convective heating principles, their pros and cons. Then designing the simple building model and heat losses calculations for one typical floor, preliminary design of heating systems with in-floor convectors and radiant ceiling panels. Finally, cost calculations for each system, analysis of all information obtained and making a conclusion.

Subject headings, (keywords)

Convective heating, radiant heating, transparent facade systems

Pages	**Language**	**URN**
41 p.+ app. 3	English	

Remarks, notes on appendices

Tutor	**Bachelor's thesis assigned by**
Martti Veuro	

CONTENTS

1 INTRODUCTION

1.1 General overview

A lot of office buildings are constructed nowadays due to the economic development and because of unsatisfactory conditions of the old buildings which not allow using them anymore. Most of these new buildings are designed so that they have simple shape (square, rectangular, etc.), open plan of the floors and suspended transparent facade systems. Therefore there is the problem of heating of these large areas, because the common old way of heating with radiators or convectors hanging on the wall isn't appropriate in this situation – they are difficult to install, don't look good and don't provide enough heating capacity.

The most common approach today is to install long in-floor convectors near the glass walls. They are easy to install and cheap but has some disadvantages such as the possibility of radiation asymmetry. The other possible approach is the use of radiant heating with ceiling panels, but this approach is not so widely applied today for such buildings. Radiant panels have some important advantages, for example, they create better indoor climate and temperature profiles and require heat transfer medium of a lower temperature than convectors, which reduces costs and heat losses from the very beginning in the individual heat substation of the building. They also may be used for cooling, so you don't need any additional equipment.

It is interesting to find out if it is still reasonable to use common approach and to design heating system with in-floor convectors for office buildings with transparent facade systems or if new methods and technologies might be more effective and not more expensive especially when carefully and thoughtfully designed.

1.2 Aims

The main aim of this work is to find out which one of two approaches is preferable for heating an office building with open plan and transparent facade system. The main aim consists of smaller ones.

The first one is to find out what are the challenges for engineers in buildings with open plan and transparent facade systems, what problems may occur at the design stage and what might be the solutions.

The second one is to study operating principles, advantages and disadvantages of convective and radiant heating and to conclude which one can create better indoor climate conditions.

And the third aim is to compare costs of each type of heating on the basis of research model.

The first part of the paper will give a comparison of two ways of heating, their working principles, advantages and disadvantages and will tell about problems in the design of heating for office buildings, for example when calculating heat losses. Also the first part will give the theory about transparent facade systems and the theory of calculations. In the second part there will be described the research object and heating system calculations and design will be presented with cost calculations. The last chapter gives the analysis of the results and discussion – whether the answers to the research questions were found, whether they match the expectations and how these results can be implied to the wider context.

1.3 Methods

For achieving the aims there are several methods used in the paper. The first one is to observe and research literature background concerning transparent facade systems, modern decisions for office spaces, principles of convective and radiant heating and their pros and cons.

The second method is to design a simple model of a common building with open plan office and transparent facade system and to calculate heat losses and heat gains of that building. Then two heating systems will be designed to cover heat losses.

Finally, the costs of these systems will be compared and conclusion about reasonability of applying of both system will be made.

2 MODERN SOLUTIONS FOR OFFICE BUILDINGS

2.1 Transparent facade system

During the past few years new technologies have let architects and designers to use transparent facade system for many different types of buildings – residential, hotels, shopping centers and, of course, office buildings. (Figure 1)

FIGURE 1. Moscow International Business Center “Moscow City” (mymoscowcity.com)

The building begins with the architect so why do architects like transparent facades so much? First of all, architecture takes care of the exterior and beauty of the building, and glass facades can create tidy building of almost any shape and show that the owner of the building uses the most advanced technologies. /1, p. 14./ It is also a matter of human perception, because the view of wisely designed and constructed buildings with glass facades reminds us about futuristic predictions of the past and makes us feel like the future is already here and we are the part of it.

From the point of technology transparent facade systems help to reduce electrical energy consumption for illumination as they permit great amount of natural light. That is why such systems are very commonly used in big office buildings where it is a high need of light. These systems also have relatively high airtightness, which reduces heat losses through the building envelope. The system may be designed in such a way that ventilation and active heat recuperation may occur in the system. /2./ Such systems have good sound- and fire-protection charachteristics as well /3/. And obviously such enclosing structures weight much less than brick or concrete and therefore passive load on load-bearing structures of the building is reduced.

But there are many arguments still about the use of glass as an enclosing structure, especially in cold climates, from the point of energy efficiency of the building. Because of the high heat transmittance coefficient of the glass the heat losses are increased several times comparing to common wall constructions. Use of energy-efficient glass and frame materials requires a lot of costs as well as the heating energy for covering these losses. /4, 5./ But anyway transparent facade system are becoming more and more popular choice for modern commercial and even residential buildings and it makes engineers to put all their effort to find new solutions, constructions and ways for reducing costs and increasing energy efficiency of such structures /6/.

Transparent facade system is a combination of frame material (aluminum, steel, plastic) and a glazing unit. There are several types of transparent facade systems commonly used nowadays. /7./

- Column-beam or classical facade system – the most common system, easiest to install and the cheapest one. Consists of internal (columns and beams) and external (clamp and cosmetic cover) aluminium or steel sections between which there is a glass or multiple glazing and rubber gasket.
- Structural system – the most complicated type of facade systems. There is no visible cosmetic cover from the outside and glazing is anchored to the building with silicon joint sealer
- Semi-structural system is a combination of classical and structural system
- Spider system is the most advanced and expensive system nowadays. The glass is fixed with stainless steel fittings without frames so it allows creating fully glazed facade of any shape.

These systems can be seen in Figures 3-5. /6/

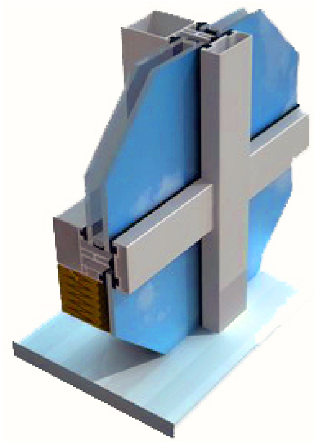


FIGURE 2. Column-beam facade system

FIGURE 3. Structural facade system

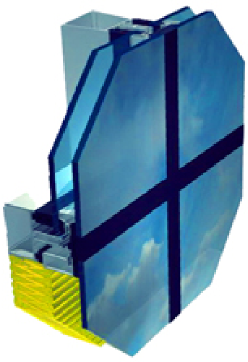


FIGURE 4. Semi-structural facade system

FIGURE 5. Spider facade system

The column-beam facade system is the most commonly used in construction of new office buildings because it is relatively cheap and easy to install and because most of the newly constructed buildings have simple shape for which this system is perfect.

Due to Russian standard SP 50.13330.2012. “Thermal performance of the buildings” /8/ all enclosing structures should have reduced total thermal transmittance resistance $R_{0,}$ $\frac{m^2 {}^\circ C}{W}$ not less than required total thermal transmittance resistance R_0^{req}, $\frac{m^2 {}^\circ C}{W}$ which depends on degree days D_d, calculated with the formula 1:

$$D_d = (t_{in} - t_{out,av}) \cdot z_{hp} \quad (1)$$

where

t_{in}, °C – room design indoor air temperature, taken in accordance with the regulation SP 118.13330.2012. “Public buildings and works” /9/

$t_{out,av}$, °C – average outdoor air temperature during the heating period for design area, taken in accordance with the regulation SP 131.13330.2012. “Building climatology”/10/

z_{hp}, days– duration of heating period, days/year, taken in accordance with regulation /8./

According to the table 3 in SP 50.13330.2012. “Thermal performance of the buildings” /8/ required thermal resistance for the calculated amount of degree days can be found with formula 2:

$$R_0^{req} = a \cdot D_d + b \quad (2)$$

where a and b are coefficients depending on the building type.

For the most of newely constructed buildings with transparent facade systems due to reduce heat losses through enclosing structure “warm” aluminium framing and energy-saving glazing with i-glass or k-glass are chosen.

“Warm” aluminium frame is made of two aluminium sections divided with plastic thermal insulating part which is working as a thermal brigde dividing the transparent structure into internal “warm” camera and external “cold” camera (Figure 6) /11/.

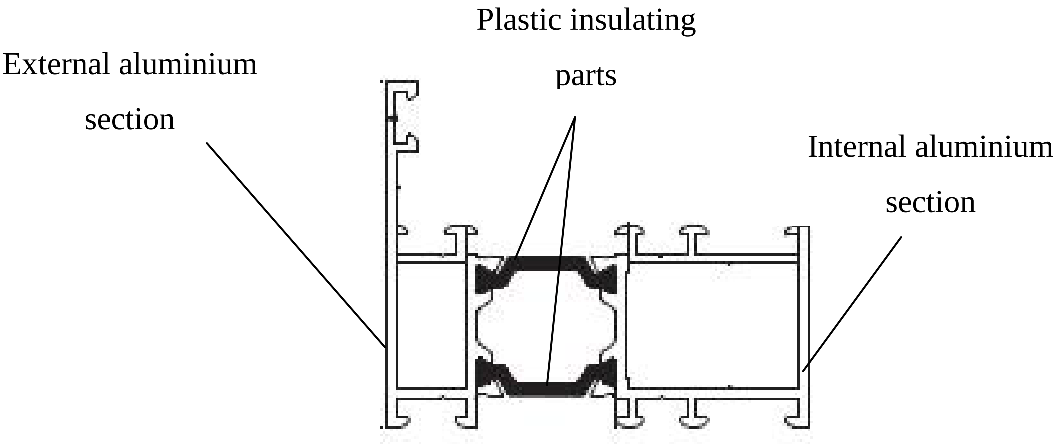


FIGURE 6. Costruction of “warm” aluminium frame /11/

Such construction increases thermal resistance of the frame and reduces heat losses through it. Thermal transmittance resistanse of these frames nowadays is about 0.3-0.5 $\frac{m^2 °C}{W}$, some measures like filling the empty space in the frames with some foamable polymers may increase the value up to 0.6 $\frac{m^2 °C}{W}$, but this is expensive and used mostly in cold climates.

K-glass and i-glass is a modern technology of low-emissive glass with so-called “hard” and “soft” cover of a thin film of metal oxides or silver which highly reduces thermal conductivity of the glass and it reflects the heat flows keeping the heating energy indoors during the heating period or outdoors during the cooling period. It helps to reduce costs for heating and cooling. The side with the film on is always inside the multiple glazing unit, but it doesn’t affect the glass properties at all.

The main difference between usual and low-emissive glass is the emission coefficient (E) – the ability to reflect long heat waves and to transmit the short ones. The lower is E the higher is energy saving properties of the glass. For usual glass E equals to 0.835 and for k-glass and i-glass it is 0.2 and 0.04 respectively. I-glass is much more expensive choice, but it pays off due to lower costs for heating /12/.

Thermal resistance R_0 of light-transparent facade systems has to be calculated in accordance with the standard GOST R 54858-2011 “Translucent facade constructions. Method for determination of thermal transmittance resistance” /13/ with the formula 3:

$$R_0 = \frac{1}{\alpha_{in}} + \frac{S_m + S_b + S_{op}}{\sum\frac{S_m}{R_m} + \sum\frac{S_b}{R_b} + \sum\frac{S_{op}}{R_{op}}} + \frac{1}{\alpha_{ext}} \tag{3}$$

where

α_{in} = 8 W/m^2°C, α_{ext}= 23 W/m^2°C – are coefficients of heat transfer from internal and external surfaces respectively, taken in accordance with tables 4 and 6 from /7/

S_m, S_b, S_{op} (m^2) - area of middle and border zones of glazing and opaque parts of structure respectively

R_m, R_b, R_{op} (m^2°C/W) – thermal transmittance resistance of middle and border zones of glazing and opaque parts of structure respectively

2.1.1 Challenges of transparent facades

From the point of HVAC-engineers every element of glazing is a “necessary evil” as it is a kind of energy drain in the envelope of the building /6/. That’s why a fully glazed facade may seem a nightmare for an HVAC-enginner. Behind the nice exterior there are a lot of problems to solve and things to take into account.

Benefits of transparent facades often create challenges in opposite. Poor design and bad choice of glazing construction will lead to big heat losses and extra costs for heating. In the opposite, if an engineer, trying to reduce heat losses as much as possible, chooses too warm construction (4- or 5-pane glazing, warm frame, etc), which is very expencive nowadays, the cost savings for heating might be less than extra costs spent on the glazing.

Transparent facades increase the amount of natural light to the room which is good for well-being of occupants and cost saving of electricity for lightning. But for construction in the areas with a big amount of sun need for cooling power might be enormous with the poor design. “Solar radiation is a very significant additional load, that even the very best of reflective and selective glasses cannot completely stop /14/.” So in the case of designing a building with transparent facades in such a climate passive methods of reducing energy demand of the building, such as orientation and shading, have to be used. Shading should be designed carefully, taking into account the orientation of the facade, elevation and the degree of the sun depending of the time of year /14/.

The best option is to use dynamic software to calculate heating and cooling loads for different types of glazing and shading in order to choose better variant.

Glass is very appreciated by architects for the possibility to create almost any shape of the building, curved facades and so on, but it creates challenges for the industry. For example, one of most interesting and discussed projects in Russia nowadays is Lakhta Center, the high-rise fully glased building of a unique curved shape. Over 11000 of different curved glazing elements is used to enclose the building, which is a unique practice for high-rise construction and it was very challenging, time- and resource-consuming for engineers and manufacturers. /15./

It can be seen, that nowadays transparent facades is still a challenging field, but promising. And as it becomes more and more popular and sophisticated it means more challenges for engineers in future, but also more researches conducted, new technologies and approaches developed and simple and natty solutions found.

2.2 Open plan of the office space

The other common thing that architects use for office buildings nowadays is an open plan of the office space. It meets the highly increasing requirements of flexibility of the office space. This flexibility is a big advantage for investors and developers because it lets to rent out either the whole floor to one major tenant or to rent out the required area for small companies and to design the floor layout accordingly to the amount of tenants and to other needs. Open plan is also an attractive decision for companies who rent these areas because it allows to reduce rent costs, to place more workers on the same area (comparing to the usual offices) and it also has a lot of communication preferences such as ability to discuss different tasks collectively and creation of friendly informal atmosphere, which is important for companies connected with creative and teamwork. /16./

Open plan is popular because of its economical and administrative (workers can be controlled easily) benefits, but for workers themselves it is not very pleasant thing. They have to work in a noisy surrounding and they are interrupted very often, which decreases productivity a lot. But in todays world investors are mostly concerned about economical profit, so it’s hard to imagine that they will start to think about workers’ privacy and comfort in near future. So here is also a task to create conditions for occupants as good as it is possible under these circumstances. And it may be achieved by smart choice of HVAC-systems, especially heating system.

2.3 Problems which HVAC-designers have to face

As it can be seen from the information above, modern developing technologies creates not only nice exterior of the building but also a lot of problems for engineers to be solved when it is needed to create good indoor climate conditions and to achieve good levels of energy efficiency.

The main problem, of course, is to design facade system in such a way that U–value would be low enough in accordance with the local regulations in order to prevent huge heat losses, but at the same time engineer should think about the cost of the system and to find compromise between the money spent on the system and the money it saves due to it’s higher energy efficiency comparing to other systems.

When it comes to the HVAC-design engineers have to be very careful with calculations at the early stages of a project. There is a common problem nowadays, at least in Russia, when engineers apply modern heating and ventilation systems for a new office building, use automation and so on and present great results of energy-efficiency calculation of a building, but during the exploitation occupants may feel overheating and need for cooling even if it’s cold outside. V.I. Livchak in his article “Why do office buildings overheat and what to do?” /17/ provide an example of a building of Moscow City Expert Examination Board constructed in the beginning of XXI century and equipped with the modern indoor climate control system and says about the unpleasant heat that he and his co-workers feel even when there is temperature below zero outside. The unpleasant feelings lead to the need for cooling system to be turned on while the heating system is on the minimum or even turned off. The author wonder why in the building constructed specially for the team of building experts such situation may occur.

The reason is that engineers use familiar scheme of heat losses and heat demand calculations and often don't take into account heat gains from people, electrical and other equipment, lightning and solar heat gains through the huge glass area. Sometimes it may cause overheating up to two times. The other problem is to set up automation regulation so heating is on and off depending on outdoor air temperature, but sometimes heat losses may be compensated with heat gains from inside as well so the automation should also take that into account. /17,18./

This may be especially a big problem for buildings in southern regions, where there are huge heat gains from the sun during almost the whole year and precise calculations and clever design are very important in order to reduce cooling energy needs and therefore to reduce costs. Microclimate conditions may change a lot depending on the glazed area and it becomes very important to calculate what temperature must be inside and how it may be changed during the day.

For the building of such dimensions and type as an office building internal heat gains from people, lightning and electrical appliances will have a significant influence on the total heat energy demand. Accordingly to the methodology "Heat losses of the building" /19/ which combines Russian standards concerning thermal performance of the buildings, building type and climate parameters of the construction zone heat inputs q_{int} (W/m^2) from people, appliances and lightning are calculated with the formula 4:

$$q_{int} = \frac{90mn_p + q_t A_1 n_t + 10A_1 n_w}{168A_1} \tag{4}$$

where

90 (W/m^2) – average specific heat gain from 1 person

m – number of people in the building (determined in accordance with guidline value of 6 m^2 per working person in office buildings)

n_p, h – average duration of people's presense in the building during the week

q_t , W/m^2 – average specific heat gain from lightning

n_t, h – duration of lights on during the week

A_1,m^2 – calculated area, determined in accordance with floor plan

n_w, h – duration of electrical appliances on during the week

10 (W/m^2) – average specific heat gain from electrical appliances

Another part of heat gains is solar radiation. In Russian designing practice its influence is taken into account for the hottest month (July) while designing ventilation system of the building and cooling system and while calculating total energy demand of the building. The there are no specific requirements for calculating solar heat gains in buildings with huge glazing area, although they might influence the total heat power demand even during the heating period in winter when there are no much sun, but because of large transparent surface these heat gains might be relevant.

The methodology “Heat losses of the building” /19/ provides method of calculating the average heat gains, but of course in real life these values fluctuate. They might be much bigger during the warm sunny winter day or there might be no heat gains at all during unoccupied period. At the beginning and at the end of the heating period monthly heat energy gains might be even bigger than heat energy losses. Researches made by the authors of the methodology /19/ have shown that for the south-, south-east (west)- and east (west)-oriented spaces daily heat gains may be bigger than heat losses even in January (for Moscow region).

So there are no methods for precise calculations of heat losses and gains depending on the period in Russian regulations yet, but these values and the fluctuations might be calculated with some kind of dynamic software.

Some researches have shown that it might be a good decision for reducing cooling energy needs to maintain the lowest possible temperature in the beginning of working day so during the day it will increase because of internal heat gains. And also at the end of the day the temperature might be at the highest possible level so it will decrease during the night when there are no occupants inside. /20./ So this approach also requires precise calculations and designing of heating system and instructions concerning the maintenance of required temperature level.

It becomes obvious that in the case of a large open space enclosed with glass walls it is no longer possible to use usual ways of heating such as wall-mounted radiators. HVAC-engineer should think about the possibility of condensation on the inner surface of the glass wall during cold period, about the possibility of draught and how the cold inner surface may influence people who are sitting right next to it. So today's solutions for these problems are the following.

3 HEATING SYSTEMS IN BUILDINGS WITH TRANSPARENT FACADE SYSTEMS

The most common decision nowadays is to install in-floor convectors near the glass wall around the perimeter of the building /21/. It prevents descending air current and protect inner surface of the wall from condensation. This equipment doesn't require a lot of space so it doesn't occupy useful space of the office area. But it also creates uneven temperature distribution when temperature difference of air near the floor and near the ceiling may reach several degrees and occupants still may not feel comfortable which makes them to set higher values on thermostats.

The other possibility is radiant heating. Nowadays it is mainly realized in one-family houses with big glazing area in a form of in-floor heating and radiant panels (walls or ceiling-mounted) and another wide application area is large halls such as sport halls, storages and workshops on the factories where big height doesn't allow using regular radiators or convectors. One of the aims of this thesis is to find out whether is it reasonable to use radiant ceiling heating as the main heating system for an office building with open plan and transparent facade system. So there is a closer look to the convective and radiant heating, differences between them, advantages and disadvantages of each type.

3.1 Convective and radiant heating

Convective and radiant heating are operating with completely different principles. Convection is a heat transfer in gases or liquids when they are mixing up. In natural convection bottom layers are heated and go up because they have lower density. Meanwhile the upper layers become cooler and go down. These so-called convection currents transport the energy around the space. The temperature of the heated air has to be higher than desired air temperature because of the low surface temperatures and the heat losses on the way of air from the heating equipment to the occupants.

Thermal radiation, on the other hand, means that every object which has temperature higher than absolute zero (0 K = -273 °C) emits energy in the form of electromagnetic waves. Other objects absorb this energy and therefore their temperature increases. The amount of emitted heat depends on the emitting area and temperature of the emitter – they increase proportionally. Thermal radiation in opposite to convection is directional and isn't affected by properties of medium it goes through and the heat doesn't dissipate on the way. So the amount of heat emitted is absorbed by furniture, clothes or surfaces without any losses on the way. So the temperature of the surfaces and objects are comfortable and close to the desired temperature, but air temperature might be lower than desired room temperature without creating any unpleasant feelings. It is a big benefit for energy efficiency, because the decrease of air temperature by 1 °C decreases energy consumption by 7% in average. /22./

In each heating system occurs both convection and radiation, but the share of each is different and depends on the type of heating system and heat emitter which are used. For example, panel radiators transfer 70% of heat with convection and 30% with radiation. Convectors transfer almost 100% of the heat with convection. /23./ In radiant heating panels about 85% of the heat is transferred with radiation /24/.

3.2 Convective heat emitters

As for heat emitters themselves, they are made as a device open for the flowing air with hot heating element. Air in contact with an element is heated and goes up, replaced by a portion of cold air (Figure 7). This is called natural convection. There is also a method of forced convection, when a small fan is installed into convector, increasing the velocilty of air flow and air change rate and therefore to heat up the space faster, and also being a preventive way to protect heating element from overheating and therefore to extent the service live of the heat emitter /27/.

FIGURE 7. Working principle of in-floor convector /23/

There are several types of convective heat emitters used nowadays. They are divided by the installation method and by the source of the energy converted to heat /26/. Installation method: floor-mouted, wall-mounted (incl. ceiling-mounted), in-floor mounted. Energy source might be water, gas, oil or electicity.

For office buildings with big glazed area in-floor convectors with water as a heat transfer medium (Figure 8) are the most popular decision because of possibility to install them in any part of the room and because of the high heat output comparing to e.g. wall-mounted convectors. Also the possibility of forced convection may be a benefit.

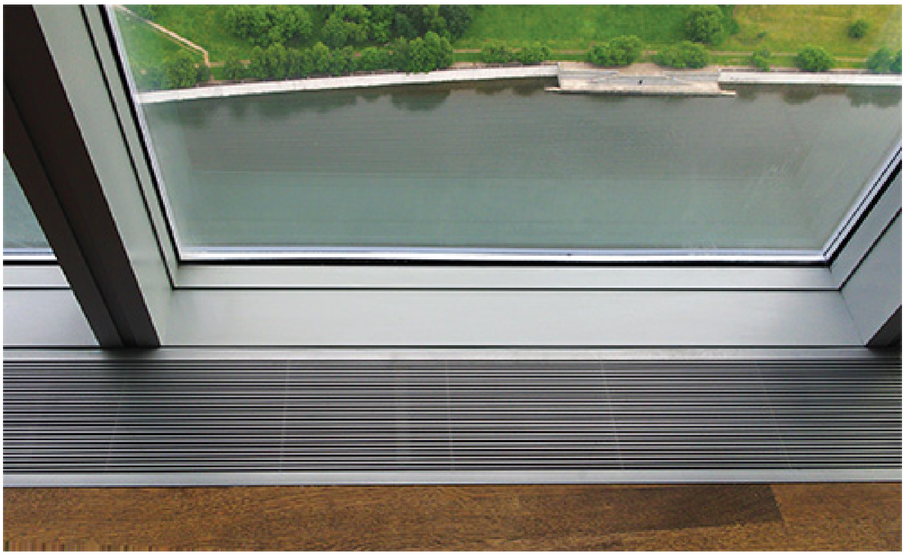


FIGURE 8. In-floor convector installed in an office building /21/

But there are still many disadvantages of convectors. Besides uneven temperature distribution already mentioned above there are also a possibility of radiation asymmetry. Convective heating is a slow process because of low thermal conductivity of air so surfaces may not be warm enough. Low surface temperature leads to lower mean room temperature, therefore energy consumption for heating increases because we need to maintain certain temperature in the room. Room air might be too hot and dry and cause unpleasant feelings for occupants. Also occupants may feel draught because of constant air movement. Another problem is the dust on convectors. Because the equipment is open to the moving air the air brings the dust which is then burnt on the hot suface of the pipe and moved to the room air, settling on the walls, floor, furniture and inhaled by people. /27./

3.3 Radiant heat emitters

Radiant heat emitters emit energy in infrared diapason. The length of infrared waves is between 0.77 and 340 μm. Depending on the wave length and the emitting surface temperature radiant heat emitters are divided into 3 groups: /28./

- Long-wavelenght or low-temperature emitter (wave length is between 100 and 340 μm, surface temperature is between 45 and 300 °C) – water-based radiant panels
- Medium-wavelength or medium-temperature "dark" emitters (wave length is between 15 and 100 μm, surface temperature is between 300 and 750 °C) – emitting tubes with hot air or gas
- Short-wavelength or low-temperature "light" emitters (wave length is between 0.77 and 15 μm, surface temperature is 750 °C and higher) - gas heaters with open flame

The radiant heating system may be air-, water- or electricity-based. Air-based systems are not very effective as a primary heating system because of the low specific heat capacity of the air comparing to water (Cp_{air} = 1.005 kJ/kg K, Cp_{water} = 4.2 kJ/kg K). As for the electrical systems, they are more effectively used as an additional system for heating of thick concrete floors because of the high heat capacity of the concrete. /24./

For residential and commercial construction use of the water-based radiant heating system is the good choice because, first of all, these buildings are connected to district water heating and, second of all, the use of water as heat transfer medium is more energy and economically efficient than use of air.

The construction of radiant heating panel with heat transfer medium water can be seen in Figure 9.

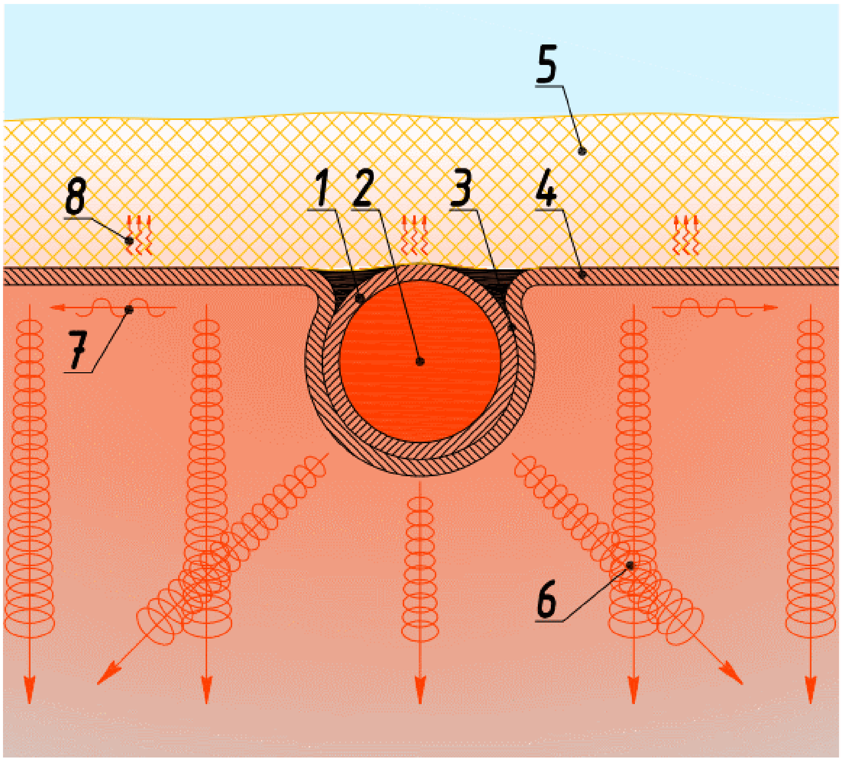


FIGURE 9. Construction of radiant heating panel /29/

1. **tube with flowing heat transfer medium**
2. **heat transfer medium – water (t=40…110 °C)**
3. **tight connection between tube and radiation surface**
4. **radiation surface**
5. **thermal insulation material to block the upward heat flow**
6. **infrared radiation heat transfer**
7. **convective heat transfer**
8. **conductive heat transfer**

The main benefits of radiant panel heating comparing with convective heating are the following:

- It creates better thermal comfort for occupants because it heats up not the air but the objects directly
- The use of thermostats is more effective for radiant heating panels as they may work only part of the time in the consumption mode because of the bigger heat transfer area and short reaction time. The panel gets warm quickly and heats up the objects in the room quickly, and if the heating is set off after that the room temperature will be kept on the desired level for a relatively long time because of the heat stored in the objects /29/
- The system works silently
- It is more hygienic type of heating and better for indoor air quality because it doesn’t create air flows which may carry the dust and harmful particles
- It is more easy to maintain and regulate and it allows creating zonal heating and optimizing room temperature according to the needs (Figure 10)

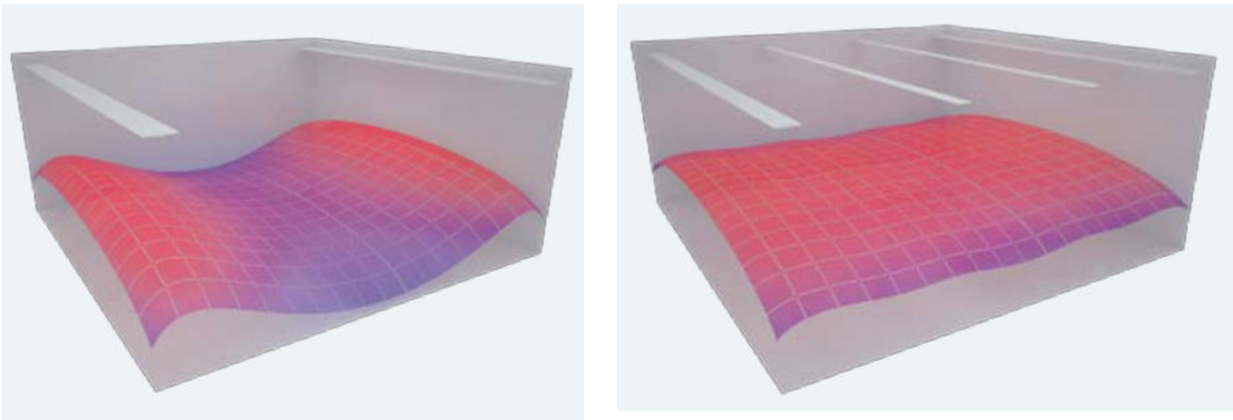


FIGURE 10. Variants of temperature profile optimization with different location of heating panels /29/

Nowadays radiant heating panels is the most popular choice for buildings with the height of the ceiling more than 3.5-4 meters, such as sport halls and industrial buildings’ facilities. For office buildings with the storey height 3-4 meters convective heating is still the most popular choice. But as it can be seen from the information above the radiant heating has a lot more advantages comparing to the convective heating. So it might be possible to create comfortable conditions with wise designing of radiant heating system, precise calculations and choice of water temperatures and well-thought-out regulation during the operation time of the system.

In case of the designing the heating system with radiant ceiling panels the total length of panels is determined accordingly to the layout. The required specific heat output of the panels is determined for one meter of the panel with the formula 5:

$$q = \frac{Q_{tot}}{L} \tag{5}$$

where Q_{tot} is the total required heat capacity of the heating system, W

L – total length of the panels, m

Temperature difference is calculated with the formula 6:

$$\Delta t = \frac{t_{sup}+t_{ret}}{2} - t_{in} \tag{6}$$

where t_{sup} is supply water temperature to the panel, K

t_{ret} is return water temperature, K

t_{in}-indoor temperature, K.

Then from the table of standard heat output values given by the manufacturer the closest value is chosen.

The other important thing is to check if the irradiation intensity at the top of the head doesn't exceed 35 W/m^2. According to /30, p.20/ irradiation intensity is calculated with formula 7:

$$I_s = \frac{Q_{tot} \cdot \eta_s}{A} \tag{7}$$

where I_s – irradiation intensity, W/m^2

Q_{tot} – installed power output of radiant strips, W

η_s – radiant efficiency, depends on temperature difference and panel width

A – floor surface area, m^2

External surfaces temperatures are playing important role in overall perception of indoor climate. People are mostly sensitive to radiation asymmetry caused by warm ceilings and cold walls. In case of a big glazing area problem of cold walls becomes the subject of focus. According to international standard ISO EN 7730 difficulties may occur with a radiation temperature asymmetry 10 K for walls. On the design stage it might be calculated with the formula 8 /31, p.6/:

$$\Delta t_{pr} = 3.96 \cdot U \tag{8}$$

where U is the heat transfer coefficient of the enclosing structure, W/m^2K.

For determing the pipes’ price in cost calculations the pipe diameter should be found. As there are no hydraulic calculations being made the average diameters are determined according to the flows. Flow in the heat emitter is calculated with the formula 9:

$$q_v = \frac{Q}{\rho \cdot c_p \cdot \Delta t} \tag{9}$$

where Q – heat capacity of the emitter, kW

ρ = 1 kg/l – density of the heat transfer medium (water)

C_p = 4.2 kJ/kgK – specific heat capacity of the water

Δt ,°C – temperature difference between supply and return water temperatures

Pipe diameter is found from the formula 10:

$$q_v = v \cdot A = v \cdot \frac{\pi d^2}{4}, \text{ so} \tag{10}$$

$$d = \sqrt[2]{\frac{4 \cdot q_v}{v}}$$

where A – area of the pipe section, m^2

d – pipe diameter, m

v – water velocity in the pipe, m/s. For design case value 0.5 m/s is chosen which is average – high enough to remove air bubbles from the water and low enough in order not to cause noise.

4 RESEARCH OBJECT

4.1 General overview

For the research case the simple model of 6-storey office building with column-beam transparent facade system and open plan of the floors was chosen. The building is located in Saint-Petersburg. The most common architectural and design decisions are used in the model in order to make possible the application of research results for as many as possible of today's cases. Unique high-rise buildings with special requirements need a unique project for each, but for most of the office buildings constructed nowadays the same principles can be applied.

As all the floors are supposed to be the same in layout it was decided to pick up one typical floor as an object of research. In office buildings first one or two floors are usually designed for public catering, trade services, administrative offices and security rooms so the heating system there must be designed in an other way than in office spaces. From the rest of identical office floors the lowest one will have the bigger heat losses because of the bigger amount of infiltration air. Infiltration occurs due to pressure difference between inside and outside of the enclosing structure. This difference occurs due to different densities of cold air outside and warm air inside the building (gravity pressure) and because of the additional wind pressure. Outside gravity pressure depends on the height and decreases with elevation, inside pressure in calculations is considered to be the same in all building. Wind pressure depends on the velocity of the wind and facade's orientation. Gravity pressure and the pressure difference on the same facade but on different heights are different and on the higher floors pressure difference might be even negative, so no infiltration will occur. /19./ So the second floor of the building was chosen as a research object.

4.2 Building characteristics

4.2.1 General

Layout of the research floor is presented in Figure 11.The length of the building within axes 1-8 is 42 meters and within axes A-F is 30 meters. The height between floor levels is 4.2 meters, room height is 3.6 meters and it is chosen so that there is a possibility to install suspended ceiling to cover building service lines (electrical wires, ventilation ducts, etc).

4.2.2 Construction

Load-bearing structures of the building are reinforced concrete columns 600x600 mm, internal concrete walls with 250 mm thickness working as a stiffening core, internal floor slabs (300 mm) and foundation slab 500 mm. Under the foundation slab there are undergroung technical floors and parking. Enclosing structures are non-opened transparent column-beam facade systems with energy-saving 3-pane plazing. Internal walls are made of brick, 120 or 250 mm thickness. Roof is flat and accessible.

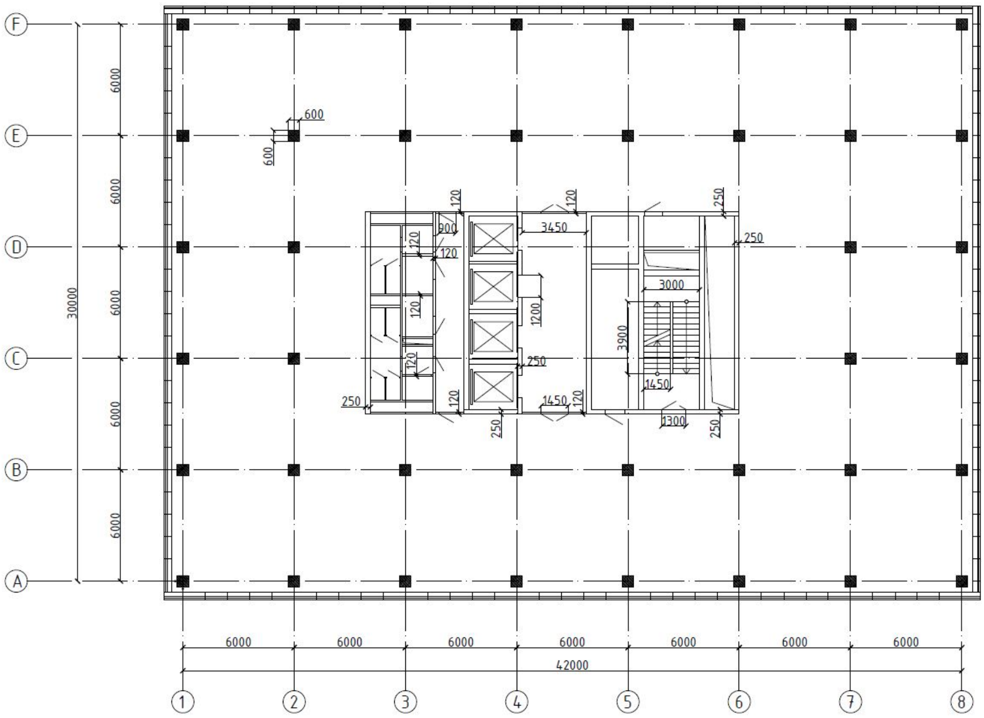


FIGURE 11. Plan of the typical research floor

4.2.3 HVAC-systems

Almost all of newly constructed office buildings in Russia have independent heating connection scheme which means that internal heating system are connected to district heating through individual heating plant (substation) where its temperature or flow can be regulated depending on outdoor air temperature.

Domestic hot water system is closed, which means that cold water from the service line is also heated up in the substation.

Ventilation system is Constant Air Flow (CAV) system and air flows, air ducts and system equipment are designed in accordance with SP 60.13330.2012. “Heating, ventilation and air conditioning” /32./

4.2.4 Characteristics of enclosing structure

Degree days D_d for Saint-Petersburg area were calculated with the formula 1.

$$\mathrm{D_d} = (20 - (-1.8)) \cdot 220 = 4796\ °\mathrm{C} \cdot \text{ days}$$

Required thermal resistance of the enclosing structures was calculated with the formula 2.

$$\mathrm{R_0^{req}} = 0.00005 \cdot 4796 + 0.2 = 0.44\ \frac{\mathrm{m^2°C}}{\mathrm{W}}$$

For the research case there was chosen column-beam facade system with “warm” aluminium framing and energy-saving 3-pane glazing with i-glass and argon between glasses. The average value of frame’s thermal transmittance resistance 0.45 $\frac{\mathrm{m^2°C}}{\mathrm{W}}$ was chosen for the case.

Glazing formula is 4-Ar12-4-Ar12-4i, which means that there are 3 panes of 4 mm-thick glass and between glasses there are 12 mm of space filled with argon. Argon prevents the oxidation of silver layer and also decrease the noise level and increase thermal insulation properties because of lower thermal conductivity than air /33/. The thermal resistance of the chosen glazing structure is 0.75 $\frac{m^2 °C}{W}$ /34/.

Construction of the transparent facade structure is shown on the Figure 12. The whole area of the part of the structure limited with frame is 2.62 m^2. Therefore area of opaque part is 0.335 m^2. Width of the border zone is about 50 mm and it's thermal resistance is influenced by properties of connection between frame and glasing. Therefore it is lower than thermal transmittance resistance of the middle zone of glazing. In our case it might be taken 0.55 m^2°C/W and the area of border part is 0.16 m^2.

Thermal resistance R_0 of the enclosing structure was calculated in accordance with the formula 3 and it equals to 0.774 m^2°C/W.

Therefore, $R_0 > R_0^{req}$, so the construction might be used under design conditions.
The value R_0 = 0.774 m^2°C/W corresponds to U-value U=1/ R_0 =1/0.774 = 1.29 W/m^2°C

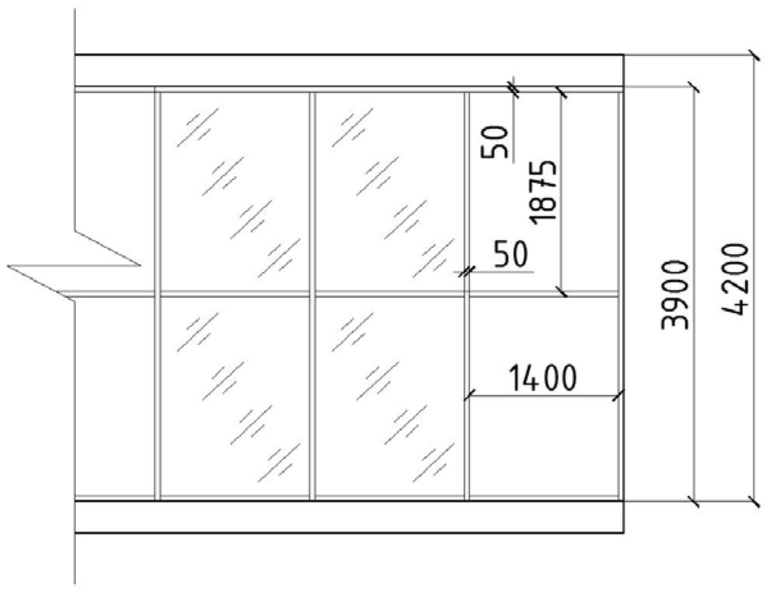


FIGURE 12. Costruction of transparent facade structure

5 HEAT DEMAND CALCULATIONS

5.1 Heat losses

Heat losses are calculated in accordance with the methodology /19/. According to this methodology heat losses of the room are calculated and presented in a table form (table 1).

For the research case as we calculate heat losses for one typical not first or last floor we only take into account heat losses of open plan office space through facade systems. Other rooms are in the middle of the building and don’t lose heat through envelope. K-value is the same as U-value. Results of calculations are presented in table 1. (Appendix 1). The total heat loss of the floor is 57.3 kW.

5.2 Heat gains

Heat gains q_{int} (W/m^2) from people, appliances and lightning are calculated with the formula 4. Number of people on the floor is 180 persons, average duration of people’s presense in the building and duration of electrical appliances on during the week is 40 hours, average specific heat gain from lightning is 20 W/m^2 and duration of lights on during the week is 20 hours. Calculated area is 1126.4 m^2.

Therefore, q_{int} = 8.18 W/m^2. And, multiplied with the area, it gives the value of internal heat gains 9.22 kW which is 16% of total heat losses. The influence is relevant and not taking heat gains into account will lead to extra costs for equipment of bigger heat capacity which will be useless as the full capacity won’t be used.

Therefore, the total heat losses value as a basis for designing heating system is Q_{tot} = 57.3-9.22 = 48.08 kW.

6 HEATING SYSTEMS AND COST CALCULATIONS

6.1 General

According to Russian standard /30/ for commercial buildings there are maximum allowed supply temperature in heating system might be 95/105 °C (for one pipe/two pipe system). The heating curves for district heating are designed for temperatures 150/70 °C or 130/70 °C and for local heating systems in the building - 95/70 °C. These values must be kept in the heating system at the time of the lowest designing outdoor temperature (-24 °C for Saint-Petersburg). Building heating system is connected to DH with individual heating substation through heat exchangers. The substation allows controlling ang regulating of the supply and return temperatures or flow of heat transfer medium in accordance with the outdoor temperature.

Big part of the costs is pipe prices. There are 3 possible materials for underfloor installation pipes: copper, multilayer, plastic. For the case it was decided to use multilayer pipes. The reasons are so that multilayer pipes are cheaper than copper pipes and can work in with bigger temperatures than plastic pipes. Also there is no risk of damage during the installation in opposite to plastic pipes. Multilayer pipes are in the middle of the prices and properties range which makes them popular choice in Russia.
The pipes used in the design are Uponor MLC pipes. Pipe's prices are taken from catalogue on Uponor website /35/.

In costs calculations the most updated prices able to find were used. Currency exchange rate of Central Bank of Russia valid for January 2017 was used /36/.

6.2 In-floor convectors

According to the principles mentioned above, capacity of heat emitters has to be chosen for t_{sup}/t_{ret} = 95/70 °C. But because of the nonconformance between standartized values and real cases in Russia and also in order to extend service life of the pipes, heating systems are often designed for the lower temperatures. So in the research case convectors are being chosen for t_{sup}/t_{ret} = 85/60 °C. Pipes are designed to be underfloor multilayer pipes and distribution is made with manifold.

For the design case it was decided to compare convectors of two manufacturers. The first one is very popular among designers Finnish manufacturer Purmo and the other one is Russian manufacturer Itermic. All the values of heat capacities, dimensions of equipment and prices are obtained from official manufacturers' websites /37, 38/.

So the first step is to choose number of heat emitters and heat capacity of each one. Convectors are placed near the external glass walls between columns. The distance between columns' edges is 5400 mm and for the best indoor climate conditions and protection of inner side of the walls convectors have to be as long as possible. So we can install either 3 convector of the approximate length 1800 mm or 2 convectors of the length 2700 mm between each two columns. Therefore, we need either 72 or 48 convectors. The total capacity required is 48.08 kW. The comparison is presented in the Table 2.

TABLE 2. Comparison of the prices for heating systems with different types of in-floor convectors

	Purmo		Itermic	
L, mm	1700	2700	1700	2700
Type	FMK26-1700-14	FMK29-2700-11	ITT.080.1700.300	ITT.090.2700.250
Needed capacity, W	668	1002	668	1002
Capacity of the convector, W	660	1003	708	958
Number of convectors	72	48	72	48
Total capacity, W	47520	48144	50998	45998
Deviation from required capacity, %	-1.2	0.1	6	-4.3

Price of the convector, €	487.5	589.8	348	411
Thermostatic valve price, €/number	35/72	35/48	35/72	35/48
Total price, €	37620	29992	27576	21408

So as it can be seen from the table, the best option is to choose Itermic convectors with the length 2700 mm. The layout of the system is presented in Appendix 2.

For each of the chosen convectors with capacity approximately 1000 W in accordance with the formula 9 water flow will be equal to 0.0095 l/s = $9.5 \cdot 10^{-6}$ m^3/s. According to the design average connection is 4 convectors for one branch, so the total flow for one branch is $38 \cdot 10^{-6}$ m^3/s.

The minimum average inner pipe diameter for the research case calculated with formula 10 is 17.4 mm. From the tables given by manufacturer choose the next bigger diameter – 25x2.5 (d_{in} = 20 mm). Price per meter of the pipe is 4.74 €. Total length of the pipelines accordingly to the drawing is 715 m . So the total price for piping of such system is 3389.1 €. As there is no accurate scheme of the piping is designed, the average cost of all the bends, fittings and so on may be taken about 40% of the piping costs. Therefore the price of piping is 4745 € and the total price of piping and equipment is 26153 € for Itermic. In case of choosing Purmo convectors Aqulio FMK29-2700-11 the total price of the system will be 34737 €.

6.3 Radiant ceiling panels

In case of creating the system with water-based radiant heating panels zonal approach is important. In marginal parts of the building near the envelope cold convective and infiltration flows and so-called “cold” radiation influence microclimatic conditions a lot so in these zones it is reasonable to install wider panels of bigger capacity than in the other parts of the space. /30./

As radiant panels are mostly used nowadays in large spaces of a simple shape such as storages, sport halls, etc, the design is also simple and the main part of it is to choose number, length and width of the panels and to place them uniformly on the layout. In our research case it’s a bit more difficult, because not all the ceiling area is available for placing the panels because of the columns grid. Also there is a need for uniform heat delivery and more heating capacity to the marginal zones.

For preliminary choice of the panels the whole space, as it is almost symmetrical, can be divided into 4 zones with equal heat demand. It was decided to use radiant heating panels by Zehnder company as one of the biggest, most well-known and reliable manufacturers of this kind of equipment. Panels chosen for the research case are Zehnder Flatline. It is claimed by the manufacturer to be the best decision for office spaces with normal height. Panel material is aluminium, pipes are made from copper. Panel also can be used for cooling and can be installed into suspended ceiling.

Accordingly to Zender Flatline technical brochure /39/ the number of needed panels is determined as:

$$\text{Number of panels} = \frac{\text{Room Length}}{\text{Installation Height}} + 1$$

For our case if we determine one zone as a room and take the length of its longest side as the room length we get

$$\text{Number of panels} = \frac{21}{3.5} + 1 = 7$$

But for uniformity of the system and heat delivery it is better to take even number of panels. So we take 6 panels and place them as it is shown in the Appendix 3.

The distance between panels are chosen from consideration of uniform heat delivery and in accordance with recommendations developed by official community of Russian HVAC-engineers /40/. So, according to the drawing, the combined length of the panels is 288 m, including the length of wider panels in marginal zone – 122.4 m. Required specific heat output of the panels is determined with the formula 5 and it equals to q = 167 W/m.

This heat output is quite low because of the big total length of the panels, but uniformal heat delivery is priority when using radiant heating panels. In the case of such low heat output there is no need to use high water temperatures. So instead of 85/60 °C we may use 60/40 °C. Desired temperature values are achieved by the means of control in individual heating substation. Temperature difference is calculated with the formula 7 and for the case it equals to 30 K.

From the table of standard heat outputs given by the manufacturer the closest values to 167 W/m for temperature difference 30 K are 136 W/m with panel of 450 mm width, 175 W/m for 600 mm width and 209 W/m for 750 mm wide panel. In our case we can take 750 mm wide panels in marginal zones and 450 mm panels in other zones. Therefore, the total heat output of all the panels is

$$Q_{tot} = 209 \cdot 122.4 + 136 \cdot 165.6 = 48103.2 \text{ W}$$

Irradiation intensity is calculated with formula 7. In the research case $\eta_s = 0.67$. /30, p.26./ The value of irradiation intensity is 28.62 W/m^2 which is lower than maximum allowed value 35 W/m^2.

Radiation temperature asymmetry is calculated with the formula 8 and in the research case $\Delta t_{pr} = 3.96 \cdot 1.29 = 5.1$ K. That is lower than 10 K, so there might be no unpleasant feeling caused by radiation asymmetry.

Cost calculations of equipment are presented in table 3 and calculations of average pipes diameters and costs are presented in table 4. Prices of equipment are taken from /41/. Diameters are calculated in accordance with formulas 10 and 11. Used pipes are the same multilayer Uponor pipes as for previous system. Calculations are made for half of the system and multiplied with 2 for final results as the system is symmetrical. Numbers of panels for table 4 can be seen in Figure 13.

TABLE 3. Cost calculation for Zehnder Flatline radiant ceiling panels

Panel width, mm	450	750
Total panels length, m	165.6	122.4
Price per meter, €	84.6	130.4
Total price, €	14010	15961

Also there is a 3-way valve with motor drive for temperature control for each main supply pipe going from manifold. Average price of such valves is 200 € /42/, number of valves is 6. Total price is 1200 €.

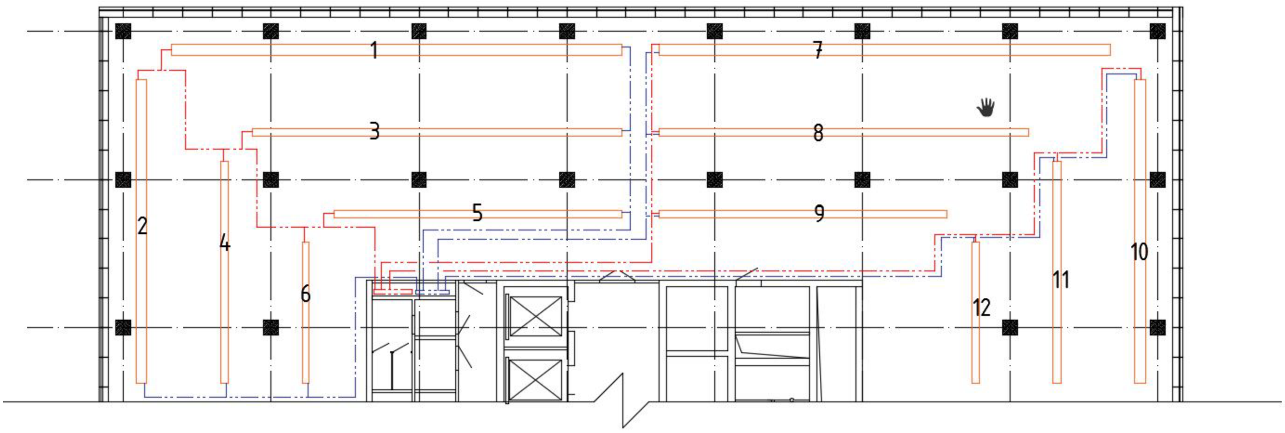


FIGURE 13. Panels´ numbers for table 4.

TABLE 4. Calculations of Uponor MLC diameters and prices for system with radiant ceiling panels.

Number and width of the panel, mm	1,2 750	3,4 450	5,6 450	7 750	8 450	9 450	10 750	11 450	12 450
Panels' length, m	30.6	25	16.4	18.4	15	11.7	12.2	10	4.7
Specific heat output, W/m	209	136	136	209	136	136	209	136	136
Panels' heat	6.4	3.40	2.23	3.84	2.04	1.59	2.55	1.36	0.64

output, kW									
Flow to the panels, l/s	0.076	0.040	0.026	0.046	0.024	0.019	0.030	0.016	0.007
Flow in the pipe part before panel, l/s	0.076	0.116	0.142	0.046	0.07	0.089	0.03	0.046	0.053
Calculated diameter, mm	24.66	30.46	33.7	19.18	23.66	26.68	15.5	19.18	20.6
Average diameter, mm	29.6			23.1			18.4		
Chosen diameter, mm	40x4			32x3			25x2.5		
€/m	14.29			7.19			4.74		
Pipes length, m	37			150			153		
Total price, €	528.73			1078.5			725.22		

Therefore, the approximate price of piping is 4665 €. Including 40% of the fitting costs we get 6531 € of total piping costs. Therefore, total price of radiant ceiling panels system is 37702 €.

6.4 Installation costs

As for the installation costs, when making the budget for new construction they are calculated in accordance with Territorial Unit Costs /43/ and for heat emitters they depend not on the number of emitters, but on the total installed power (the unit is 100 kW), so for the both systems the costs will be approximately equal as the installed power is almost equal. For convectors it will be about 140 € and for radiant panels about 110 €.

The main difference will be in piping installation costs as the pipes length and diameters are different for each case. In case of the system with convectors it is 715 m and for radiant panels total pipes length is 340 m. According to the Territorial Unit Costs /44/ in the first case (convectors) costs for piping itself will be 1980 € and in the second case (radiant panels) it will be about 1000 €. Also costs for additional piping equipment such as flanges, stop valves, connections are already considered in the TUC and the longer the pipe the higher these costs will be.

6.5 Analysis of cost caclulation results

Combined results of cost calculations are presented in table 5.

TABLE 5. Comparison of two heating systems' costs

Costs, €	In-floor convectors		Radiat ceiling panels
Manufacturer	Purmo	Itermic	Zehnder
Equipment	29992	21408	31171
Piping	4745	4745	6531
Installation	2120	2120	1110
Total	36857	28273	38812

It can be seen from the table, that in case of Itermic convectors the total price of the system is 27% less than the price of radiant heating panels system, but in case of Purmo it is 5% less, which is not crucial and as the calculations are approximate, these costs might be considered equal. More precise design may decrease piping costs and make the differene smaller.

7 DISCUSSION AND CONCLUSION

Even though the results of cost estimation are quite approximate they still can show that difference between costs of the heating system with in-floor convectors or with radiant ceiling panels isn't big enough to talk about significant money saving in case of using in-floor convectors.

The results of the study show that radiant heating panels might be a good competitive alternative to the in-floor convectors. This technology is a way better in terms of indoor climate conditions as it creates even temperature distribution, allows lower air temperature in the room than convective heating for the same resulting mean radiant temperature, doesn't create air flows which may cause draught or carry the dust around. Radiation heat is not dissipated on the way to the object and it is perceived by occupants as more pleasant type of heat. Irradiation asymmetry might be lowered if using enclosing structures with low U-value (which is also important for reducing heat losses and preveting condensation on the inner cold surface).

The possibility of zonal approach is also a benefit while designing heating system for a building with open plan of the space and transparent facades. It allows delivering more heat to the marginal zone near glass walls and to control heat delivery to the spaces as desired if, for example, a part of the space is rented and walled in.

From the technical point of view radiant heating requires the water of lower temperature than convective heating and the equipment might also be used for cooling if it is envisaged in the project. Therefore it reduces costs for additional cooling equipment. Also operational costs for radiant heating are lower thus it doesn't include cleaning costs.

Combining all the results of study it can be said that when designing heating system for large open plan buildings with transparent facade system traditional designing approach should be reconsidered. It is reasonable to give up on the use of common calculation patterns and choice of equipment and to apply newly developed approaches as they are proving to be more energy-efficient, creating much better conditions and to be as cost-efficient as the common ones.

Of course, each project is unique and it requires precise calculations and thoughtful design, so there might be cases where convectors or combination of two systems can be more reasonable choice. But it doesn’t mean that engineers shoudn’t think over all the opportunities and variants. For most of the common cases if on the design stage calculations are made properly and all crucial factors are taken into account, radiant heating systems may become a much more better choice for open plan office buildings with transparent facade systems.

BIBLIOGRAPHY

1. Magay A.A., Dubynin N.V. Светопрозрачные фасады высотных многофункциональных зданий. Vestnik MGSU vol.2, 14-22. Ejournal. 2010. (transl. Light-transparent facades for high-rise multifunctional buildings)
2. Achmyarov T.A., Spiridonov A.V., Shubin I.L. Энергоэффективные вентилируемые светопрозрачные ограждающие конструкции. Energy saving vol.1, 64-69. Ejournal. 2015. (transl. Energy efficient ventilated light-transparent enclosing structures)
3. Светопрозрачные конструкции и фасады. WWW document. http://rona34.ru/svetoprozrachnye-konstrukcii-i-fasady.html. Updated 15.10.2016. Referred 15.10.2016. (transl. Light-permitting structures and facades)
4. 10 недостатков панорамных окон. WWW document. http://panoteka.ru/17-nedostatki-panoramnyh-okon.html. No update information available. Reffered 02.10.2016. (transl. 10 disadvantages of floor-to-ceiling windows)
5. Alter, Lloyd. Can an all-glass office building really be considered green? WWW document. http://www.treehugger.com/sustainable-product-design/can-an-all-glass-office-building-really-be-considered-green.html. Updated 15.10.2016. Referred 15.10.2016.
6. Grynning, Steinar. Transparent facades in low energy office buildings. Thesis for the degree of Philosophiae Doctor. Norwegian Univercity of Science and Technology. 2015.
7. Светопрозрачные системы из стекла. WWW document. http://stab-group.com/ru/products/svitloprozori/svitloprozori-sistemi-zi-skla.html. (transl. Light-transparent systems made of glass) Updated 16.10.2016. Referred 16.10.2016.
8. SP 50.13330.2012. Thermal performance of the buildings. Ministry of Regional Development of Russian Federation.
9. SP 118.13330.2012. Public buildings and works. Ministry of Regional Development of Russian Federation.
10. SP 131.13330.2012. Building climatology. Ministry of Regional Development of Russian Federation.
11. “Тёплые” оконные алюминиевые конструкции. WWW document . http://www.wikipro.ru/index.php/"Теплые"_оконные_алюминиевые_конструкции.

(transl. “Warm” aluminium window constructions). Updated 20.10.2016. Referred 20.10.2016.

12. Стеклопакеты: k-стекла и i-стекла – в чем преимущества? WWW document. http://www.europlastproekt.by/vse-ob-oknah/poleznaya-informatsiya-ob-oknakh-pvkh/steklopakety-k-stekla-i-i-stekla-v-chem-preimucshestva.html. (transl. Multiple glazing: k-glass and i-glass – what are the advantages?) Updated 10.11.2016. Referred 10.11.2016.

13. GOST R 54858-2011. Translucent facade constructions. Method for determination of thermal transmittance resistance. Federal agency of technical regulation and metrology.

14. Shade: A hot climate design challenge for 21st century. WWW document. http://www.ecospecifier.com.au/knowledge-green/articles/shade-a-hot-climate-design-challenge-for-the-21st-century.html. Updated 06.01.2017. Referred 06.01.2017.

15.Lakhta Center. WWW document. http://lakhta.center/ru/about/hightech/facade/ Updated 08.01.2017. Referred 08.01.2017.

16. Открытая планировка офиса – за и против. WWW document. http://www.topdom.ru/articles/interior_design/otkrytaya_planirovka_ofisa_-_za_i_protiv.html. (transl. Open plan for offices – for and against). Updated 16.10.2016.. Referred 16.10.2016.

17. Livchak V.I. Why do office buildings overheat and what to do? AVOK vol. 7, 4-16. Ejournal. 2014.

18. Anichkhin A.G. Новое в системах отопления, вентиляции и тепловодоснабжения жилых, общественных и многофункциональных зданий в XXI веке. Vestnik MGSU, vol. 7, 32-38. Ejournal. 2011. (transl. New in heating, ventilation and water supply systems of residential, public and multifunctional buildings in XXI century)

19. Malyavina E.G. Heat losses of the building. Reference aid. AVOK-PRESS. 2007. WWW document. http://www.samteplo.ru/_snip/spteplo/spteplo.html. Updated 02.11.2016. Referred 02.11.2016.

20. Malyavina E.G., Polikarpova A.A. Heat shielding of office buildings with high surplus heats. Интернет-вестник ВолгГАСУ, vol.4, 1-9. Ejournal. 2011.

21. Smirnova I.N., Kravchuk Ivan, Syryh P. Yu., Shilkin N.V. Heating systems in high-rise buildings with large glazing area. AVOK vol.4, 30-40. Ejournal. 2013.

22. Radiant heating and cooling systems. AVOK vol.6, 38-50. Ejournal. 2003.

23. Конвекция и излучение при отоплении помещений. WWW document. http://verano-konwektor.ru/konvektsiya-i-izluchenie.html. (transl. Convection and radiantion for space heating). Updated 09.10.2016. Referred 09.10.16.
24. Заметки о лучистом отоплении. WWW document. http://waterinpanel.com/publ/zametki_o_luchistom_otoplenii/1-1-0-9. (transl. Notes of radiant heating). Updated 09.10.2016. Referred 09.10.16.
25. Виды и типы конвекторов отопления. WWW document. http://otoplenie-doma.org/vidy-i-tipy-konvektorov-otopleniya.html. (transl. Types of convectors). Updated 10.10.2016. Referred 10.10.16.
26. What’s more effective: convection or radiant heating? WWW document. http://www.newair.com/articles/convection-heating-vs-radiant-heating. Updated 10.10.2016. Referred 10.10.16.
27. Ernst, Tatiana. Излучение или конвекция? WWW document. http://www.ernst.kiev.ua/Strahlheizung_ru.html. (transl. Radiation or Convection?). Updated 10.10.2016. Referred 10.10.2016.
28. Теория лучистого отопления, водяные инфракрасные потолочные панели отопления. WWW document. http://waterinpanel.com/index/teorija_luchistogo_otoplenija/0-14.html. (transl. Radiant heating theory, water-based infrared ceiling heating panels). Updated 18.10.2016. Referred 18.10.2016.
29. Принцип действия лучистых панелей, водяные инфракрасные потолочные панели отопления. WWW document. http://waterinpanel.com/index/princip_dejstvija_luchistykh_panelej/0-15. (transl. Radiant panels’ work principle, water-based infrared ceiling heating panels). Updated 18.10.2016. Referred 18.10.2016.
30. Karel Kabele, Ondrej Hojer, Miroslav Kotrbaty and others. Energy efficient heating and ventilation of large halls. REHVA Guidebook. Finland. Forssa Print. 2011.
31. Olesen, B.W. Thermal comfort criteria in heating system design. AVOK, vol. 5, 4-10. Ejournal. 2009.
32. SP 60.13330.2012. Heating, ventilation and air conditioning. Ministry of Regional Development of Russian Federation.
33. Энергосберегающий стеклопакет. WWW document. http://www.spbokno.ru/plastikovie_okna/steklopaket/energosberegaushiy. (transl. Energy saving multiple glazing.). Referred 20.10.2016. Referred 20.10.2016.

34. Характеристики стеклопакетов. WWW document. http://okna-bm.ru/post_harakteristiki-steklopaketov.html. (transl. Characteristics of multiple glazing). Updated 21.10.2016. Referred 21.10.2016.
35. Uponor production in Russia. WWW document. http://uponor.pro. Updated 05.11.2016. Referred 05.11.2016.
36.Central Bank of Russia. WWW document. https://www.cbr.ru/. Updated 07.01.2017. Referred 07.01.2017.
37. In-floor convectors FMK. Price list from 01.02.2015. WWW document. пурмо.рф/images/PDF/purmo_aquilo_fmk_euro2015. Updated 01.02.2015. Referred 07.11.2016.
38. Heat output and prices of in-floor convectors. WWW document. http://itermic.ru/characteristics.jsp. Updated 07.11.2016. Referred 07.11.2016.
39. Zehnder Flatline. Radiant Cooling and Heating Ceiling Panel.
40. Kuvshinov U.Y., Baranov A.V., Shilkin N.V. AVOK Recommendations. Heating systems with suspended ceiling raiant panels. AVOK-PRESS. 2009.
41. Price list Zehnder Como, Flatline. WWW document. https://www.yumpu.com/en/document/view/25913888/rhc-price-list-2012-zehnder-como-flatline. Updated 10.11.2016. Referred 10.11.2016.
42.Danfoss products. WWW document. http://products.danfoss.com/. Updated 07.01.2017. Referred 07.01.2017.
43. TER 2001-18 SPb “Territorial unit costs of construction works in Saint-Petersburg. Collection 18. Heating – internal equipment”. Administration of Saint-Petersburg. 2001.
44. TER 2001-16 SPb “Territorial unit costs of construction works in Saint-Petersburg. Collection 16. Internal pipework”. Administration of Saint-Petersburg. 2001.

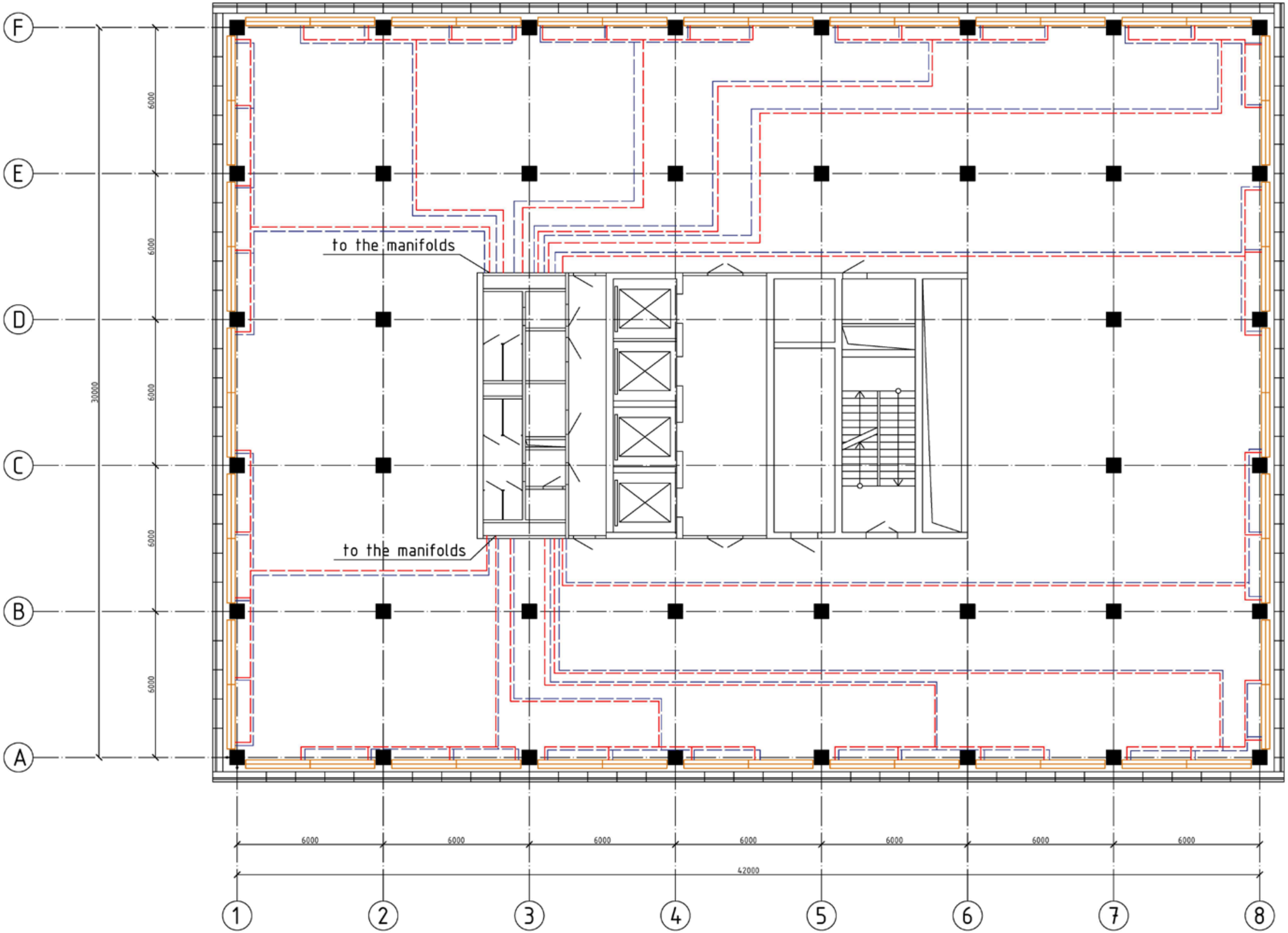
Appendix 1.

TABLE 1. Heat loss calculations

Room number	Room name and t_{in}, °C	Building envelope structures					Design temperature difference, (t_{in}-t_{out}), °C	Basic heat losses Q_0, W	Additional coefficient β		Coefficient (1+Σβ)	Heat losses through building envelope Q_{env}, W	Heat losses	
		Name	Orientation	Dimensions a·b, m	Area A, m²	Heat transfer coefficient K, W/m²·K			Orientation	Other			Infiltration Q_i, W	Total Q_{tot}, W
1	Office, 20	Transparent facade	N	42x3.9	163.8	1.29	44	9508.6	0.1	0.05	1.15	10691.9	6388.2	17080.1
		Transparent facade	E	30x3.9	117	1.29	44	6791.8	0.1	0.05	1.15	7637	4563	12200
		Transparent facade	S	42x3.9	163.8	1.29	44	9508.6	0	0.05	1.05	9762.1	6388.2	16150.3
		Transparent facade	W	30x3.9	117	1.29	44	6791.8	0.05	0.05	1.1	7305	4563	11868

Appendix 2.

Layout of the heating system with in-floor convectors



Appendix 3.

Layout of the heating system with radiant ceiling panels