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Electrical floor heating systems in China

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ABSTRACT

There is two parts' in my thesis.

First part is called magnetic field analysis of the electrical floor heating cables. I've been doing measurements and technical studies for two different kind of electrical floor heating cables, which are two wire cable and one wire cable. Measurements are made in AC-fields and the results are compared to different kind of electrical devises like TV, hair dryer, computer – appliances what are in every day use and works mainly with 230VAC/50Hz. Electrical floor heating cables are produced in ENSTO factory in Finland.

Second part is called electrical energy analysis of the electrical floor heating. It includes studies from different kind of electrical heating systems in China. Analyse of energy efficiency of heating systems. Energy analyses of two different kinds of control methods which are called smooth control and ON/OFF-control. In this part of the my thesis ON/OFF – control means a control what is done by switching floor heating system totally OFF from thermostat for several hours on daytime. Special energy storage systems are not handled in my thesis. The last area in second part of my thesis is to do an energy analysis when room temperature is increased by few degrees, results strait in RMB. From the results you can see what is the percentage difference and concrete raise of the heating bill. Practical measurements are made in Shenyang Jianzhu University's laboratory, China.

Keywords : Magnetic field analysis ; Electrical energy analysis ; Electrical floor heating systems

1. Magnetic field analysis

1.1. Background

1.1.1. What is electro magnetic radiation?

Electro magnetic radiation radiates electrical and magnetic pulses with speed of light. It is divided to two parts, ionic and anionic radiation. Ionic radiation for example x-ray is so powerful that it can detach electrons from the atoms. This is called ionisation. Anionic radiation, for example ultraviolet- and infrared radiation, also visible lights power is not that powerful so it can't detach electrons.

Anionic electro magnetic radiation of electrical installations is not usually called radiation, it is called electrical fields or electromagnetic fields because in 50 Hz it's length of one wave is very long (about 6000km) and energy of photon is 3.31 x 10^{-32}J (calculated with Planc´s constant and frequency) so it is remarkable small when you compare it to tied energy of molecules or their heat energy.

Near by electrical installations appear electrical- and magnetic field in cogency of all current carrying and voltage active conductors. In the vicinity, magnetic field of conductors doesn't invalidate each other totally.

1.1.2. Characteristics of magnetic field

Electrical floor heating cables are commonly used for heating apartments, shower rooms and public buildings. Heating is based on feeding electric current to heating cables placed to the concrete of the floor. Typically heating capacity of the cable is 200W – 2200W. Benefits of using electrical heating cables are smooth and easy controllability and good energy efficiency, floor can be used as a thermal energy storage, whole floor area is used for heating and heating solution is very reliable compared to for example water circulation floor heating systems. Electrical current creates magnetic fields what can be harmful for the environment. In this thesis we have studied the magnitude of the magnetic fields created by two different type of cabling solutions and compared those results to theoretical calculations.

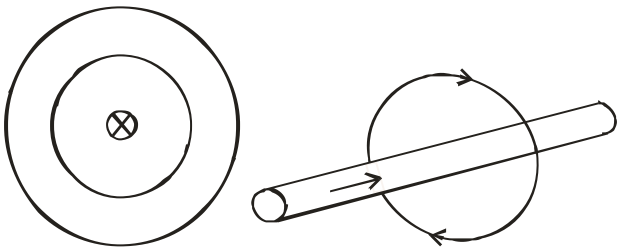


Image1- 1, magnetic field around conductor

Electric current causes magnetic field around it. Field strength can be calculated by using following equation if we assume that the cable is supposed to be infinite long.

$$H = \frac{N \cdot I}{2 \cdot p \cdot r} \qquad (1\text{-}1)$$

Where:

N = number of cable loops

I = current

r = distance to the cable

Magnetic field density can be calculated by using following equation

$$B = m_0 \cdot m_r \cdot H = m_0 \cdot m_r \cdot \frac{N \cdot I}{2 \cdot p \cdot r} \qquad (1\text{-}2)$$

Where:

m_0 = absolute permeability $(4p \cdot 10^{-7} H / m)$

m_r = intermediate relative permeability.

Density unit of magnetic field is Tesla (T). Magnetic affects to persons fabrics relative permeability m_r is almost 1, so biological material permeability is almost same than vacuum. ($m \approx m_0$). Because of this, when you take non-magnetic material to the magnetic field, the original field doesn't change just like in the case of electrical field. Electrical field's typical deformation effect doesn't occur.

Just ferromagnetic materials like iron, nickel and cobalt permeability is so different than vacuum permeability, so notable deformation effect occurs. Also magnetic field doesn't abate in the typical construction materials!

We can describe magnetic field by field lines. If there is 1000A current in a straight, infinite long conductor, the density of magnetic field is 200µT in distance of 1 meter.

When magnetic field is changing, it has ability to induce electric field to the intermediate agent. In conductive material, this electric field cause's movement in electric charge which is also called a current (A). Magnetic field of this current attempt to resist change's of external magnetic field. These induced currencies are called whirling currents. When this phenomenon occurs it's energy also cause's heat. Phenomenon is stronger when magnetic field's frequency is faster. In 50Hz frequency induced currencies to human body are very insignificant.

Magnetic field is strictly comparative to current of a conductor. Changes of load in the conductor causes also changes in the level of field near by the conductor relating to the time (IEEE, 1998). We have to think that magnetic field is time dependent statistic variable. Average field can not determine by the instantaneous measurement or calculations as reliable as in the case of electro magnetic field. On the other hand, phenomenon of deformation won't cause problems of definition of magnetic field, in the normal circumstances.

1.1.3. Magnetic fields strengths and what affects magnetic fields have?

Typically floor heating cable is either made by using single conductor cable or double conductor cable, see figures 1 and 3. Cable is typically installed that the:

- length of the cable is depending of the size of the heating area
- distance of cables are defined by the power of the heating system
- minimum distances has been defined by the manufacturer
- cable bending radius has certain minimum value
- cable has to be only in one layer, crossings are not allowed

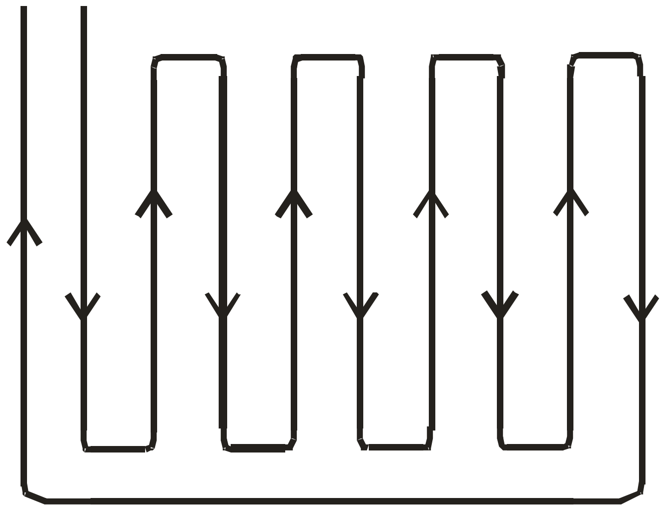


Image 1-2, floor heating cable with one conductor cable

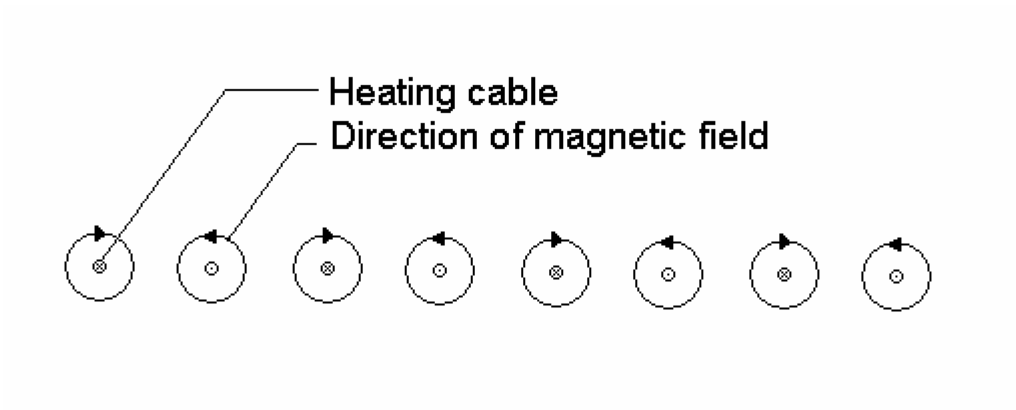


Figure1-3, magnetic field directions in one wire cable, picture is from the side

In single conductor cable the current flows through the whole cable in one direction.

Another option is to use a twin conductor cable, see image 3 below.

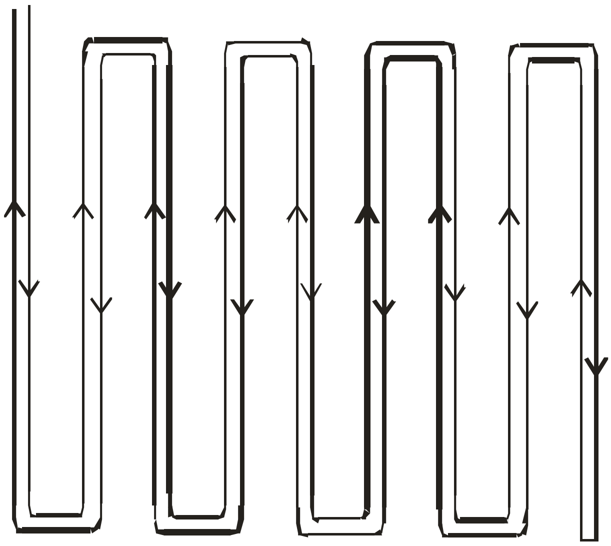


Image 1-4, floor heating cable with twin conductor cable

In this case the current flows forth and back in the cable because of its double conductor structure. This picture below you can see the structure of two conductor cable and how the magnetic field goes in the structure. Normally the magnetic field is not like that because those two magnetic fields abend each other and the summary of these two is status quo. So here I have just described two different fields.

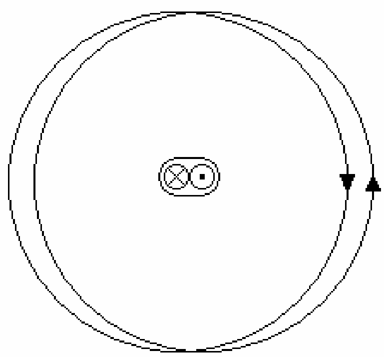


Image 1-5, magnetic field directions in twin wire cable

Floor heating is experienced to be very reliable heating method. Cable with good quality lasts for many decades without problems. Typically if there are problems with the heating system:

- 85 % of the failures are related to the connection of the cable and feeding line
- 10 % with the end connection of the cable
- 5 % with the cable itself

Electrical heating solution can bear mechanical damages much better than water pipes and water circulated floor heating systems. Also the energy efficiency of the electrical heating is better that other heating sources, because electricity is strait transformed to heat. (There is more in the chapter 2.1).

Here is some information about ENSTO conductor cable:

Twin conductor heating cables (TASSU) consist of either two resistive conductors or one resistive conductor and a return conductor. Both conductors are separate and individually insulated and polyester wrapping around the conductors increases durability and security of the cables also when bending. The power output of a heating cable is specified so that the insulation materials never get overheated, as stated in the IEC 800 standards.

1.1.4. Magnetic field measuring devices

Next I will tell you very shortly about measurement devises. There are many low frequency magnetic field measurement devices available on the markets, which are based on inductance, Hall-phenomenon or hysteresis. Devices what have different measurement phenomenon have all different kind of typical probes, demanding on phenomenon. Type of the probe in my meter what I used was Hall-type.

1.2. Research & Data

This part of my thesis, I have been testing two different kinds of magnetic field measurement devices and I have noticed that if you want to measure the magnetic field of electrical floor heating cable, you have to have very accurate meter. The most accurate devise what I had, was:

F.W. BELL, Hand-held gauss / tesla meter model 4048, Based on Hall-phenomenon and real root-mean-square value.

In fact and to our displeasure the smallest intensity of the device was 0.01mT. I did study different kind of research reports about what is the intensity of magnetic field in electrical floor heating cables and the results has been between 0.1µT – 3µT dependent the structure of the cable. Lowest values have been measured with the twin conductor heating cables and biggest values with the single conductor cables. All values are far below the limit values in Europe. (Check part 1.2 Conclusion for the recommendations.)

So I did do the measurements with my meter in the laboratory and because the smallest noticeable value for the meter was 0.01mT, the meter showed 0.00mT almost all the time. Exemption was in the ends of the loops, meter did give me value 0.01mT. But in this point, we can't know what is the magnitude of the background magnetic field. It would be very interesting to measure that with a more accurate meter. To see what is the actual magnitude and the direction where magnetic field affect, and draw a 3-D – model of magnetic field around the cables.

There is table on the page 37 what shows the electro magnetic radiation from different electrical household devices, I've been collecting there just normal devices what are normally used in every day life.

1.2.1. Theoretical examples

I did measure the resistance of the cable in the heating laboratory. It was 25.7O and voltage was 220V. From these values we can calculate easily the heating power of the cable because it is very near by constant. Formula is of course the basic formula, Ohm's Law. Result, $P = U^2 / R = 1883W$. Of course we have to keep in our minds that voltage changes some percents from a power output, actually next day I did measure 231V.

Theoretical example 1

Next I would like to show how to calculate theoretically magnetic field of the cable. We use the formula number 2.

$$B = m_0 \cdot m_r \cdot H = m_0 \cdot m_r \cdot \frac{N \cdot I}{2 \cdot p \cdot r}$$

The values what we have to use are:

$m_0 = (4p \cdot 10^{-7} H / m)$

$m_r = 1$

N = 1, because of the structure of floor heating cable

I = 1883 W / 220 V = 5.56 A

r = 0.1m

$$B = m_0 \cdot m_r \cdot H = 4p \cdot 10^{-7} H / m \cdot 1 \cdot \frac{1 \cdot 5.56A}{2 \cdot p \cdot 0.1m}$$
$$= 111.2 \cdot 10^{-7} T$$
$$= 11.12 \cdot 10^{-6} T$$
$$= 11.12 mT$$

But this is just a theoretical calculation for the one loop, because of the structure of the cable, the magnetic field from the other loops affects to this results also. With a simple calculation you can see that the magnetic field abates down directly proportional to the measurement distance. For example 1m away from the cable, magnetic field should be 1.1µT.

Theoretical example 2

Also second example just to show you the values of different kind of radiuses and amperes in the infinite long conductor where is 1000A. I did use the same formulas than example 1. In the radius of 1m the magnetic field is 200µT, which is already 2 times more that ICNIRP (International Commission of Non-Ionizing Radiation Protection) recommends. But 1000 Amperes in the house hold is very ignorant and uncertain.

1.3. Conclusion

As a conclusion of the measurement results of other sources we can state that the magnetic field level of the heating cable is 10 – 100 times smaller compared to for example to PC-power source or ventilation fan. The magnetic field of single conductor cable is 10 - 30 times higher than the fields of twin conductor cable. But in both cases the field level is 0.1 – 0.2 µT for twin conductor cable and 2 – 3 µT for single conductor cable. In my case we can not know what is the intensity of the background magnetic field in the university’s heating laboratory. But I can state that the magnetic field of the twin conductor cable in the heating laboratory is 0.01mT or under, which is more than 10 times bellow ICNIRP recommendations.

There has been lot’s of conversations about health risks of electrical and magnetic fields. European Union (EU) recommends that 0 Hz – 300GHz electromagnetic fields can be maximum 100µT for being exposed to humans and 500µT for a short time. Basis of this regulation comes from ICNIRP.

Next chart shows you the difference between these two heating cables.

Table 1-1, Comparison of different cables

1-wire cable	2-wire cable
Magnetic field around 2 - 3µT.	Magnetic field around 0.1 – 0.2 µT.
Electricity flows just one way in the cable, which increases the magnitude of magnetic field.	Electricity flow forth and back in the same cable, this decreases the magnitude of magnetic field.
Have to take both cable ends back to room thermostat.	Little bit more easily to install than 1-wire cable because of its ending.
Is little bit more flexible	Not so flexible than 1-wire cable.

2. Energy analysis of electrical heating

2.1. Background

When we think about electrical heating, electricity is transformed to heat in the electric resistance. Because electricity is produced from the heat, it is usually more expensive per energy unit than heat what is produced straight from propellant. Also energy distribution lines are expensive and it raises the price of electricity. Electrical heaters, especially straight electric heaters are cheaper than other heating devices what use different energy source. They are cheaper because the structure of the heater is simpler and the way of transforming the electricity to the heat in the resistance is very simple.

For example in the water circulated floor heating system the water is firstly heated up in the boiler, then the distribution pipes gives heat also there where we don't want it, this means that the energy efficiency is worse than electrical floor heating systems. Water circulation heating has also high-risk, it can be broken under the floor, binding between the boiler and pipe can leak. The valves can leak. These kinds of problems are very expensive to repair if the leak is rather big, because of the water inside the building structures, sometimes the whole floor structure has to be changed.

Straight electric heating uses electricity just that amount what is needed in the destination. Easy and quick controlling is one of the best characters of electrical heating. Heat flow from the system to the room will stop very quickly when heat load in the room raises the temperature, for example sun starts shine to the room or group of people comes to the room. These examples are under the control of the room thermostat. This just means energy saving and very comfortable temperature for living. Other hand, if the electric heater is enough powerful, it can give enough heat to the room when exp. outside temperature goes very low and fast.

There is lot’s of different kind of electrical heating devices on the markets. Here are some examples:

- electrical floor heating
- electrical ceiling heating, in the shape of foil
- closed electrical radiator
- open electrical radiator
- combination of open and closed electrical radiator
- heating lamps
- infrared-heaters
- electric windows
- heat pumps which includes ground heat, water heat and air heat
- Electrical heat exchanger in the air condition system

Also we have to think that almost every room has other heat sources like electrical devices (illumination, computers, ovens and so on), human body gives normally more that 100W and sunshine thru the window is quite effective heat source. When sunshine goes thru the window, it has a very short wave length and that is why it goes very effectively thru the window. Part of these rays absorbs to the structures inside the room and in the same moment the wave length changes to longer when the ray bounces from surface. These rays mostly can’t go thru the window anymore. This is the explanation why the sunshine is quite powerful heat source; also its irradiance is rather powerful.

2.1.1. Control

When the control is done room by room, then control is usually done by room thermostat. Thermostat should be installed to the place what is very stable for heat- and air flows and doesn’t have harmful affect to place the furniture’s. Such place as next to ventilation fan or next to outer door is not possible. Good mounting height would be around 1.4 meters. Also if thermostat is installed to outer wall where is not enough good insulation, it affects to controllability.

2.1.2. Basic formulas

Heat is transferred basically in 3 different ways. There is an explanation for the each way and also the basic formulas for heat transmission.

Here are the basic formulas for conduction, what basically means how much heat energy is transferred thru a structure.

$$\Phi = +lA\frac{T_1 - T_2}{s} \qquad (3)$$

Where:

Φ = heat flow thru a structure [W]

l = thermal conductivity [W/mºC]

s = thickness of a structure [m]

T_1 = inside temperature [ºC]

T_2 = outside temperature [ºC]

A = area [m²]

This is usable when we observe one structure as a whole structural element.

And then if you have different layers in the structure you can derive the formula to look like this:

$$\Phi = A\frac{T_1 - T_4}{\frac{s_a}{l_a} + \frac{s_b}{l_b} + \frac{s_c}{l_c}} \qquad (2\text{-}1)$$

Where in addition:

$s_a ... s_c$ = thickness of the different layers [m]

$l_a ... l_c$ = different layers thermal conductivity [W/mºC]

T_4 = outside temperature [ºC]

Next image shows the heat flow thru the structure where is 3 different layers, Concrete wall, insulation and outer wall. Arrow shows the direction of the heat flow when outside temperature is lower than inside temperature.

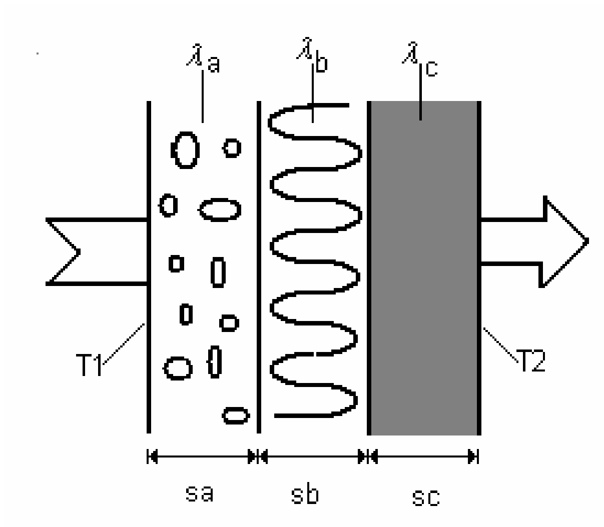


Image2-1, Heat flow thru the structure where is different material layers

I would like to show also the basic formula to the convection. Formula of the convection can be used in the case where air flow is natural or forced.

Convection is heat flow near by the surface; it can happen in gas or liquid. When we have solid surface and straight next to the surface is gas or liquid and these two has different temperature, then there is heat flow to surface or from surface, this is called convection. If the vertical flow near by the surface happens just because of the temperature difference, phenomenon is called natural convection. If the flow is done by other external force (for example fan of wind), it is called forced convection. Direction of natural convection is vertical; either up or down, but forced convection can be also in different directions; 2 dimensional direction on the surface. Convectional heat transmission is described usually by experimental heat transmission factor. It is defined by following formula:

$$\Phi = aA(T_1 - T_2) \quad (2\text{-}2)$$

Where:

Φ = heat flow from/to a structure [W]

a = heat transmission factor

A = area [m²]

T_1 = warmer (room) temperature [ºC]

T_2 = colder (surface) temperature [ºC]

Now I have demonstrated two basic formulas for heat transmission models. Because there are totally 3 different cases how heat is transferred, so I would like to tell basics of the last one. Of course the phenomenon is called thermal radiation. Here is very short explanation of thermal radiation:

Thermal radiation is electro magnetic radiation, every item emits it just because of those has a different temperatures. This radiation radiates to ambient and when it hits to the other item, the part of it will absorb to the material. Irradiance of the actual surfaces M is smaller than the black surface. This part is described by the emissivity of the surface e. Remember to use temperature as an absolute temperature in Kelvin scale.

$$M = eM_m = e\,sT^4 \quad (2\text{-}3)$$

Where:

M = irradiance

M_m = irradiance of black item

s = Stefan-Boltzman's constant, $5.67 \cdot 10^{-8}$ W/m^{2}K

T = absolute temperature of the item (K)

2.1.3. Formulas of the thermal dissipation

Most important part of thermal dissipation in the building is the shell of the building (walls, roof, base floor, windows and doors). Thermal loss thru the different structures can be calculated with the following formula:

$$\Phi = k_i \cdot A_i \cdot \Delta T_i \qquad (2\text{-}4)$$

Where:

Φ = heat flow thru a structure [W]

k_i = thermal coefficient of transmission [W/m^{2}ºC]

A_i = area of a structure [m^2]

ΔT_i = temperature difference between different sides [ºC]

This k_i can be calculated from wall heat resistance M:

$$k = \frac{1}{M} \qquad (2\text{-}5)$$

In the next formula, the thermal resistance includes surface resistances of the structure and material layer resistances.

$$M = m_i + \frac{s_1}{l_1} + \frac{s_2}{l_2} + ... + \frac{s_n}{l_n} + m_o \qquad (2\text{-}6)$$

Where:

m_i = surface resistance of the inside-wall

m_o = surface resistance or the outside-wall

s_1, s_2 = thickness of the layer

l_1, l_2 = layer heat conductivity

Previous formula is usable when whole wall layers are homogenous. Usually there is different kind of parts inside the structure; witch all has different heat conductivities and witch also makes it non-homogeneous. This makes calculations little bit more difficult. You just have to think about the area of different layers inside the wall and its heat conductivity. To simplify this more it's good to think one layer of the wall structure as a area, but you have to divide this are in 2 or more different areas what all has a different thermal conductivity. Then you add that to the calculations. I think that in this thesis this knowledge about the heat transmission is enough to make simple heat dissipation calculations.

2.2. Research & Data

2.2.1. Room details

Room was normal room in the teaching area of the university. Area was 5.84m x 3.86m and height was 3.70m. So total area was 22.54m² and volume was 83.41m³. Outside window was 2.20m x 3.46m + small window above the door to the corridor was 0.90m x 0.42m. Big window construction was two layers and all windows were sliding type witch are not very energy efficient and by the way, those are almost impossible to clean properly. All walls were concrete except one on the long wall was plasterboard with styrox insulation. Door to the corridor was 1.95m x 0.90m. Door was in the corner of the room and because heating system was constructed afterwards, the heating area was not all floor area. In the corner where door was, there was area of 1.50m x 0.96m without heating cables. Therefore total heating area was 21.10m².

Heating cable in the heating laboratory was ENSTO 1800W twin wire cable and therefore the average heating power was 104.3W/m² or when you consider the whole room area it was 97.6W/m².

Next values for the heating cable are taken from ENSTO brochure. Here are described just 2 different cables and these values are recommendations for the installation:

Table 2-1, statistics of two different heating cables

Cable model and heating power	1800W	2200W
Suitable heating area	12 – 20 m^2	15 – 25 m^2
Heating power per square meter	80 – 150 W/m^2	80 – 150 W/m^2
Length of the cable	86 m	106 m
Resistance of the cable	29 O	24 O

Next image shows the room's layout with the heating cable.

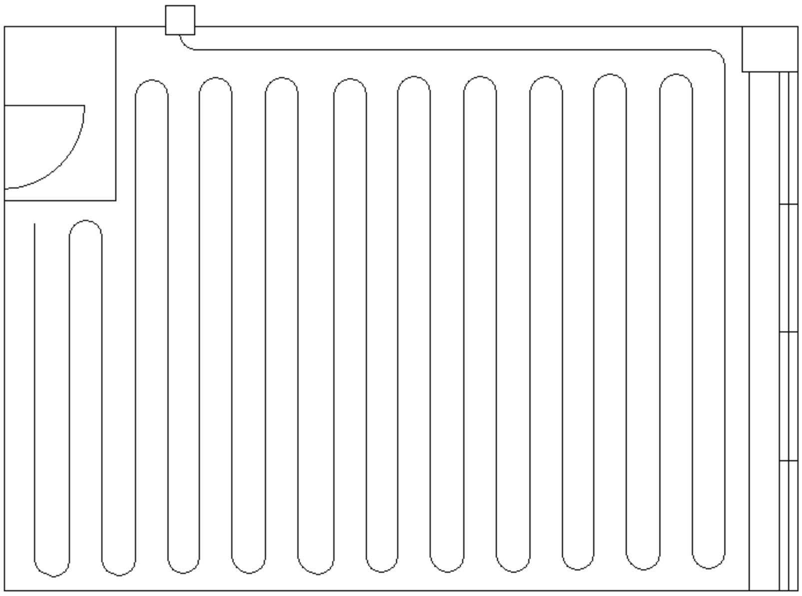


Image 2-2, General layout drawing of the heating laboratory and the heating cable

2.2.2. Floor details

The heating system was constructed afterwards on the normal stone floor. Here are layers downwards from the surface of the concrete:

- 2cm concrete
- heating cable (installed with cable ties to the metal mesh)
- metal mesh

- 2cm concrete
- aluminium foil
- 2cm insulation

Surface of the floor was just uncoated concrete, so the temperature flow behaves differently than normal floor where is normal coating. It gives the heat energy to the room much more quickly than coated floor. So the temperature control of the room was also much quicker than normal coated floor.

2.2.3. Experiments

I did do research work in the periods of 24 hours. Starting from 8:00 o'clock at morning and stop at 8:00 next morning. There were 3 main experiments:

- Keeping room temperature in 18ºC
- Keeping room temperature in 20ºC
- Keeping room temperature in 18ºC but I switched of heating period of 8:00 – 17:00

Then I was comparing total energy consumption in different temperatures and different control methods. Here is an example for heating the room normally, these 2 pictures below are just a sketches, take a look how many times and how long time heating is on:

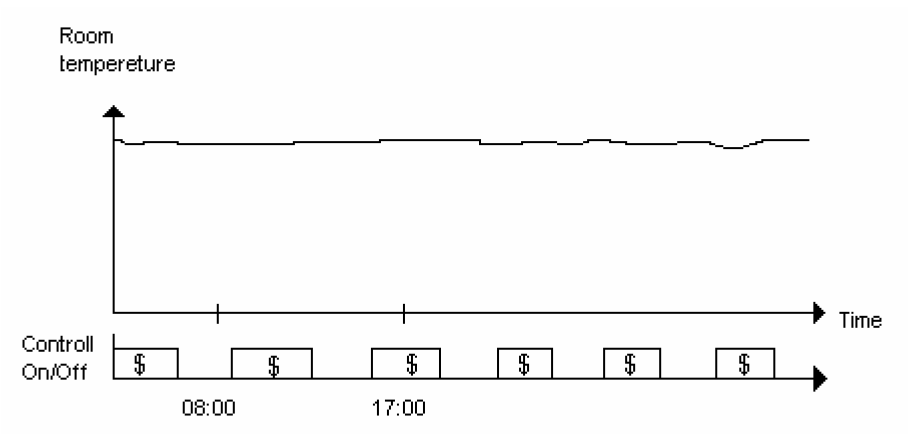


Figure 2-1, Normal control method

And here is example picture where heating system is turned OFF from the room thermostat from 8:00 – 17:00, take a look how long time the system have to heat the room continuously when it is turned on again:

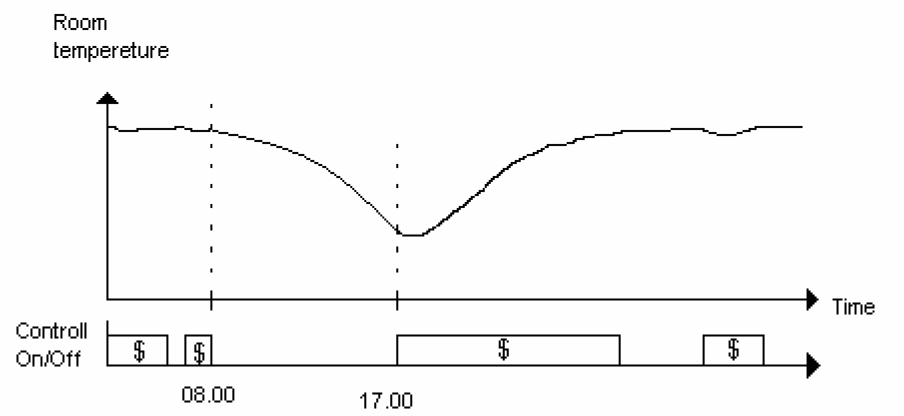


Figure 2-2, ON – OFF – ON – Control method

Now the situation is following, people might think that switching OFF the heating system over working hours, saves lots of energy and money. Witch is several hours during the daytime. After doing this they come back to home and switch on the heating system. They also have to wait several hours to get comfortable living conditions and good inner air temperature. Do people think about that period what is after switching ON the system? Thermostat controls the system and keeps it heating up the room for a long time, when the other hand if you keep room temperature under control of thermostat, you don't have to feel cold when you came back from daily routines.

Here is an example that what kind of results I had from heating room. I could ask from the program that what is different channels average temperatures and what time the heating was switched ON or OFF. In this diagram average temperatures were:

- outside was -6.77ºC
- floor surface was 23.7ºC
- inside 18.20ºC

Inside temperature was measured from altitude of 1.40m, outside temperature 2cm away from outer wall and floor surface temperature is approximated average of all 12 sensors what I had on the floor.

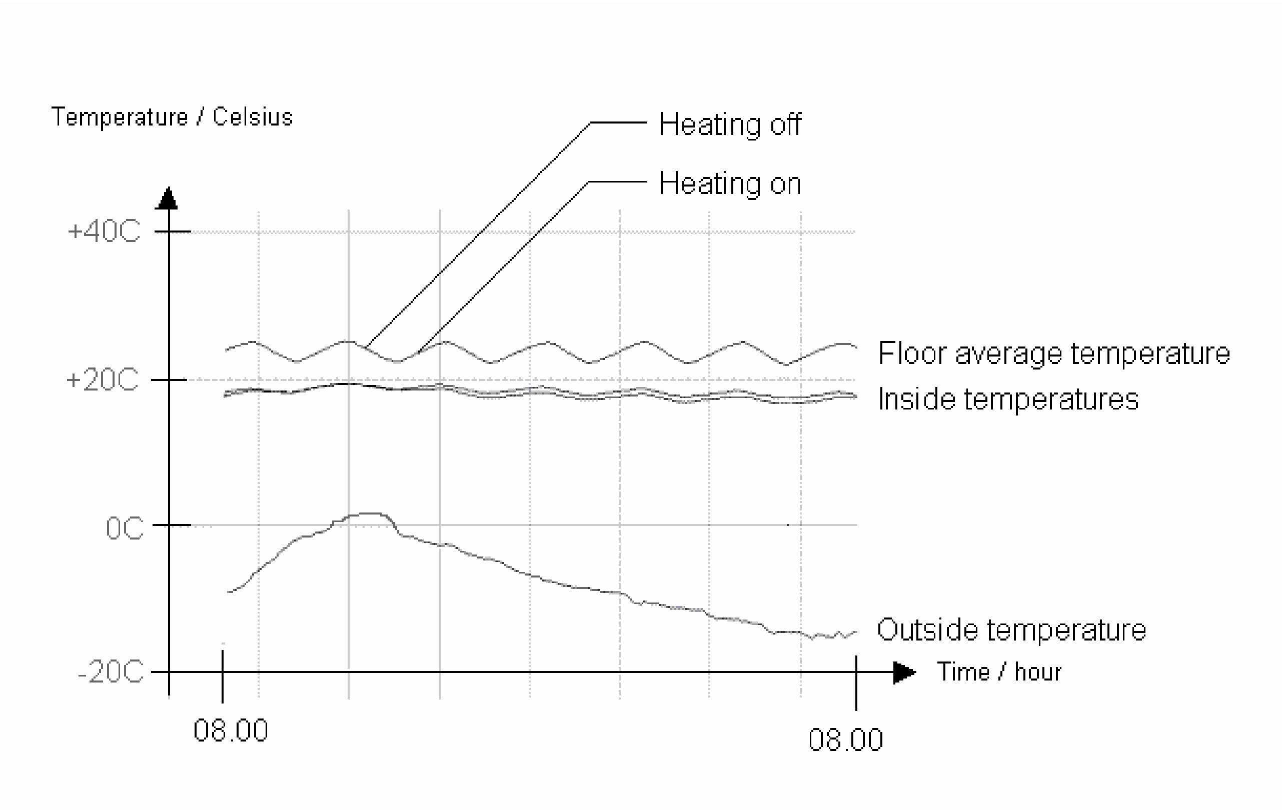


Figure 2-3, Example from temperatures in heating room

Next diagrams show how the inside temperatures react in different outside temperature conditions. My Professor asked me to add these pictures to my thesis, they look a little bit same but mainly the difference is how different outside temperatures affects the inside temperature. Next photos are almost straight screenshots from the analyzing program:

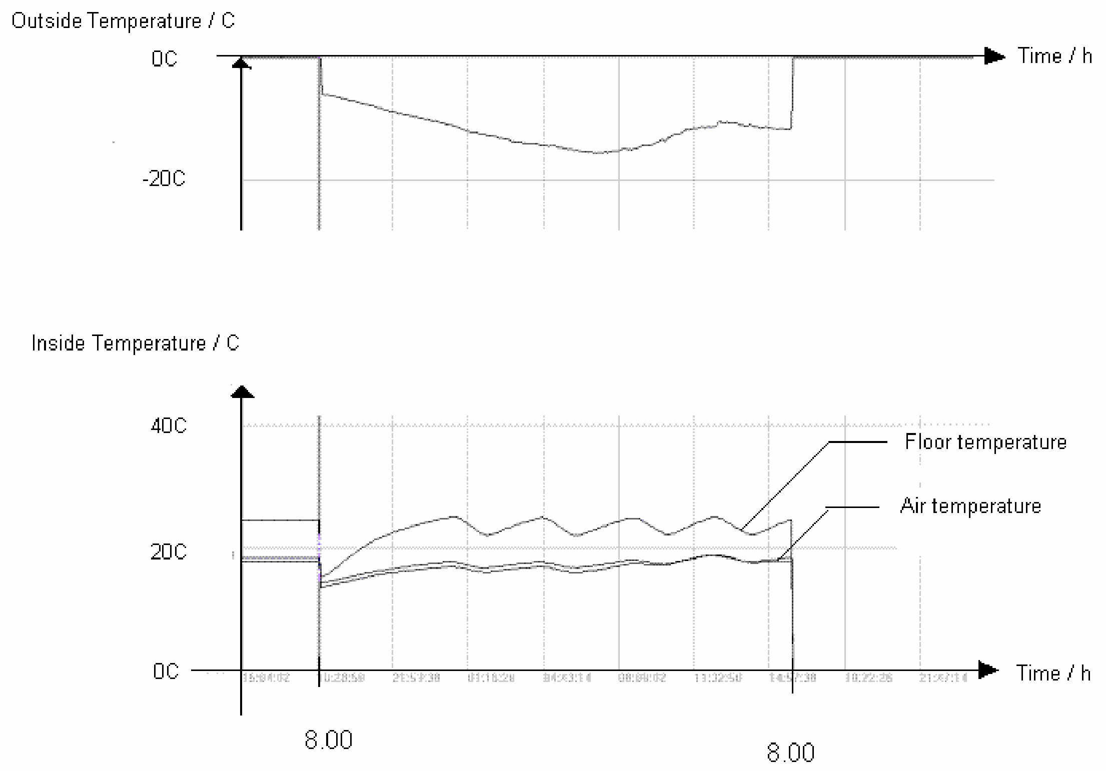


Figure 2-4, Example from temperatures in heating room

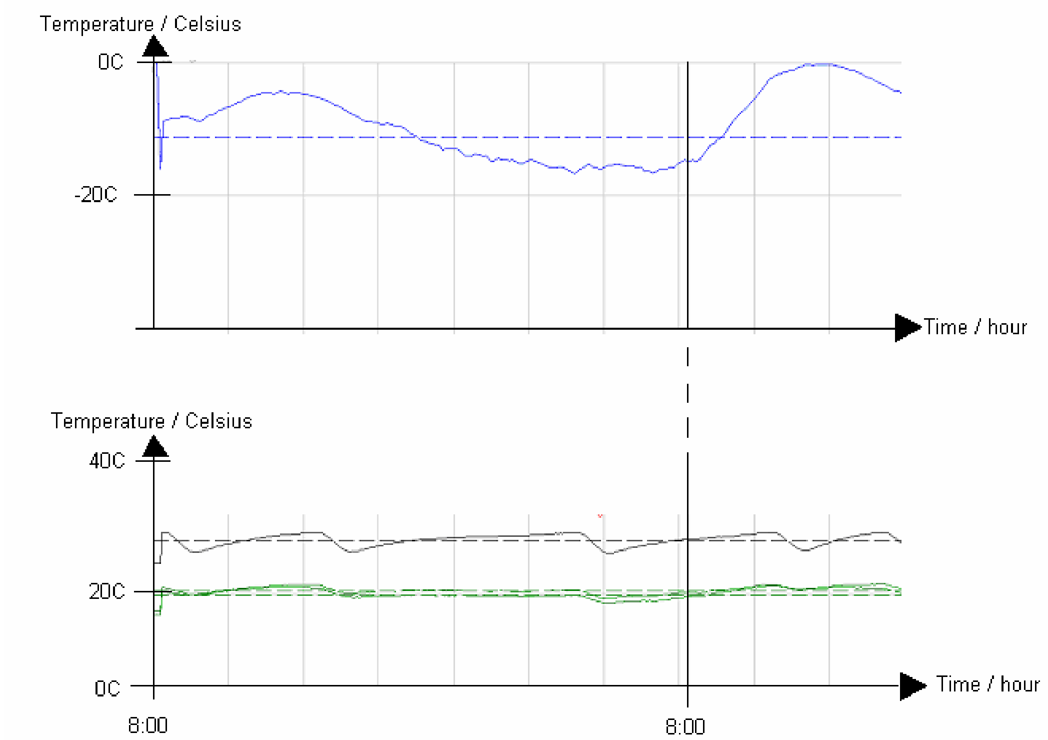


Figure 2-5, Example from temperatures in heating room

In next diagram is also a heat flow thru the outer wall, you can read these heat flow values from right hand side axis.

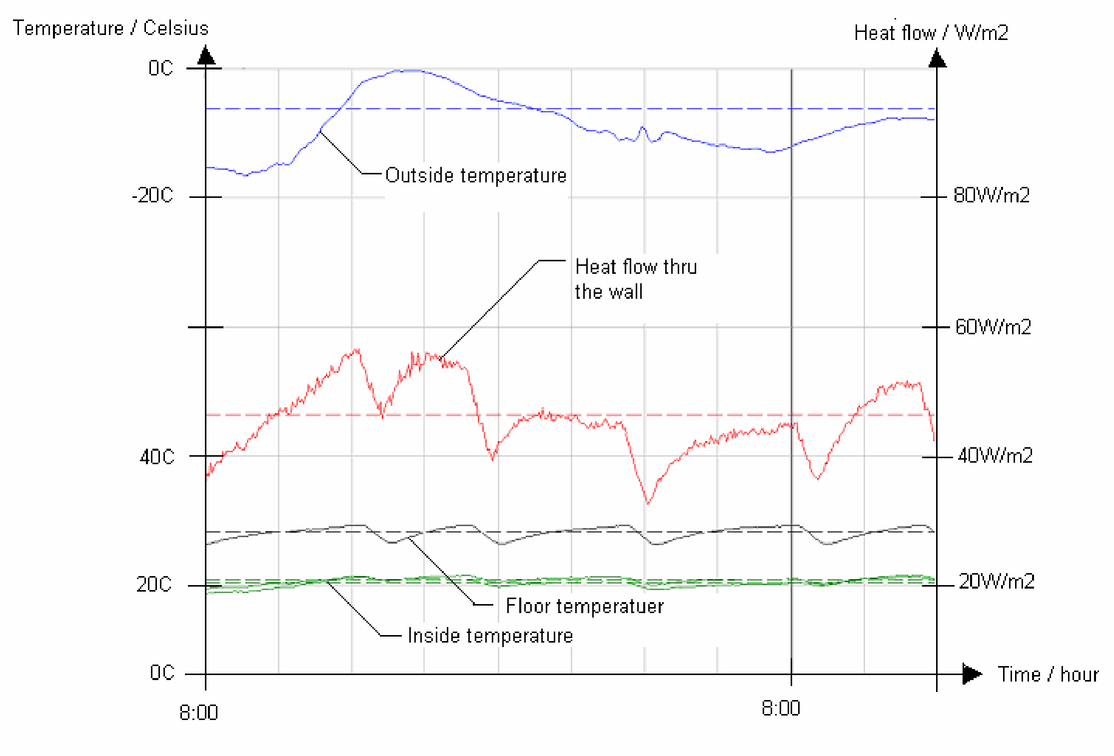


Figure 2-6, Example from temperatures in heating room + heat flow thru the outer wall

Next diagram shows how the temperature reacts in function of height in the room. Ventilation system was turned of, so the biggest external air flows were the natural convection on the window surface and as we all know that the warm air rises up from the heated floor surface. Take a look how high the warm floor temperature affects. In altitude of 0.6m – 0.9m the floor temperature abates to the room temperature. The 3500mm value is taken from the surface of the ceiling, that's the reason why it's so low. This temperature comes from outside temperature because the outside temperature was quite low. Thermal conductivity of the concrete is rather poor, so the surface temperature of the concrete in the ceiling abates in the ceiling concrete. Values are taken in the center of the room; witch is about 3meters from the outside wall.

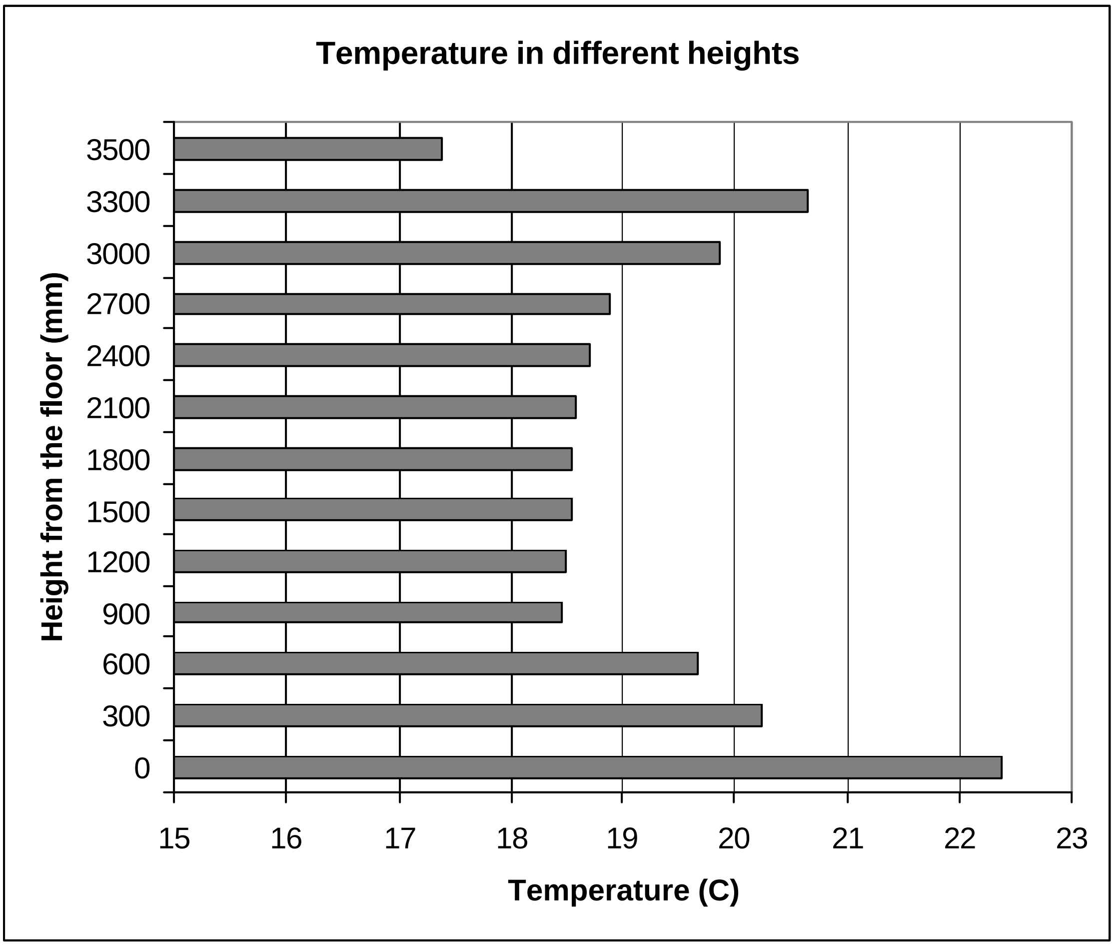


Figure 2-7, Example from vertical temperatures in the heating room

The computer also gave us numerical information from different channels. First we didn't know how to use the graphical diagrams so we used these. But from these tables we couldn't get any information about the average temperatures or minimum- / maximum temperatures. Then later on I solved the problem to use the programs and get the diagrams. It was quite hard because the whole program was in Chinese language. I could say that it was something like a shooting in the dark. Here is a screen print from the program:

Image2-8, Example from temperatures in heating room

I had too often problems with the measurement devise from the unknown reason, some channels showed just 0 degrees whole observation period. If this happened in the certain channels then the whole measurement was useless. For example when I couldn't take the outside temperature, the measurement was almost useless.

2.2.4. Calculations

I did use W/m^2 - sensors in the laboratory. Here are the calculations and the heat coefficients from the heating laboratory.

I did make a simple excel table where was just a measurements of different structures, the values from sensors and outside- and inside temperatures. I had also a temperature sensor on the surface of window. I did take calculations with different inside temperatures and outside temperatures. And also the value of heat flow thru the structure in that same time. In next table I've been using the basic formulas what I did show you before. Here is the table what I did make:

Table2- 3, Calculation table for the wall and the window

Structure area, m^2			
Out wall	5,79		
Window	7,61		
Total	13,40		
Temperatures			
outside	-8,80	-12	-19
inside	21,40	20,6	16,4
difference	30,20	32,60	35,40
W / m^2			
window	107,00	120	134,1
wall	45,00	53	46,4
Watts thru the structure			
window	814,27	913,20	1020,50
wall	260,55	306,87	268,66
total	1074,82	1220,07	1289,16
W / m^2ºC			
ikkuna	3,54	3,68	3,79
wall	1,49	1,63	1,31
total	2,66	2,79	2,72
Average values thru the structure			
ikkuna	3,67		
wall	1,48		
total	2,72		

Values for the window were between 3.54…3.79 W/m^2ºC and the wall 1.31…1.63 W/m^2ºC. Average values for these two structures were 3.67 W/m^2ºC for the window and 1.48 W/m^2ºC for the wall. I use factor **k** for these W/m^2ºC values .In fact this is little bit less when you pay attention to the resistance of heat transmission factor of the surfaces. For example outside wall value would be 0.07 m^2ºC/W and same value for the inside surface 0.13 m^2ºC/W. Here is exact explanation for the wall with these heat transmission factors.

Take the inverse value of the heat coefficient of transmission and add these values to it. Then take again inverse value and the result is for the wall 1.14 W/m^2ºC. With this method the value changes a little bit better. Exactly 23% better.

If we take these values, we can calculate the thickness of the insulation inside the wall structure. I assume that there is 2 times 15cm concrete wall and between these structures is insulation. I also assume that insulation material is glass wool which thermal conductivity is 0.04 W/mºC and concrete wall is 0.15 W/mºC. Now we can use factor k to calculate the heat resistance of the wall. We call this heat resistance as an M-value. It is just an inverse value from k-value, as formula 5 shows. Because the total heat resistance of the wall, M is sum of the part values. M = $m_a + m_b + m_c$…

$$M = \frac{1}{k}$$

Then the total M value for the wall is inverse value from 1.14 W/m^{2}ºC which is 0.877 m^{2}ºC/W and when:

$$M = m_a + m_b ... \text{ and } m_a = \frac{s_a}{la} ...$$

And because we have 2 concrete walls we can just multiply the m_a by 2. So the final formula is like this:

$$M = 2m_a + m_b \qquad | \; m_x = \frac{s_x}{l_x} ...$$

$$M = 2\frac{s_a}{l_a} + \frac{s_b}{l_b}$$

$$s_b = l_b M - l_b 2\frac{s_a}{l_a}$$

Where:

l_b = thermal conductivity of the glass wool, 0.04 W/mºC

M = thermal resistance of the wall, 0.877 m^{2}ºC/W

s_a = thickness of the concrete, one layer, 0.1m

l_a = thermal conductivity of the concrete, 0.15 W/mºC

The result of this formula is actually -0.018m which is just -1.8cm if the concrete is 2 x 0,10m and the thermal conductivity are 0.15 W/mºC and 0.04 W/mºC. So the heat flow just thru the 20cm concrete is better that the whole wall structure.

If we take totally 10cm concrete wall + insulation the result for the insulation is just 8.4cm.

Of course we have to think about the sensor on the wall, it gives values but what kind of tolerance of those values what the sensor gives. There is conventional heat dissipation to the wall and it affects some way to the sensor.

Calculations when room temperature is changed few degrees

Next I did calculate the difference when room temperature is changed by 2 degrees. I did make these calculations just thru the outer wall and - window. This is the reason because I can't know what is the heat loss thru the other structures. Mainly the heat flow out from the room is thru the outer window and outer wall.

Here is an example for heating times, temperatures…

- Set temperature 18ºC
- Inside average temperature 18,20ºC
- Outside average temperature -10,20ºC
- Heating time 24h
- Where heating was on 12h 50min, 53,5%
- Energy usage was 24,49kWh / 24h

So the window area was 7,61m^2 and outer wall was 5,79m^2. Average values for these two structures were 3.67 W/m^{2}ºC for the window and 1.48 W/m^{2}ºC for the wall. Temperature difference was 28.40ºC. So energy usage, calculated with the formula 7 thru this outer wall and window is:

$$
\begin{aligned}
\Phi &= k_{wa} \cdot A_{wa} \cdot \Delta T + k_{wi} \cdot A_{wi} \cdot \Delta T \\
&= \Delta T \cdot (k_{wa} \cdot A_{wa} + k_{wi} \cdot A_{wi}) \\
&= 28{,}40^{\circ}\mathrm{C} \cdot (1{,}48\mathrm{W/m2^{\circ}C} \cdot 5{,}79\mathrm{m}^2 + 3{,}67\mathrm{W/m2^{\circ}C} \cdot 7{,}61\mathrm{m}^2) \\
&= 1036W
\end{aligned}
$$

This value seems to be quite accurate for the room's energy consumption. Because when I compare the percentage heating time (when the thermostat feeds electricity to the cable) witch is 53.5% of 24hours and the power of the heating cable. Measured power of the cable was 1883W and if I take that 53.5% from the measured power, it is 1007W. So this proofs that almost all the energy goes out thru this outer window and outer wall.

When I increase this inside temperature by 2 degrees, the theoretical heat consumption would be like this:

$$
\begin{aligned}
\Phi &= (\Delta T + 2^{\circ}\mathrm{C}) \cdot (k_{wa} \cdot A_{wa} + k_{wi} \cdot A_{wi}) \\
&= (28{,}40^{\circ}\mathrm{C} + 2^{\circ}\mathrm{C}) \cdot (1{,}48\mathrm{W/m2^{\circ}C} \cdot 5{,}79\mathrm{m}^2 + 3{,}67\mathrm{W/m2^{\circ}C} \cdot 7{,}61\mathrm{m}^2) \\
&= 1110W
\end{aligned}
$$

So there is 7.1% difference between these values.

So if we think this in real life, with the most common value for the people, money. In China, Liaoning province, Shenyang – the energy price for the kilowatt-hour is around:

- 0.45 RMB on day time (05:00 – 20.00)
- 0.20 RMB on night time (20:00 – 05:00)

The night time energy is 9 hours and day time 15 hours. Next I assume that the energy usage is same on night time and day time, normally at night the outside temperature is lower and the energy consumption is higher. So the results of these calculations are a bit more than in normal situation. Next formula gives cost of 24 hours when outside temperature is -18.

$$RMB = 1{,}036kW \cdot (15h \cdot 0{,}45RMB / kWh + 9h \cdot 0{,}20RMB / kWh) / day$$
$$= 8{,}86RMB / day$$

And with the higher temperature it will cost:

$$RMB = 1{,}110kW \cdot (15h \cdot 0{,}45RMB / kWh + 9h \cdot 0{,}20RMB / kWh) / day$$
$$= 9{,}49RMB / day$$

Here is some calculations and something about the glazing:

If we take 3 layers – window, the heat transmission of coefficient value should be around 2.44 W/m^{2}ºC, when we compare it to 2 layer window what we had in the heating room. That means around 30% savings in energy consumption thru the window. Just for example if the outside temperature is -8.8ºC, inside temperature is 20.4 the heat flow thru the window is 107 W/m^2 and that mean 3.54 W/m^{2}ºC. Next table shows the difference between 2 and 3 glazing windows and also dependence of distance between glasses.

Table 2-4, window heat transmission of coefficient

distance between glasses	2 layers (W / m^2 ºC)	3 layers (W / m^2 ºC)
4	3,90	2,79
6	3,55	2,44
8	3,37	2,27
10	3,26	2,15
12	3,14	2,09
14	3,08	2,04
20	3,02	1,90

So if we take 3 window-glazing the whole energy consumption is 30% lower than 2 window glazing. In one month it means over 80 RMB savings.

2.3. Conclusion

Electrical floor heating system is very reliable heating method, it have lot's of good sides, but the only minus would be price of electricity. Especially in China electricity is rather expensive. This heating method is very considerable when municipal heat is not available, for example in country sides.

I hope that nowadays people would think more about the control method of their heating systems. What it the price of good living circumstances, how to control the system and what does it cost.

I know that people use rather much coal heating in China, that heating method gives pollution to the nature, also usage of electricity gives if it's produced with wrong way, for example coal power plant.

Next I did list just some good hints what would be good to have in mind when people are designing or renovating their estates.

- good insulation, exact and enough thick material
- try to minimize cold bridges in the structures
- 3 layer windows
- collect energy from the outgoing air
- correct control method with room thermostat
- use as much as possible free heating solutions for example sunshine (solar panels and straight radiation thru the window)
- use energy when it is cheap (night electricity), to storage it to mass collectors (concrete coated floor, insulated water boiler, etc).

3. References

Table3-1, references

Leena Korpinen	Kauppa- ja teollisuusministeriön tutkimuksia ja raportteja 9/2000	Laitteiden ja elinympäristöjen sähkö- ja magneettikenttien mittaaminen
Olli Seppänen Matti Seppänen	Sisäilmayhdistys	Rakennusten sisäilmasto ja LVI-tekniikka
D5	taustaraportti Versio 1.8	Rakennusten energiankulutuksen laskentaohje
ENSTO OY	www.ensto.com	

Examples of different kind of devices and magnetic fields, measuring distance is 25cm.

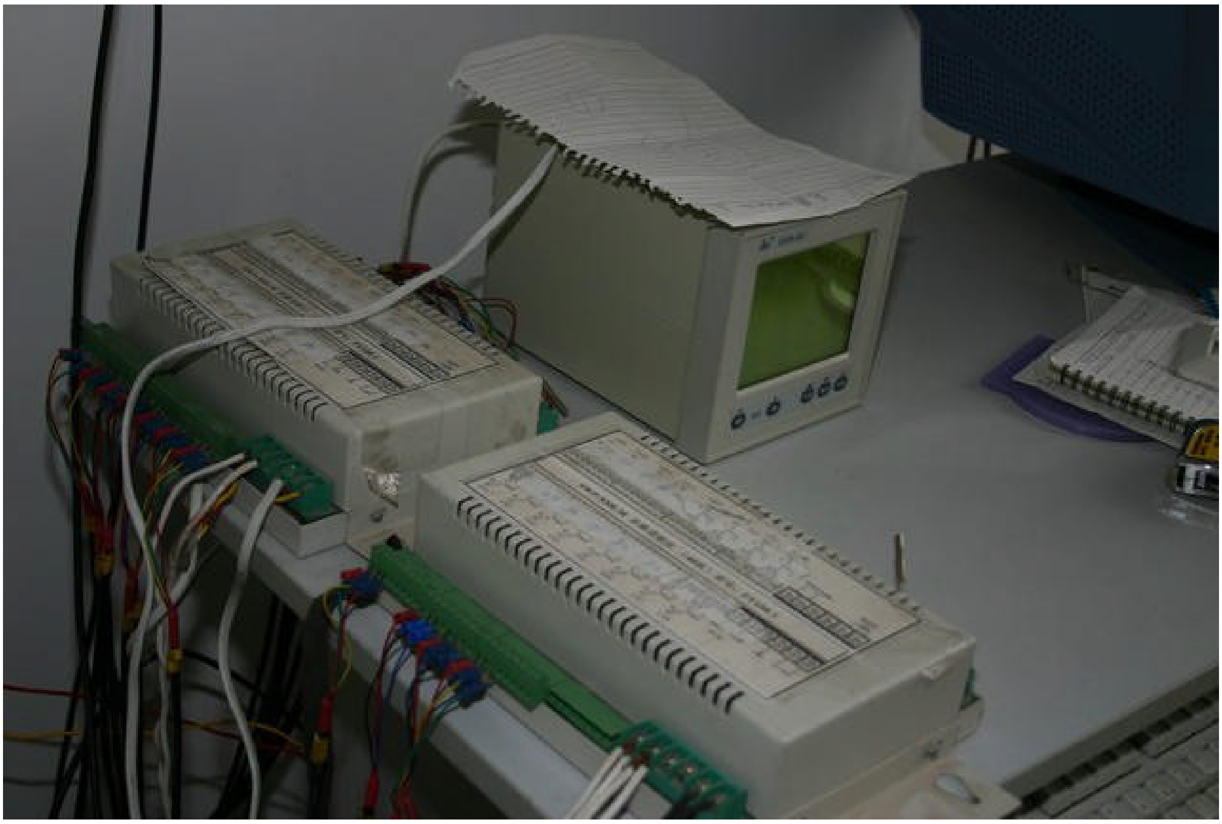
Table 3-2, examples for the different electrical household machines and their magnetic fields

Device	**Average B, μT**
Toaster	0,1…0,2
Water cooker	0,16
Hairdryer	0,4
Power source	1,79
Fan	4,33
Microwave oven	6
Vacuum cleaner	6

4.Pictures

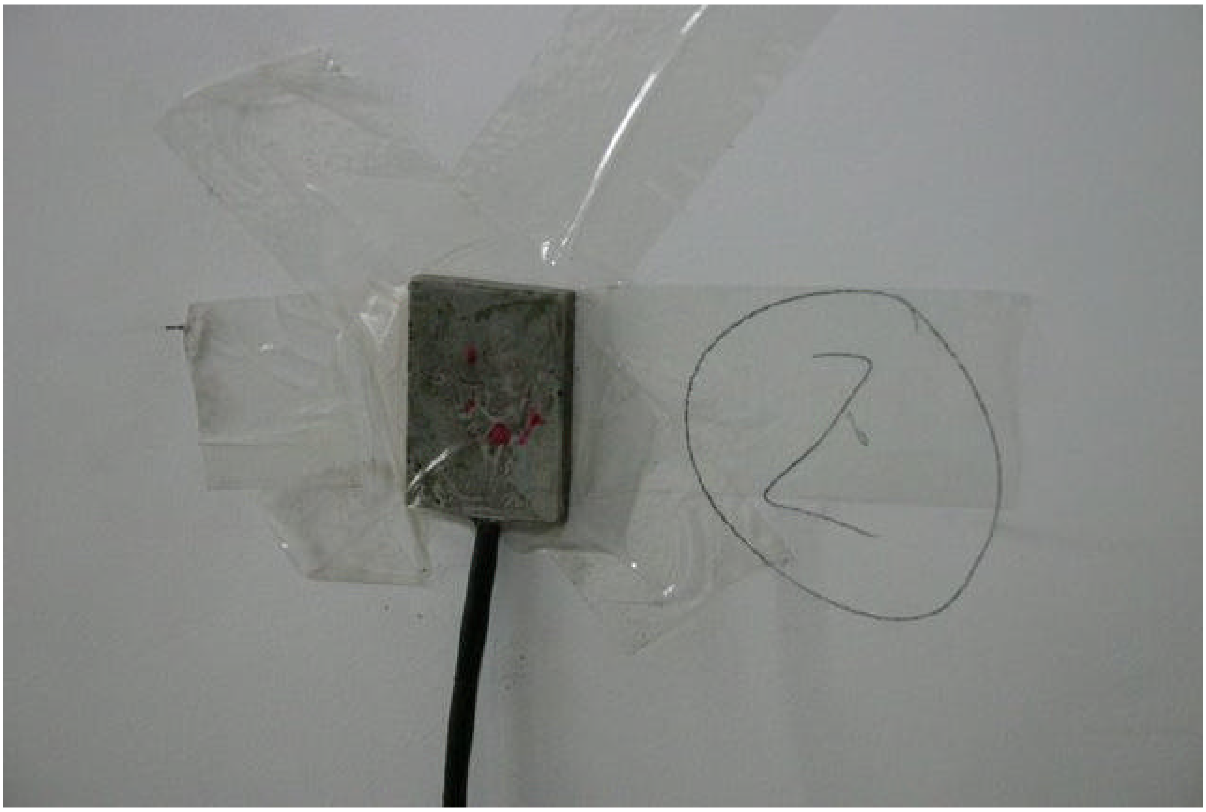
Pictures from the heating laboratory:

Picture 4-1, Window



Picture 4-2, 64-chanel temperature measurement unit + screen

Picture 4-3, Heat flow sensor on the outer wall.



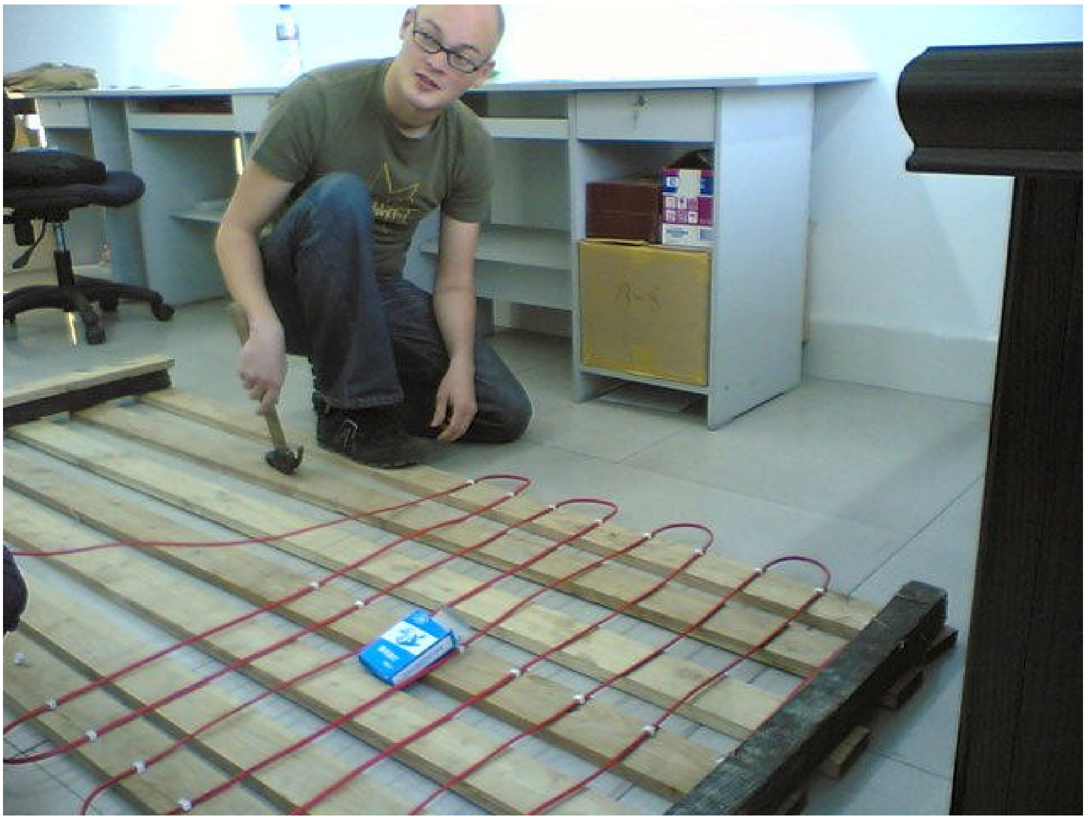
Picture4- 4, Temperature sensor on the wall.

Picture4- 5, afterwards constructed floor structure (taken from the door)

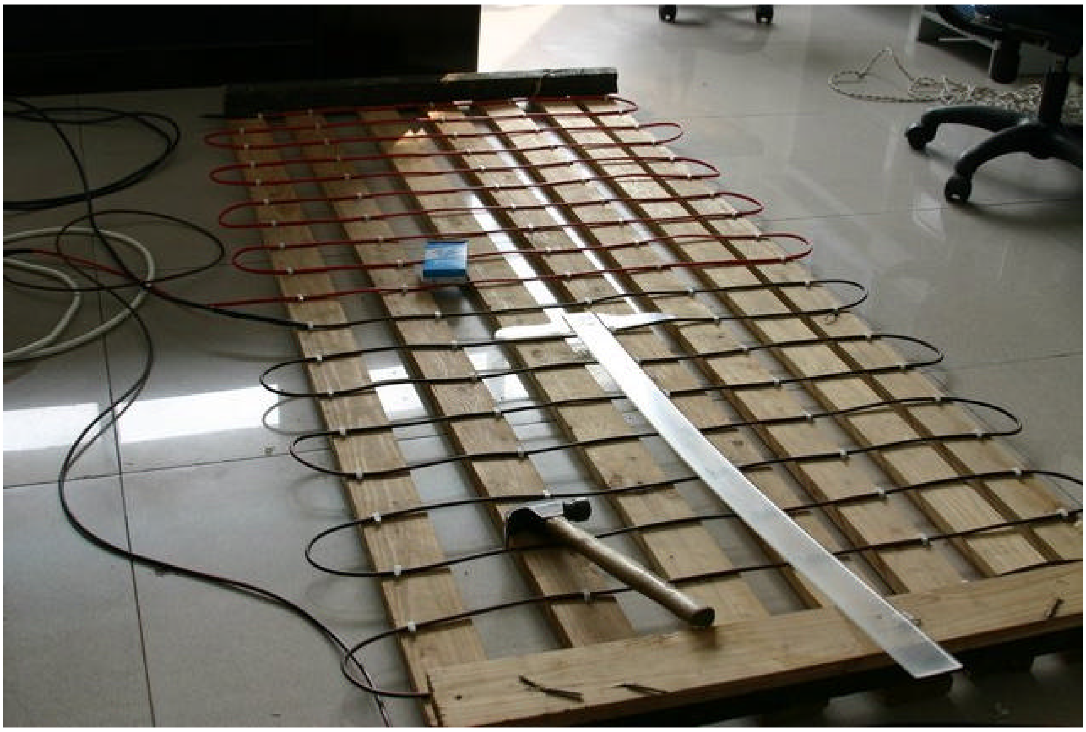
Picture4- 6, door and the window and 2 temperature sensors

Picture4- 7, window structure

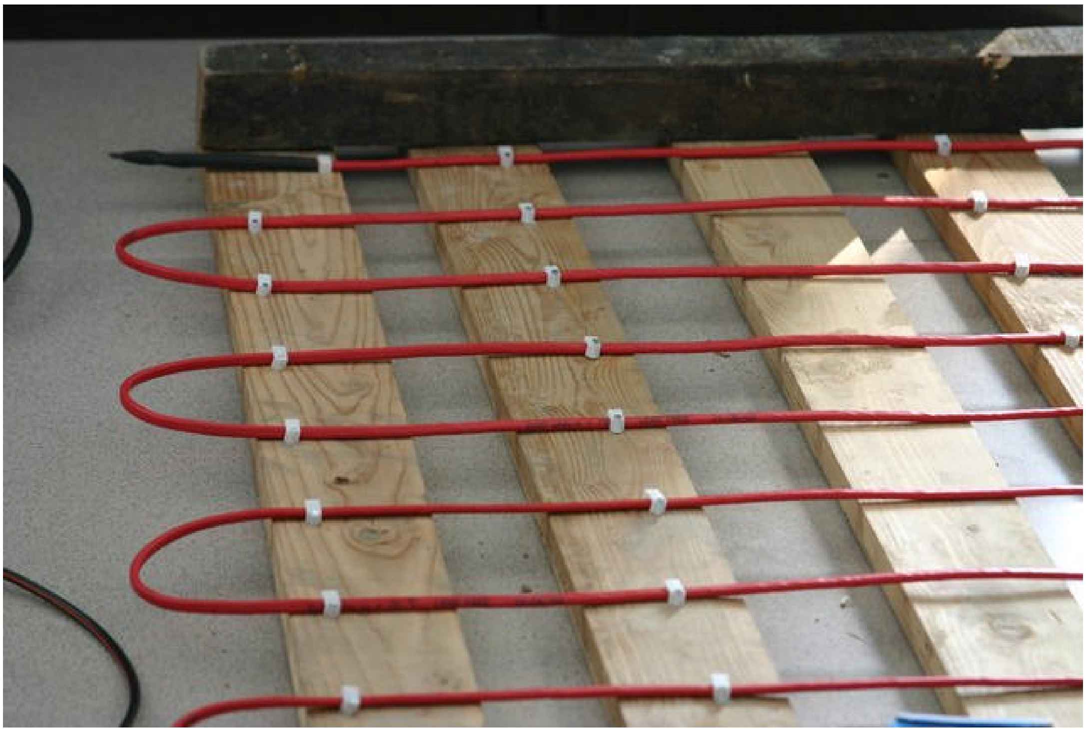
Pictures from building the bed for the 2 different heating cables:



Picture 4-8, Building the bed (2 wire system)



Picture 4-9, construction ready (1m^2 – 1 wire cable and 1m^2 – twin wire cable)



Picture 4-10, twin wire cable, take a look to the ending of the cable

I want to thank these people below who did make my project possible, helped me to organise necessary devises and laboratory facilities and helped me in the research work:

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