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Energy performance of Hydronic heating systems in residential building in Iceland

Designer's thoughts and steppingstones to energy savings

Preface

In the last couple of months, a group of people has been working on Clime Change projects to minimize Carbon footprint from construction. In the field of space heating for new building Carbon footprint in geothermal water will be met by 7% reduction of CO_2 by cutting energy consumption down to 50%.

The team is developing a databank for energy use for existing houses connected to Veitur ohf. The team will publish a coordinate rule on how to calculate and document energy use.

There was an architect from Denmark who is specialized in reuse of concrete. This is a very interesting method and they have started a project in Reykjavik.

The Ministry of the Environment, Energy and Climate has published report about the Geothermal district heating operation and condition assessment of heat-source, sustainable Utilization of hot water. The finding was that 2/3 of utility companies will face a great challenge soon due to demand.

The specific energy use is getting higher per resident and Orkustofnun has estimated that in the future this specific energy use will decrease due to energy saving means but now trends is in that direction. There is a hope that Smart energy and water metering will be a driver for better energy management.

Thermal comfort

People spend 90% of their time indoors. When people are spending time inside premises, especially in a cold climate, it calls for supplying energy for heating. The building HVAC designers are specialists in creating a pleasant, productive, and healthy indoor environment. Adequate thermal comfort plays an especially key role in achieving this goal and is also closely related to energy use. To maintain body temperature within a narrow band, the heat production by an occupant must be released to the indoor environment. If too much heat is lost, the room temperature should be increased, or warmer clothes be worn. The heat transfer on the human skin, the indoor temperature and the heat transfer through the building envelope are factors that influence thermal comfort. Fig. 1 shows schematically the ranges of temperature variation of the

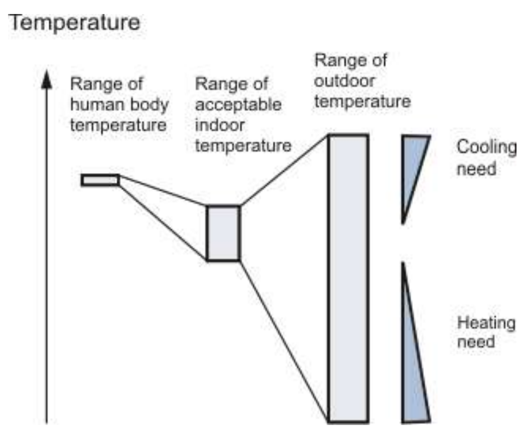


Figure 1

human body, of the room air and outdoor air. Adjustment of heat transfer around the human alone (by variation of clothing or sweating) is not normally sufficient to control body heat release at large outdoor temperature variations without the thermal protection of the building envelope and heating or cooling. The dynamic storage of heat in building components is important to control indoor temperature variations. The heat transfer through an envelope is from higher temperature to a lower one. The heat loss is the difference T_{inside}-$T_{outside.}$ Heat losses grows linearly with surface area A, one finds:

$$Q = UA(Tinside - Toutside)$$

U is the Overall Heat Transfer Coefficient in W/(m^2K). To reduce heat loss and heating energy one should look at the heat loss formula. In the heating season reduced **temperature inside**

(Tinside). **Insulate the building (U)** envelope to reduce the coefficient U, and if it is possible **the surface area should be reduced** (A) without changing the enclosed volume.

Calculating energy consumption

To calculate energy use for building we will use equation (eq.1). The building is in Reykjavík, the Capital city of Iceland. It is 200m^{2}med of concrete . Building envelopes is a physical barrier between exterior and interior and enclosing a structure. All insulation is on the outside of the wall. All thermal bridges on walls are eliminated.

The construction process should minimize the need for energy, water and material and satisfy these needs in a least disruptive manner.

One parameter in this equation is heating degrees day. Heating degree days (HDD) are a measure of how much (in degrees), and for how long (in days), outside air temperature was lower than a specific "base temperature" (or "balance point"). Here, Tbalance is that outside temperature at which no heating is required to maintain a prescribed inside temperature at given internal heat gains. For Iceland, the degree days is 4882 (°C days) (HDD) for weather station in Reykjavik (21.9W,64.1,3N) and base temperature 18,5°C for the year 2022. With a base temperature of 18,5°C it has been considering for internal heat gain from solar gains, internal heat gain from people, lights, cooking, and TV. This base temperature is a guess, it could be lower but its dependence on how much internal energy is in the house and how the windows collect sunlight in the building.

$$Q = \Sigma UA' \cdot HDD(18{,}5°C) \cdot 24 \left(\frac{hours}{day}\right) [\frac{kWh}{year}]. \text{ (eq.1)}$$

$$\Sigma UA' = \Sigma UA + 1/3nV$$

∑UA´ is the Overall Heat Transfer Coefficients U-values (W/m^2 °C) and Envelope A (m^2) for the Building and the Air change rate n (-1/h) and Buildings total volume V(m^3). Windows area is 30% of walls (WWR) and U-value for windows is 1,7(W/m2°C). All other U-values are by Building Code. Residential ventilation units (RVU) are in the house. The RVU unit has an extremely good recovery heat exchanger so the energy to heat the fresh air is 0l. It is provided with heat recovery heat exchanger and is able, by using energy from exhaust air to heat -15°C outside air to 18,8°C. But due to air leakage through building envelope calculation was done for one site of the building a converted to air change and used in eq.1. In Appendix II is clarification of calculation around air exchanges and air leakage. Results of calculation of energy use by (eq.1) for heating is 170 (kWh/m^2). Eq.1 do not take in includes energy that goes to hot domestic water but adding 10% for domestic hot water will count for it. Total energy use of energy from geothermal district heating 187(kWh/m^2 year).

In Europe, final energy use intensity (EUI) for normal climate of European building is 178,8(kWh/m^2) for residential building and 270,6(kWh/m^2) for non-residential. The utility company (Veitur ohf.) is billing the house owner for heating energy by m^3 of hot water. 187 (kWh/m^2) can be converted to m^3 by divide with 50(kWh/m^3) where Δt is 43K for the heating system and that leads to 3,74(m^3/m^2) of hot water or 1,13 (m^3/m^3). Single family houses on Veitur homepage shows usage index 1,2 -1,8. The lower index, 1,2 ($m^{3/}m^{3)}$ for well-insulated house with well-balanced heating system. To change from area to volume 3,3 are used (not 2,5) Calculation for heat demand is in Appendix I.

System for Space heating in the past

Space heating systems for houses in Capital Region in Iceland was mainly hydronic radiators and oil-fired boiler as a heat source. Controller for the boiler temperature was simple on/off but with sophisticated outdoor reset controllers. The controller was equipped with night setbacks. On each radiator where hand adjusted valve.

In the years 1945-1970 a radiant ceiling (R. Crittal & Company) system was installed in few houses, in one school in Reykjavik, the new wing at Landspitali hospital and as example in

apartments building at Birkimelur. This system was controlled by outdoor reset, and indoor temperature was controlled by thermostat on the wall in the corridor. But there are crucial things about this “old system” which can destroy otherwise good systems. It happens when they stop working and some consultants, due to lack of knowledge or experience about these old systems recommended a complete renewal of the heating systems. But what was needed in fact, was new controls and upgrades for balance and equipment this system has to day to be able do a better job heating the buildings.

If nobody is taking cares of them and any maintenance program is in takt, then it can easily go out of track if these systems do not get attention by professionals, getting upgrade, recommissioning and maintenance. As Sigurður Guðmundsson pluming master wrote in 2008 “*Let's then turn to the "old" radiant heating that was installed in many houses half a century or so ago. These are houses of various sizes and types, not least apartment buildings. There is no doubt that in many houses there is a lot of dissatisfaction with radiant heating, but then you can ask, why? It is very easy to answer, it is in almost all cases because the radiant heating has not been maintained, everything has been allowed to leak and become obsolete. Now this is not an entirely accurate description; it's not the beam system itself that has lost power or failed, it's the controls. It is the devices that are supposed to control what the heat is in the system, where the heat should go, and that each apartment owner can choose the heat that suits him.*

Underfloor heating (UFH) was installed in houses and institutions before the days of plastic piping material. Large UFH systems with welded steel pipes were installed in the large lobby. Pipes made of plastic withstanding high temperature made a breakthrough in a many underfloor heating (UFH) was installed. It is better to use UFH were heat loads are moderates (<60-75(W/m2) and temperature on the surface can be low, 2-3°C than the self-regulation effect is effective. Cold draft from large windows shall be taken into consideration both for floor heating and radiator systems. Nevertheless, there can be situations in which it is better to provide as much output as possible in either convective or radiant form. For example, radiant heating may be desirable in buildings with soaring ceilings. There are of course always blend radiators and floor heating systems depended after characteristic of the room. For planning houses, it is popular to use

floor heating downstairs and radiator upstairs.

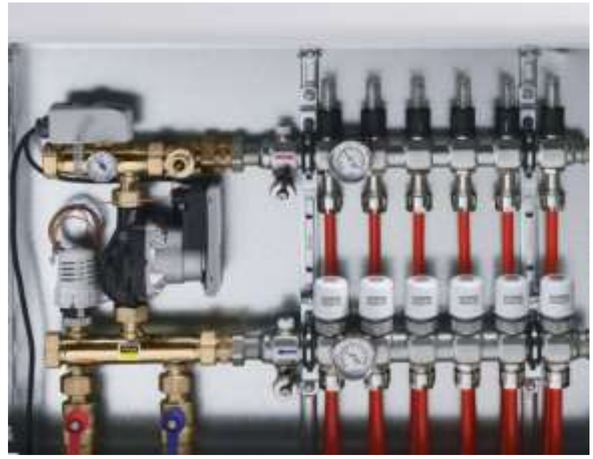
Hydronic radiator

Radiators and convectors emit heat by virtue of their surface temperature being greater than room temperature and the mean radiant temperature of the surrounding. In each case, heat is emitted by both radiation and convection. Manufacturers are obliged to present the nominal output of the emitter under the standard method for testing as specified in EN442-2. The heating system is connected directly to the geothermal district heating system, and it delivers water at 80°C. It is common practice to cool the water to 40°C in the heating systems but it is up to the designer if he chooses to deviate from this common practice and cool the water more. Radiator systems can thus be categorized as low-flow systems. Veitur measures water use in m^3 (cu. meters). Magnitude of system flow is not entirely free choice, as it linked to the Δt (80-40). The size of the radiators for each room in the house depends on the heat loss of the room. It is the best practice to place the radiator under the windows. If there is to or more windows in the room the heat loss is divided between radiators and the physical size of the radiators is length of radiators are to make a space for TRV and pipe fittings about 300mm shorter than the windows and the radiator is 100mm from the floor due to circulation of air from the room to be heated and 100mm from the window. If the heating system is with night setback the size of the radiator shall be oversized by EN12831 depending on how many degrees, the temperature is setback and how many hours it will take to heat the room after setback. It is not common in Iceland to have heating system with night setback, but it gives energy saving, but can backfire if one and more rooms er cold in the morgning times and take too long to heat. If the heating time is 2 hours from night setback temperature to normal temperature (setback 2°C) the 15% oversize will be enough. Thermostatic radiator valves (TRV) are on all radiators where there is an internal heat gain and heat from the sunsine.

Under floor heating

Under floor heating (UFH) uses the floor a surface itself as a heat emitter. Heat is supplied with embedded pipes with circulating water. The insulation beneath the heating elements is clearly.

important for good control of output and to avoid unnecessary heat loss. Under floor heating emits most of its heat by radiation. Surface temperature should not exceed 29°C (100 W/m^2) in general or 35°C (175w/m^2) for peripheral areas due to comfort. The optimum floor temperature range for comfort lies between 21 and 28°C. The design surface temperature is controlled by the spacing between pipes and flow temperature. In practice, systems are usually designed to operate at flow temperatures between 40 and 50°C with a temperature between 5-10 K across the system. UFH may be used in conjunction with radiators. Separate circuits are required to control floor temperature. UFH is best suited to well insulated buildings. Power intensity for floor heating can be calculated by equation (2) $q= 8{,}92\ (T0 - Ti)^{1{,}1}$($W/m^2$), q is specific effects, where T0 (°C) is average surface temperature on floor and Ti (°C) is indoor temperature. A room heats up because of external heat (e.g., solar radiation, electrical devices, people). The smaller the temperature difference between the floor temperature and the room air temperature, the lower the heat output of the underfloor heating. At the same temperatures or opposite temperatures, the floor no longer emits heat or even absorbs heat (e.g., when exposed to direct sunlight). This process is known as the self-regulating effect. UFH in embedded floor screeds will be assumed to keep the floor at constant temperature, 30°C on average the whole year. Δt is with temperature of the ground 5°C is (30-5) = 25K and if the slap were unheated, it will be (20-5)=15°C. It is quite important to insulate floor slap at the perimeter and leave no open connection in the insulating material. Heat loss from the perimeter is calculated separately with heat loss coefficient pr.m.



U-values and Building Codes

The Icelandic Building Codes sets requirement for energy efficiency in buildings. The U-values

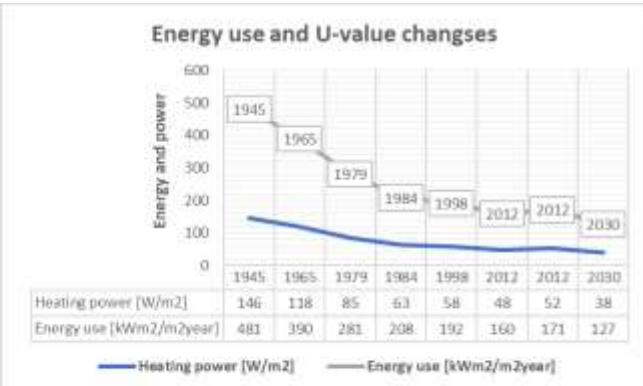


Figure 1 – Overview over changes of U-value over time

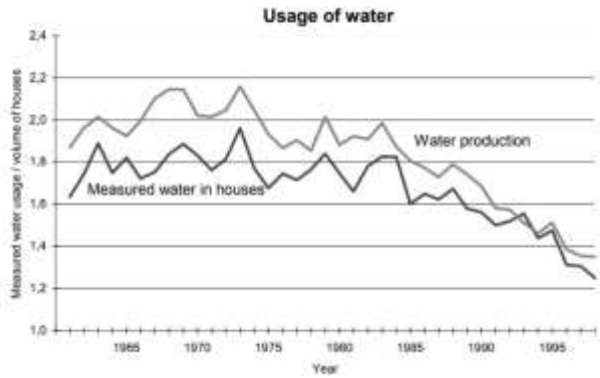


Figure 2- Water usage /Volume of house

tells us how well building elements isolation against heat loss. In the past changes have been made to the U-values. In the year 1945 there was no restriction on U-values for walls and windows. In 1945 heating power was as high as 146W/m^2. After 1950 people started to insulate building walls with 50mm cork who wase clued with concrete. The U-value dropped from 1,2 to 0,8. From 1955 to 1980 were the biggest changes in the Building Code that made good effort to reduce the energy use of building, but it has been very modest due to low energy prices for geothermal energy. The U-value for windows was set to 2,5(W/m2°C) from no restriction and U-value for roof and floors were set to 0,2(W/m2°C). Calculations show energy use dropped to 45%. Figure 2 shows a clear fall in water usage pr. building volume. No major changes have been made to the U-value since. 2012 came a major change in building regulation text and not so much in U-value. There are shown to changes in 2012. The first one was not realized.

Energy efficiency – better use of TRV and educating users.

There are many reasons why energy consumption can vary between buildings of the same size and insulation. One of the main factors is the occupant's behavior. The way people use their homes, including their heating and cooling habits, can significantly affect energy consumption. For example, in energy inefficient houses people's behavior is energy – efficient. Occupants in energy-efficient dwellings are more likely to have higher comfort level than occupants in less-energy-efficient dwellings. Some people may prefer to keep their homes at a higher temperature in the winter or use air conditioning more often in the summer, leading to higher energy consumption. Another factor that can affect energy consumption is the efficiency of the building's systems, such as heating, ventilation, and air conditioning (HVAC) systems. Even if two buildings have the same insulation levels, if one has a more efficient HVAC system, it will consume less energy. The orientation and shape (design) of a building can also play a role in its energy consumption. For example, a building that receives more direct sunlight may require less heating in the winter but may require more cooling in the summer. Heating control and right use of it and commissioning. Building characteristics are caused by the performance gap. Thermal mass can have an influence. There is thing that is ignored, that is heating system must be properly hydraulic balanced.

Today, every house is equipped with radiator thermostat (TRV) but unfortunately, they often lose their effectiveness because the residents do not use them correctly. The key point is setting the desired room temperature on the thermostat, not the heating power. If the room is colder than set (e.g., after shock ventilation), the thermostat will select the maximum heating power. So, it is pointless to turn it up to full speed: this does not help at all when it heats up but prevents the heating power from being throttled again when normal room temperature is reached. If user forget to do this by hand, the room will be overheated unnecessarily.

Reset control – weather- station.

Hitaveita Reykjavíkur is supplying geothermal water at 80/40°C all year round for heating a heating hot domestic water. It is most popular to have thermostatic radiator valves (TRV) to control indoor temperature in a building. They have proved to be excellent at controlling indoor temperature. TRV opens or closes when the temperature in the room changes due to internal heat gain. If the outside temperature is getting lower (e.g.,5°C to 0°C) and indoor temperature is falling, then TRV will try to correct it with delay and will open for 80°C supply temperature. The radiators are at 50% partial load and getting 80°C and TRV before the outside temperature disturbance was near closed. When the outside temperature starts to fall the TRV doesn’t open because it takes for the heat loss to change the indoor temperature. The delay of the TRV is not efficient. If supply temperature for the radiators changes with outdoor temperature by reset control is energy efficient for hydronic heating systems because it allows the system to continuously adjust its rate of heat delivery to match the building's current rate of heat loss. Underfloor heating must be with an outdoor reset. Heating pipes in floor med of concrete will delay the room temperature when the outdoor temperature drops. This is achieved by changing the temperature of the water supplied to the system in response to outdoor temperature. There is not any marginal for water to lead flow to be unattaining and waste.

When the reset control is properly adjusted, the water temperature supplied to the heat emitters is just high enough for the prevailing heating load, with a well-adjusted heat-curve. The rate of heat delivery is always kept remarkably close to the rate of building heat loss. This yields very stable indoor temperature compared to less sophisticated hydronic systems that deliver water to the heat emitters as if it were always the coldest day of winter.

In summary, outdoor reset control allows a hydronic heating system to work at best efficiency by continuously adjusting the supply water temperature based on outdoor conditions. This results in more consistent and comfortable space temperatures while reducing energy consumption.

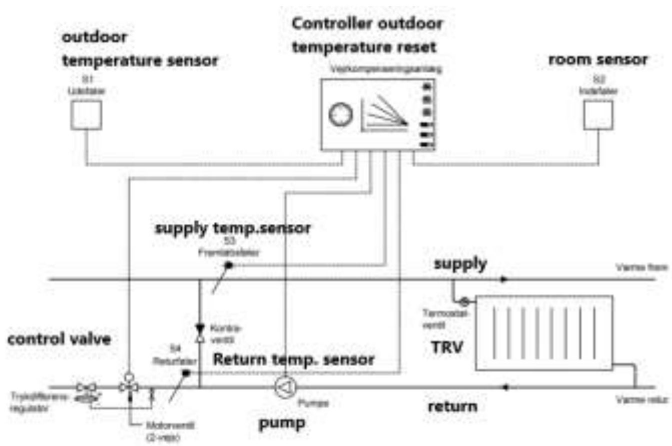


Figure 3- controlling supply temperature.

Monitoring results from field studies have documented that actual energy savings range from approximately 5% to more than 15%.

Hydronic balancing

Hydronic balancing of a floor heating and hydronic radiator systems are crucial to energy performance for the system is typically done by a heating professional or HVAC technician. In Germany, this work is out of housebuilders scope due to complexity, and it is needing a special knowledge and trained technicians to finish the work. It is mandatory to do the work.

Hydronic balancing shall be done when the system has been commissioned. Thermal adjustment is the fine adjustment of the individual room heating circuits, with the aim that all rooms reach the desired temperatures. The background is the fact that when calculating the space heating loads from bare rooms are assumed. After people move in, they change rooms heat loads from the design (furniture close to the floor, closets or any additional floor covering. So, they must now be real circumstances to be considered. The comparison can ultimately only be carried out by the occupant of the room, because of the change in the flow rate at the distributor and the heating curve. It takes a lot of time to regulate. The effect of the new settings is used especially with surface heating (floor, wall and ceiling heating) only measurable after many hours due to the sluggish systems. Theft's way thermal adjustment is not offered by any specialist company, because this work is very time consuming, and the customer is not willing to do this accordingly charging high costs.

Every operator will notice that after the adjustment for surface heating (the heating systems common today) individual room controls.

Hydronic balancing is a process is getting the right flow to the right parts in a hydronic heating system by balancing the system pressure. This is done by adjusting valves and flow restrictors in the system to control the flow of water to each zone radiators and pipes in floor heating. The balancing work or process.

Many building in Iceland is without a hydronic balanced system. The same can be stated about balancing ventilations ducts. It has been estimated that hydronic balancing can save 15% of energy. Testing and balancing work requires knowledge and discipline. General contractors (construction) misunderstanding this work :

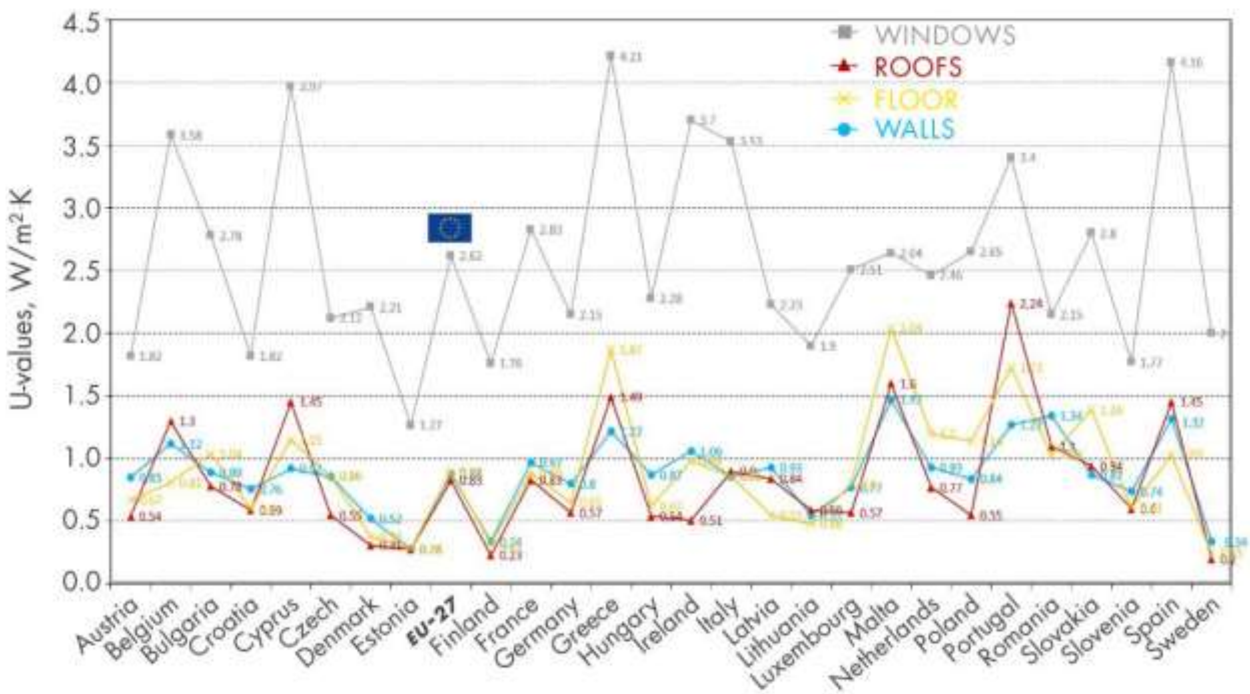
- This action does not have a significant impact on heat consumption.
- Preparation of technical document for correct hydraulic balance difficult
- These are low-cost actions (with a small profit for the contractor) that simultaneously require a lot of time-consuming effort and require specific knowledge in this area.

In Germany it is obligatory to optimize heating systems in privet houses.

Conclusion and some thoughts about the future.

This paper outlined that due to very low energy prices designers and technicians don't install all controls on the systems which give the system best for thermal comfort and excellent energy efficiency. First, **outdoor whether station shall control the supply temperature** for the radiator and underfloor heating. Mark my word, the magnitude of supply temperature shall be found in the room that has the most heating loss. The supply temperature for the radiator and underfloor heating shall be high enough to heat that room to 20°C. The pipefitter does not finish his job and does not spend any time **hydronic balancing** the heating system. It can be found by checking if radiator will fully open for TRV when doors are open for a minute and water is flowing from the radiator at 60-70°C when it should temper the flow to 35-40°C when it is max open TRV. Internal adjustment at TRV has not been done. This controls where the heating systems are used when oil is used for heating systems. Nobody would pay for oil heating the house all night when the family was fast asleep. When it was warm outside then of course the radiator where not so hot. Why are we not using this type of control like all the countries we are comparing us with.

Icelandic buildings are with same standards compared to European countries, but Icelander have not as we can call it a “energy user mentality” which can be learned and trained. I think that due to demand problem with our geothermal district heating, it should be mandatory to balance heating system in all hoses in Iceland. To do that same time installing smart meter is something to think about, Energy saving from hydronic balancing gives 5-15% and installing weather station are giving the same, 5-15%. Total 10-30% energy saving is may be helping the Utility company to take the heat of in the futur.



Appendix I

RVU- energy calculations for ventilation

Heating energy for ventilation supply is calculated for operations hour t_{22} to supply air set point (18,5°C), and summed for all hours. The maximum flow for RVU is 250(m^3/h) but airflow for the house is 327(m^3/h). The heat exchanger is a crossflow plate and with -15°C outdoor temperature, t22 is 18,8°C, SPI=0,5.

The energy consumption for heating for ventilation without a heat exchanger is calculated to be 63,2kWh/m2. This is all so the energy saving with a heat exchanger. If the air changes part in the heating equation (eq.1) is replaced by this consumption, but this part (1/3nV) is also air permeability is leakage part through building envelope. Code leakage factor is <3m^3/hm^2. The envelope of the house is 150m^2. If wind is building up more than 50Pa we can expect $150 \cdot 3 = 450m3/h$ which is very high or 0,75 (1-/h). If wind is pressing air through the envelope of the building it will not affect the leeward side of the building so the air will penetrate on the windward side. The leakage is estimated to be half or 225m3/h.

$Q = m \cdot cp \cdot \text{HDD} \cdot 24 \rightarrow v \cdot \rho \cdot cp \cdot HDD \cdot 24 \rightarrow Q = \frac{0{,}09m3}{s} \cdot \frac{kg}{m3} 1 \cdot \frac{1{,}2kj}{kg} °C \cdot 4882\text{days} \cdot \frac{24h}{day} \rightarrow$

$Q = 12654kWh \rightarrow$

$\frac{63{,}2kWh}{m2}. Heat\ energy\ for\ heating\ from\ 18{,}8\ (use\ 18{,}5) to\ 20°C. HDD(20°C) is\ 5439\ minus\ 4882 = 557.$

$Q = m \cdot cp \cdot \text{HDD} \cdot 24 \rightarrow v \cdot \rho \cdot cp \cdot HDD \cdot 24 \rightarrow Q = \frac{0{,}09m3}{s} \cdot \frac{kg}{m3} 1 \cdot \frac{1{,}2kj}{kg} °C \cdot 557\text{days} \cdot$

$\frac{24h}{day}$ →1443kWh/a~7,2kWh/m2a. This will be added to energy use for heating.

$SEC = 8760h/a \cdot 2{,}5 \cdot 1{,}3m3/hm2 \cdot 1{,}1 \cdot 1 \cdot 0{,}0{,}00014 - 6552h/a \cdot 14{,}5k \cdot \frac{1}{0{,}75} \cdot 0{,}000344 \cdot$

$(\frac{2{,}2m3}{hm2} - \frac{1{,}3m3}{hm2} \cdot 1 \cdot 1{,}1(1 - 0{,}8) \rightarrow SEC = 12{,}5 - 43{,}575(2{,}2 - 0{,}286) = 12{,}5 - 83{,}4 =$

$-70{,}9 =$ **+A**