Low Temperature Heating and Cooling Systems for Low Energy Houses, Proved in Practice.

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1. Introduction

The author has erected very low energy houses as office buildings etc. when he was in industrial management and development. Their specific energy need was in the range of 90 - 150 MJ/m^{2}y (25-42 kWh/m^{2}y) for heating in the climate of Switzerland and of 0 - 80 MJ/m^{2}y (0-20 kWh/m^{2}y) for cooling. The main feature was a new building shell made of extremely well insulated walls and super windows of a U-value of 0.6 W/m^{2}K. The traditional heating and cooling systems were not appropriate and new ways had to be found. As one result, new ways for HVAC systems adapted to such low energy houses were developed. The first such building was erected in 1986 and went in operation in 1987. Many different realisations, all on the same basic principle were erected, the most extreme in 1990. In the following chapters, the basic principles are outlined and then some realisations discussed.

2. Basic Principles.

The effect of low specific power need.

The low energy houses mentioned above had a very low specific peak power requirement. This was due to the extremely insulating building shell as well as due to the fact, that a very low volume ventilation method with heat recovery was applied: displacement ventilation. This is in contradiction to many so-called passive solar houses, where sometimes a low energy need is accompanied by quite high peak power requirements.

Whereas standard houses in Switzerland work with a specific power for heating by 50-80 W/m^2, these new houses needed not more then 20 to 30 W/m^2 floor area. To keep temperature differences between the delivering system and the room low, large areas and efficient heat transfer were used:

- radiation instead of convection,
- floor and ceiling instead of radiators or convectors.

Floor or ceiling based systems however are charged with prejudices of having to large inertia to react to load changes as for instance the sun.

What is the reason for this „experience“? Standard systems with high specific loads of 50-80 W/m^2 and relatively small areas require high temperature differences. Even if they use the large area of a ceiling or a floor, the temperature of the systems fluid is still well above room air comfort ranges: e.g. 30-38°C. If now the sun irradiates the room and reduces the heating load, the room temperature starts rising. At 26°C (upper comfort limit) the system still heats, e.g. delivers heat to the room because of its to high inlet temperature. This effect is called „inertia“ by practitioners and blamed on the „mass“ of the ceiling or floor. Instead, not the „mass“ **but the too high inlet temperature is the reason for this so-called „inertia“.**

Rooms with much lower power requirements allow for much lower inlet temperatures, sometimes even within the comfort range, and therefore also for a reduction of this inertia until the range of inertialess autocontrol behaviour if the inlet temperature stays in the comfort range.

An example: Suppose a floor based heating systems. The specific power requirement be
a. q = 60 W/m2 and b. q= 25 W/m2.
The thermal resistance from the system to the room consists of the material layer and the heat transition from the surface to the room:

$$R = \frac{d}{\lambda} + \frac{1}{h_i} \cong 0.056 + 0.2 = 0.256 m^2 K / W$$

corresponding to 10 cm concrete and for the transition only taking radiation transfer.
The mean systems temperature has to be at:
a. $\Delta\vartheta = 25 \cdot 0.256 = 6.4° C \quad \vartheta = 26.4° C$ b. $\Delta\vartheta = 60 \cdot 0.256 = 15.4° C \quad \vartheta = 35.4° C$
When now the room temperature rises to 26°C as an upper comfort limit, the power of the first system is reduced to 6% (almost 0) whereas the other system still heats with 61% of its initial power. System a. is almost autocontrolled whereas system b. shows a strong inertia with tendency to overswing. It can therefore be stated that
Buildings with low specific power requirements allow for low inlet temperature systems with large areas and of autocontrolled behaviour without any inertia.
The key elements are thus the **low specific power requirement** and the **large transition area**. Depending on the type: ceiling or floor, the transition resistance is even further reduced by convection and thus the limit for the maximum specific power handable within the comfort limits can be further extended.

How much mass should be used.
As the author has demonstrated elsewhere [1], in internal rooms, the boundary conditions for the instationary heat penetration into material layers are such that the layers can be taken as very thin until a thickness of $d = \frac{1}{\sqrt{2}} \cdot \sigma$:

$$\frac{C}{A} = c \cdot \rho \cdot d$$

and from thereon the storage capacity remains constant at

$$\frac{C}{A} = \sqrt{\frac{T}{\pi}} \cdot b .$$

The penetration depth being determined by: $\sigma = \sqrt{\frac{T}{\pi}} \cdot \sqrt{\frac{\lambda}{c \cdot \rho}}$

and the thermal effusivity by $b = \sqrt{\lambda \cdot c \cdot \rho}$.
For the time period of T=24*3600s one obtains for the **critical thickness**:
concrete d= 0.1 m, brick d= 0.08 m, timber d= 0.044 m etc.
Standard concrete floor slabs, brick walls etc. just exploit the available storage capacity.

The role of the massive floor or ceiling consists together with the low temperature supply system in a **heat buffer**: it can almost without delay accumulate heat from or spend heat to the room. If the system is located internal of the material layer it mainly acts as a charge and discharge device in order to compensate for the deficits or the surplus of heat the slab spends or accumulates. The system is of no more direct importance.

3. Realisations

Depending on the strictness of comfort requirements and also on the size of the specific loads for heating and / or cooling, different systems can be realised on the base of the above mentioned principle: air and water based, using walls, ceilings, floors etc..

The author himself has experienced some development, so the first buildings where not of the same sofisticatedness as the later ones.

Using the supply air as heating / cooling medium, it can be used to flow through hollow walls or tubes in the floor or ceiling to bring or to extract heat from there. For larger loads and for an independent control of fresh air supply and energy management, one uses a separate water based circuit. The warm/cold water is led through radiators on the ceiling or through tubes in the floor.

Some examples are characterised in the subsequent part. They all are now for several years in operation and are working very well. Moreover, they were sold on the market and had no need for government support except the very first one, but this got only a funding of about 2%.

Building	Type	System element	Medium	Temp Range: Cool-heat	Specific Power
Rutishauser	Office	inner walls	air	16 - 28°C	C:35 H:25 W/m^2
Messerli	Office	ceilings	water	18 - 28°C	C:40 H:22
Sarinaport	Office	floor slabs	air	20 - 28°C	C:20 H:25

The comfort as well as the dynamic behaviour of these and some more buildings of these type have shown to be very satisfactory and the energy need also to be very low.

The combined system of a very low loss building shell together with an adapted low temperature autocontrolled HVAC system has been patented by the company under the name „BATISO“.

The author thanks his former colleagues from GEILINGER Ltd for the data and some documentation about the buildings.

[1] B.Keller: Klimagerechtes Bauen. (Climate Adapted Buildings, in German). Teubner, Stuttgart 1997. ISBN 3-519-05080-3