Building Integrated System Design for Sustainable Heating and Cooling

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WaterTraditional water based systems operating at optimal temperature levels represent a low tech but easy and accessible potential for energy optimisation and integration of renewable energy in the construction sector.

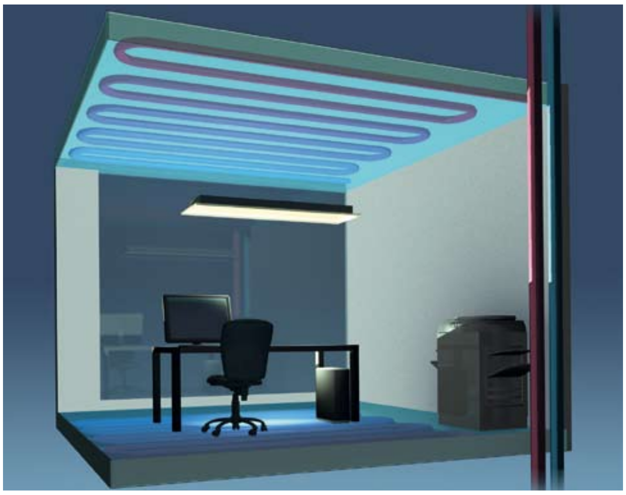
Good Indoor Environment with Low Energy Use Required

The requirements to modern buildings are numerous. Energy consumption must be minimised and the necessary building services must be provided in the most sustainable way in order to ensure adequate indoor climate and healthy conditions for the users. Improved energy efficiency is among the fastest and most cost efficient ways of lowering energy consumption but is often not offered the same attention as new and more exotic technologies.

Several tendencies indicate that the cooling needs in buildings are increasing due to changed indoor comfort requirements, more extreme weather types and new building codes with stricter requirements for the tightness of building envelopes. A promising strategy for sustainable cooling is water based solutions utilising large radiant surfaces at relatively high temperatures, coupled with free cooling sources. By using large surfaces, both heating and cooling can be obtained at temperatures close to ambient, which offer optimal operating conditions for integration of renewable energy and free cooling. In buildings where occupancy pattern yields large cooling loads during day time, embedded water based systems can in addition yield substantial peak load reduction and consequent plant size reduction (Thermo active construction/building).

Sustainable Heating and Cooling

The building sector account for approximately 40% of the total energy consumption and the majority of this energy is used to maintain adequate indoor climate



Thermo active constructions works by activating the building's thermal mass with embedded piping. This gives an optimal indoor climate while energy consumption for heating and cooling is minimized. The TAB system is a combined heating and cooling system with pipes embedded in the structural concrete slabs or walls of multi storey buildings, typically applied for buildings where occupancy pattern yields large cooling loads during day time. As the system is often operated asynchronously to the thermal loads of the building, parts of the loads can be shifted from day time to night time, resulting in substantial peak load plant size reduction.

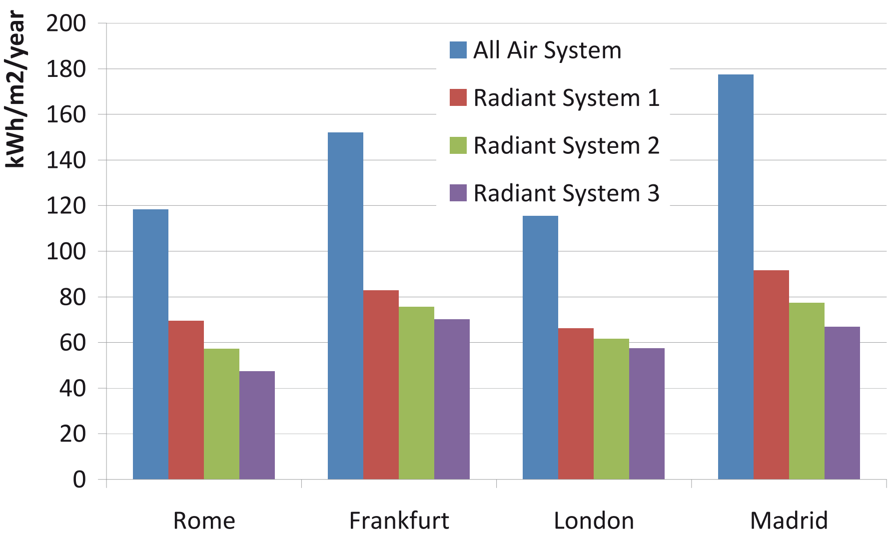
conditions by heating, cooling and ventilation. It is estimated that about a third of this energy consumption can be eliminated by using known technologies with a very short pay back time. There exist thus a big savings potential that can be achieved by an integrated optimisation of the buildings architecture, thermal envelope and the technical HVAC systems.

A sustainable strategy for both heating and cooling is water based solutions utilising large radiant surfaces applying high temperature cooling and low temperature heating. Low energy consumption is this achieved by maintaining a mean operating water temperature (18–28°C) that is close to the ambient temperature. This increases the efficiency of heat sources such as heat pumps and enables the use of renewable energy and sources of free cooling. Radiant systems are embedded in the building's structure, which leaves visually clean surfaces, with no obtrusive and disturbing appliances, and flexible indoor architecture.

Low exergy systems

Both heating and cooling can in principle be obtained at temperature levels that are close to the ambient environment. A low delta T only requires that the heat transmission takes place over relative big surfaces as for example applied in under floor heating systems. The favourable temperature levels make it possible to utilise energy that in principle has a low quality, or more correctly a low exergy content. The exergy concept can be seen as a measure for the quality and availability of a given energy stream. I the recent years a number of international research and demonstration projects have been accomplish focusing on exergy optimisation of energy systems, including the LowEx programme under the international energy agency IEA. The conclusions underline that the future interaction between collective supply systems and the individual building will be a key element for improving the total energy efficiency on district level.

	System 1		System 2		System 3	
	T (°C)	Efficiency	T (°C)	Efficiency	T (°C)	Efficiency
Condensing boiler	80	0.95	80	0.95	80	0.95
Air-cooled chiller	7-12	3.1	7	3.1	7	3.1
Condensing boiler	55	1.0				
Air-cooled chiller	18	3.5				
Heat pump			55	4.05	55	4.05
Reversible heat pump			18	6.50		
Free cooling (ground water)					18	



Example of simulated radiant system performance based on a comparison between a system based on a radiant floor and ceiling for heating and cooling and an all air reference system. (Annual primary energy use per square meter of the conditioned area). The simulations are done with EnergyPlus v.3.1.0. and climatic conditions adapted from the IWEC (International Weather for Energy Calculation database of climatic data.

Optimal utilisation of energy sources

Water based systems such as under floor heating and under floor cooling are born as low exergy systems since they facilitate heating and cooling at temperatures close to the ambient environment. Consequently the systems can utilise all sort of energy supply very efficiently, in particular renewable energy sources such as solar, biomass, ground heating and heat pumps. The over all efficiency of most energy sources strongly depends on the supply temperature in the heating system, the lower the supply temperature, the higher efficiency. This is in particular the case for heat pumps and for condensing boilers (natural gas and biomass). For heat pumps a rule of thumb says that lowering the supply temperature in the heating system by 1°C will yield a reduction of the annual energy consumption by approximately 2%. If the heating system is designed with under floor heating operating at a supply temperature on 30°C instead of radiators with a supply temperature on 50°C this will yield and annual saving on the energy bill of about 30–40%, dependant of course on the heat pump type and other parameters.

Radiant systems

Heating and cooling systems with water conducted in pipes integrated in the floors, ceilings or walls of a building are named radiant systems, as more than 50% of the energy exchange is by radiation. Typically applied radiant systems for office environments spans from traditional under floor heating and cooling systems over various wall and ceiling integrated systems to thermally active building systems where pipes are embedded into the concrete slabs. Heat output of up to 100 W/m² can typically be achieved with floor and ceiling systems whereas cooling output of typically 60 W/m² is achievable with thermally active building systems and up to 75 W/m² cooling can be achieved with comfort panels for suspended ceilings.

Low temperature heating and high-temperature cooling is the key to energy efficiency in high-performance buildings. With a low-temperature radiant heating system, energy source efficiency will significantly increase in comparison to traditional, high-temperature systems and air heating. This results and reduced primary energy consumption. The feasibility and performance of thermally active building systems has been investigated with results showing energy savings of 25–60 % and thermal comfort yielding a decrease of extended air circulation of 25–75 %.

Integration of renewable energy sources

Using large surfaces as emitters allows heating and cooling at temperatures very close to that of the ambient environment. This means that renewable energy available from the ground, water, sun and air can be integrated and utilised with ease. Ground-source heating can be incorporated into the system via ground heat pumps. Combining a radiant cooling system with a free cooling source can reduce energy consumption by 80–90%, since traditional chillers can be eliminated and only electricity for circulation pumps is needed. Natural-ground water has ideal temperature levels for radiant cooling systems. Alternatively, the systems can be operated with sea-water cooling or solar cooling that uses absorption chillers.

Need for sustainable cooling

Several tendencies indicate that the cooling needs in the entire building mass will increase in the future. This is partly because we experience more extreme weather types with warmer summers and partly because people's requirements for indoor comfort are increasing continuously. New improved building codes with stricter requirements for the tightness of building envelopes also introduces significant cooling demands in summer. This applies in office and industrial buildings, where cooling is already widely used, but also increasingly in private housing.

Using a combined under floor heating and cooling system, the cooling need can be met by using floor cool-

BOB (Balanced Office Building), Aachen, Germany. A highly energy efficient office building controlled by advanced building technology. Heating cooling is provided by a TAB system fed by borehole heat exchangers in combination with a heat pump.

BO CAFOD Headquarters, London, England. Occupying a difficult triangular site, the building is an exemplar of sustainable workplace design with cooling provided by a Thermally Active Building System in the exposed thermal mass in situ concrete structure.

ing with a flow temperature relatively close to room temperature, typically at 15–17°C. With this favourable temperature level the cooling needs can be covered with minimal energy consumption, for example via free cooling with a ground-coupled heat pump.

Energy efficient cooling is also required for office and industrial buildings. In these building types it is in similar way favourable to utilise high temperature cooling solutions that can exploit free cooling sources and thus reduce energy consumption to an absolute minimum. Water-based cooling solutions in the form of chilled beams and cooling panels are well known in most European markets. Thermo-active constructions, primarily known from Central Europe, are gradually increasing their market share due to their favourable comfort characteristics and energy performance. The principle of a thermo active construction is that pipes integrated into the concrete and floors, whereby the building mass is activated. This is optimal for the thermal indoor climate, and in addition peak loads can be reduced substantially, as a part of the cooling needs are shifted to the non-occupied night hours when the building's thermal mass is cooled down.

In office buildings, the need for cooling is often much greater than that for heating. A major advantage of radiant cooling us the possibility to integrate free cooling sources for example in the form of ground water, sea or lake water. Combined with a radiant cooling system this can reduce the energy consumption for cooling as traditional chillers can be eliminated, and only electricity for circulation pumps is needed. Also with conventional cooling technology such as traditional roof top chillers, a radiant system will potentially yield energy savings.

In particular when using thermally active building system, it is possible to run the system during periods when the building is unoccupied. The system utilises the concrete's thermal mass storage and discharge of thermal loads. This conserves energy by reducing the load on traditional HVAC systems and allows using off-peak energy rates for lower operation costs.

Minimizing losses

In addition to a building's net heat requirements there will typically be a loss of up to 20% from the total heating system. This additional loss can be assigned to boilers, pumps, control, distribution, emissions, etc. Emission losses depends on the choice and positioning of heat emitters (under floor heating, radiators etc.) and the system's ability to maintain an optimum temperature profile and compensate for changes in heat demand over time.

This airport in Bangkok provides cooling and thermal comfort by combination of two separate systems: a displacement ventilation system with variable flow volume and an underfloor cooling system supplied by Uponor.

A significant portion of these system losses can be minimized by proper design and layout of system parameters such as emitter location in the construction, pipe spacing and dimensions. There are also significant savings to be gained through developing and implementing dedicated control algorithms. For example, Uponor has developed a self-learning control algorithm for floor heating systems based on pulsed heat input, which virtually eliminates control loss with a documented annual energy savings of up to 8%.

Conclusion and perspectives

A radiant heating and cooling system makes commercial buildings more energy-efficient, also when it is paired with a traditional HVAC system. The radiant system works with water temperatures close to the ambient temperature, which allows low-exergy design, resulting in reduced primary energy consumption. In order to utilise our energy resources in an optimal way, it is suggested that integrated low temperature water-based systems are a key element in the future construction design practice and energy system design. Thermal comfort with minimum energy consumption can be achieved using radiant heating and cooling systems in combination with appropriate conditioning of the indoor air. Heating can be provided at optimal efficiency using large emitters with temperatures close to ambient and the cooling loads can be efficiently removed at favourable temperature levels by using free cooling sources with a ground coupled heat pump. 3ε