Radiant heating and cooling systems are part of a low-cost, energy efficient building strategy that delivers a high degree of human comfort.

Radiant Solutions

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Sustainable buildings can be built without resorting to premium cost technical solutions, and at an overall lower cost than a conventional building.

In order to achieve this seemingly mutually exclusive solution, we only have to look back in history and stick to some fundamental laws of physics. Roman hypocaust heating systems used radiant heating coupled with building mass to maintain comfort in the cold northern European climates. Turkish aristocracy channeled cool stream water through their palace walls to provide effective cooling during the warm summers. These two systems use building mass and radiant heat transfer systems to create effective indoor comfort conditions, and were constructed and designed over two millennia ago.

Modern society has found many technical solutions to creating indoor comfort, usually considering the lowest capital cost solutions while sacrificing long term building performance. Unfortunately current methods of design and construction result in neither acceptable indoor comfort, nor good long-term performance and life cycle costs. In today's development market, the usual mandate is to try to use the lowest cost components and systems, while addressing the ever-intangible and complex indoor comfort and quality equations. This building delivery method leads to restrictions and a lack of imagination in terms of what the appropriate building systems approaches could be.

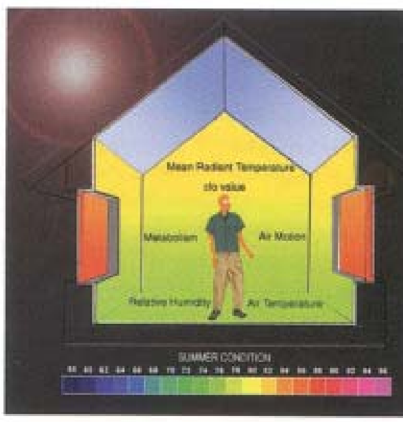
A building is, simply speaking, a man-made shelter from the outdoor elements. Building design issues such as the skin/envelope, thermal mass, glazing performance, daylighting, solar orientation and building thermal loads must be considered together in an integrated design team approach. If the entire building design team is involved as early as possible in the project design effort, many more mutually beneficial, innovative and cost effective solutions can be found.

Human comfort

Many studies of human thermal comfort have shown that the three fundamental factors are: 50% radiation; 30-40% convection; 10-20% evaporation (humidity/perspiration).

Unfortunately, typical North American building HVAC systems only address convection (moving a lot of air) and humidity control. Fully half the human thermal comfort equation is seldom if ever addressed. No wonder technical solutions like fast-acting control systems and a wide variety of air temperature control and air distribution systems have been developed.

Typical conventional "all-air" HVAC systems have been designed to move large volumes of conditioned air, which are flexible enough to be applied to any building, anytime, anywhere in any climate. They can handle high transient peak loads with relatively short response times. This is particularly critical due to the types of light curtain wall construction used on many commercial buildings, and the lightweight construction of other building types (wood frame residential, steel stud and built up exterior walls, etc.)



Above: radiation, convection and evaporation all contribute to human comfort and their impact on room temperature must be taken into account.

Most HVAC engineers' calculations and equipment sizing methods are based on the high peak thermal loads and short response times created by low performance envelopes.

In North America, radiant temperature control systems have seen limited use, primarily in suspended radiant panel systems or as radiant heating floor systems. Very few radiant cooling systems have been tried, and those have been based mainly on suspended metal panel systems, with varying degrees of success. The lack of successful radiant cooling and heating systems in North America is due in part to lack of knowledge, poor understanding of the control systems required and the inability of radiant temperature control systems to deal with the high thermal load variations of perimeter zones to interior zones in a building.

Radiant cooling is far less understood compared to radiant heating, and past misapplications have led to a general suspicion of this type of cooling system in residential and commercial buildings. Even radiant heating systems have had their share of horror stories, mainly due to incorrect application, wrong material selections and fundamental installation and control problems.

Radiant temperature control systems

The principle to finding the energy efficiency in a radiant temperature control system is to effectively disengage the temperature control function from the ventilation function of the HVAC system. Fan power consumes up to two-thirds of the system energy required for conventional all-air HVAC systems. Water can hold 3,000 times as much thermal energy as air. So, it makes sense that an energy-efficient HVAC system can be designed using a hydronic (water based) temperature control system, which would allow the air moving systems to be minimized to fulfill only the ventilation requirement.

Proper application and effective use of radiant temperature control systems can result in extremely good energy performance and a total solution to the human thermal comfort puzzle. The key to successfully implementing these systems is to start with the building envelope, to reduce the building thermal loads to a point where radiant systems can be applied economically. This requires a different approach to building design—a "building physics" approach where the design team can work in an integrated manner to optimize the building's relationship with the climate and site.

European building systems have recognized the radiant component of the human comfort equation, and radiant temperature control systems are widely used and have been functioning well for over two decades.

The most common method used for radiant cooling and heating systems in Europe is applied capillary tube sheets. Normally these consist of small diameter plastic tubing mats which are embedded into plastered walls and ceilings, or integrated into suspended ceiling panels. This type of system is relatively cost-effective, but still does not effectively make use of the building's structural mass for thermal storage and stabilization of the interior temperature.

The Swiss "building physics" approach has led to the development of the BATISO building concept (an acronym for *Batiment Isotherm*—constant temperature building).

The BATISO building system uses plastic tubing cast into the concrete structure of the building. Warm and cool water is pumped through the tubing to control the concrete slab temperature to create radiant cooling and heating as required. The exposed floor slabs are the primary space temperature control system. The high thermal mass of the building structure also enables great energy efficiency by delaying or offsetting the effects of transient thermal loads in the building—acting like a static heat pump. Coupled with a displacement ventilation system, much of the heat from lights and equipment can be removed from the space directly, resulting in a very stable indoor climate.

Capillary tubing systems

Capillary tubing mats offer more versatile installation schemes, and are also used for spot cooling or heating applications to supplement other building HVAC systems in many different building applications. It is a commonly used system in Europe for older building retrofits where space for ducts is minimal, but small diameter piping can be easily run through the building to provide cooling and heating where required.

The capillary mats can be zoned and controlled on a room-by-room basis, but this adds capital cost for the piping and controls work. Capillary tube systems are intended and used in Europe as primary temperature control devices, and are normally integrated with a displacement ventilation system for good energy performance.

Cast-in-place tubing

The in-slab tubing method and the applied-to-slab capillary tubes allow the building mass to work with the HVAC system as an energy storage reservoir (heating/cooling storage) in a "thermo-active slab" application. Once the building structure temperature has been stabilized, and the transient loads from the exterior (solar, heating, etc.) are minimized by the high-performance envelope, then the building HVAC systems do not need extreme operating temperatures or controllability to maintain a stable slab temperature year round. The thermal storage of the concrete slab will easily handle local transient loads (meeting rooms and offices) while maintaining a steady temperature control effect. Radiant heating and cooling is infrared energy which works at the speed of light and, since it represents 50% of the ideal human comfort equation (radiation component), it can provide superior indoor comfort, compared to conventional all-air systems. Imagine a warm, even hot, summer day, and you walk into a large concrete parkade. The cooler concrete creates a radiant cooling effect, and in spite of the air temperature being warm, you feel cooler and more comfortable. The concept here is to look at the resultant temperature of the space, rather than the air temperature.

Technical issues

The key technical issue is to get the interior cooling load of the building down to below 70-75 watts/m^2. In climates like the Pacific Northwest, the heating takes care of itself, as winter heat losses are easily met by building interior heat gains when high-performance glazing is used. In more severe winter climates, supplemental perimeter heating may be needed, depending on the extent and type of glazing and how cold it gets in winter. In fact, high-performance buildings in many areas of Switzerland and Germany, where the winter design temperature is –10°C to –15°C, do not require auxiliary perimeter heat at all.

Another issue to consider is the ambient relative humidity. The performance of chilled ceilings and chilled slabs is limited by the dew point of the air in the building. The lower temperature limit for radiant cooling systems is approximately 16°C, which prevents any condensation problems in most climates. It may be possible to use lower chilled ceiling temperatures in drier climates, or if dehumidification equipment is used in the supply air system (but this adds cost and equipment, which is what we want to avoid). The rule of thumb is, if the building cooling load exceeds 80 watts/m^2, a chilled ceiling or thermo-active slab is not going to be able to handle the load effectively, and alternate or supplemental systems must be examined. This cooling load is actually quite generous when considering a typical office building. Excluding perimeter solar load and heat gains due to transmission, typical internal heat generation rates are: lights, 15 watts/m^2; people (one per 15 m^2), 7.2 watts/m^2; equipment (computers etc.), 27.2 watts/m^2, for a total Interior Average Load of 49.4 watts/m^2.

As we can see, there is still a relatively generous allowance for some degree of perimeter heat gain. Properly executed, the minimal ventilation air supply (20 cfm/person or 10 litres per second/person) is "energy neutral" using a heat recovery system. This is primarily because much of the heat gain from lights and equipment is drawn off directly by the exhaust side of a displacement ventilation system, and should not result in a net local heat gain to the occupied space. The cooling energy required is also very low considering that the volume of air being circulated is much lower than a conventional system, and the supply air temperature is normally one or two degrees cooler than the ambient room temperature, so that the radiant slab water can be used for the cooling coil of the air unit. ca

Top: an example of capillary tube "mat" installation just prior to the application of a plaster ceiling.
Above: cast-in-place tubing is placed just before the concrete slab is poured at the ICT Building, University of Calgary.