GLOBAL WARMING AND INDOOR AIR QUALITY: HOW SUSTAINABLE BUILDINGS CAN HELP

*By Geoff McDonell, P.Eng.**

The energy crisis of the 1970's and 80's spawned a lot of knee-jerk design reactions among developers and designers of commercial and residential buildings. The desire to conserve energy led many people to create airtight shells, and reduce outdoor air ventilation rates in order to lower energy consumption and costs.

Unfortunately, the short-term gains were paid for by long-term pain. Indoor air quality, building envelope moisture problems, and mold issues raised their ugly heads and are now a leading aspect of construction project litigation. Many of the buildings and structures built in the last three decades have proven that we need to take a much harder look at what buildings want to be, and how they work.

While the "energy crisis" of the past is behind us, we now face the impact of our society's zealous use of fossil fuels and chemically laden lifestyle. This has given rise to "green buildings" and "sustainable development" initiatives, driven by many sectors, primarily the environmental movement. Global warming by greenhouse gases and indoor air quality issues are now growing issues, but there are ways to mitigate and solve these problems. Studies have been compiled that clearly show that the quality of our indoor and outdoor air at places of business, offices and homes cannot be underestimated in its value to increasing personal, workplace, and societal productivity.

PAST PROBLEMS

Buildings significantly impact the environment. They directly impact people's lives as well as the health of the planet. In the United States, buildings consume approximately 30% of the total energy produced, use 65% of all electrical energy generated, and require 13% of the water. Buildings also use up land and ecosystems that further degrade our environment. The atmospheric emissions generated as a result of the energy consumption of buildings, and building products, produce acid rain, ground level ozone, smog and global climate changes.

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Some air quality facts:

- Legionnaires disease was formed in poorly maintained air conditioning ductwork, and 29 people died as a result in 1976; [1]
- At least seven people are known to have died in the Los Angeles area as a result of Legionnaires disease; [2]
- Indoor air in some buildings has been found to be 70% more polluted than the local outdoor air; [3]
- People spend between 60 to 90% of their lifetime indoors; [4]
- It is estimated that poor indoor air quality directly results, on an annual basis, in over one billion dollars in medical care costs and up to $168 billion in lost productivity costs due to indoor air quality problems. [5]

The cost of litigation, and the resulting settlement costs are difficult to document, as many cases are settled out of court, but there are a number of notable cases that established the apparent costs of dealing with indoor air quality problems:

- Call vs. Prudential[6]
- DuPage County Courthouse[7]
- Polk County Courthouse[8]
- Martin County Courthouse[9]

Building designers are held to somewhat nebulous standards. The main standards to which most Heating, Ventilating and Air Conditioning (HVAC) design engineers strive towards is ASHRAE 62-1999 and ASHRAE 55-1992 for indoor air ventilation and comfort conditions. ASHRAE is the American Society of Heating, Refrigeration and Air-conditioning Engineers, and this group publishes handbooks of design standards as well as many other related technical standards.[10]

These standards are based on 80% of the occupants not complaining. That leaves at least 20% of the building occupants in potentially unsatisfactory conditions. Applying dollar values to this results in a pretty significant impact on productivity and lost revenue due to increased absenteeism and health care claims.

I believe we can certainly do a lot better than that!

Other regulations are available to add to the ASHRAE standards, such as the OSHA/NIOSH[11] requirements to health and safety. These standards require maintaining indoor air pollutants below certain concentrations, but given the varied types and sources of

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indoor air pollutants, coupled with the tight budgets of both building designers and developers, simple solutions are usually applied: move more air, and dilute and remove as many pollutants as possible. Unfortunately, heating and treating these higher ventilation rates results in higher energy costs and increased outdoor air pollution.

SOLVING THE PROBLEMS

In spite of the increasing risk to someone deciding to build a new building, there are many new building design approaches that minimize indoor air quality problems, and reduce our use of the fossil fuels that contribute to outdoor air pollution and global warming. Building designers now realize that an integrated design approach is needed.

In the past, the developer and architect came up with a building design, and then handed it off to various mechanical, electrical, and structural consultants to design the rest of the building systems. This normally results in a hodge-podge of approaches that may seem reasonable on their own, but once assembled into a functioning building it often leaves a lot to be desired for long term life cycle operations.

There are now growing mounds of evidence that "green" sustainable building approaches result in greatly reduced greenhouse gas/outdoor air pollution, and increased indoor comfort, as well as improved indoor air conditions. The net result is substantially increased revenue and productivity levels for the building occupants. Additionally, the reduction of outdoor air pollution lowers general health care costs for society.

Some examples:

- **Herman Miller SQA Building in Holland, MI:** For this re-manufacturer of office furniture, a new 290,000 sq.ft. showroom, office and production facility was designed by noted sustainable architect William McDonough & Partners. The project was intensively tracked to compare the business metrics for the old facility with the new building. The studies showed measurable increases in product quality, productivity and occupant satisfaction and performance.
- **West Bend Insurance Building:** A detailed study of West Bend's new "green" building was made by the Center for Architectural Research (CAR) at Rensselaer Polytechnic University in Troy, New York, which indicated that the West Bend employees experienced a productivity increase of 16% when compared to working in their old building. This represents a significant revenue generator considering the $13,000,000.00 annual payroll.

To facilitate an integrated design approach, everyone on the design team must be involved as soon as the developer decides he wants to build something. This way, the design team can work together for each other's mutual benefit, and create a truly functional project in which the building systems work together, in harmony, for the life of the building. When done properly, it will reduce operating costs and create superior indoor comfort conditions.

Siting and shaping a building to take advantage of passive solar daylighting and solar heating, in winter, will reduce the need for lights and energy. Natural ventilation can further reduce energy required to move air.

An integrated design team can lead to other innovative solutions, creating much better indoor and outdoor air quality. With the increasing frequency of "sick building" litigation, building designers must take more responsibility for our work, and provide better building designs.

In Europe, where people pay over four times what we pay for energy, the environment has taken a beating since the dawn of the industrial revolution. Outdoor air pollution, energy costs and human comfort issues are the same as they are here in North America. One European approach to building heating, ventilating and air conditioning systems that shows a great deal of promise for North America is radiant cooling and displacement ventilation.

Radiant cooling/heating operates at the speed of light...

Human comfort is made up of three main components - radiation, convection and perspiration/evaporation. Many studies have shown the total human comfort package depends on 40 to 50% radiation, 30 to 40% convection, and 10 to 20% perspiration/evaporation. Conventional North American HVAC systems provide for only half of this comfort equation, relying primarily on "all air" systems to control indoor comfort conditions by convection and humidity control. "All air" systems are defined as any HVAC system that uses hot or cold air as the primary space temperature control method.

A radiant cooling/heating system uses passive radiation as the primary space temperature control device, thus freeing up the air system to perform only the ventilation function. Over the last 20 years in Europe, the technology has been improved and understood so well that most new European office buildings and residential buildings use passive radiant heating/cooling systems with displacement ventilation systems. The construction costs and energy performance have been tracked, and these systems have improved energy efficiency, indoor air quality, and comfort conditions.

Recent studies at Penn State University, with dedicated outdoor air systems and suspended radiant panels, confirm the superior performance of these types of systems.[12] However, the key to making any radiant system work in North America is minimizing capital costs in order to pay for the high performance building envelope that is required to make these systems work.

A high performance glazing system (thermal resistance R value =3.9) must be used for two reasons:

1. to minimize the building perimeter thermal zone variances/transient transmission loads;

2. to ensure that the inner surface temperature of the glass is neither too warm or too cool compared to the desired indoor ambient temperature (otherwise the glass acts as a large radiant surface which "fights" the radiant cooling system). *(SEE GRAPHIC 1)*

Solar gain control minimizes the transient heat gains around the perimeter zones of the building during the summer, while still allowing the winter sunlight to penetrate the building and provide additional passive solar heating. This is very important because the design cooling capacity of a radiant cooling system is limited to about 100 watts/m2. This figure reflects the requirement of keeping the radiant cooling device's minimum surface temperature above the ambient dewpoint temperature of the space being cooled, to prevent condensation.

Once the total internal cooling loads (heat gains) of the building are below the 100 w/m2 threshold, radiant cooling is very applicable as a space temperature control method.

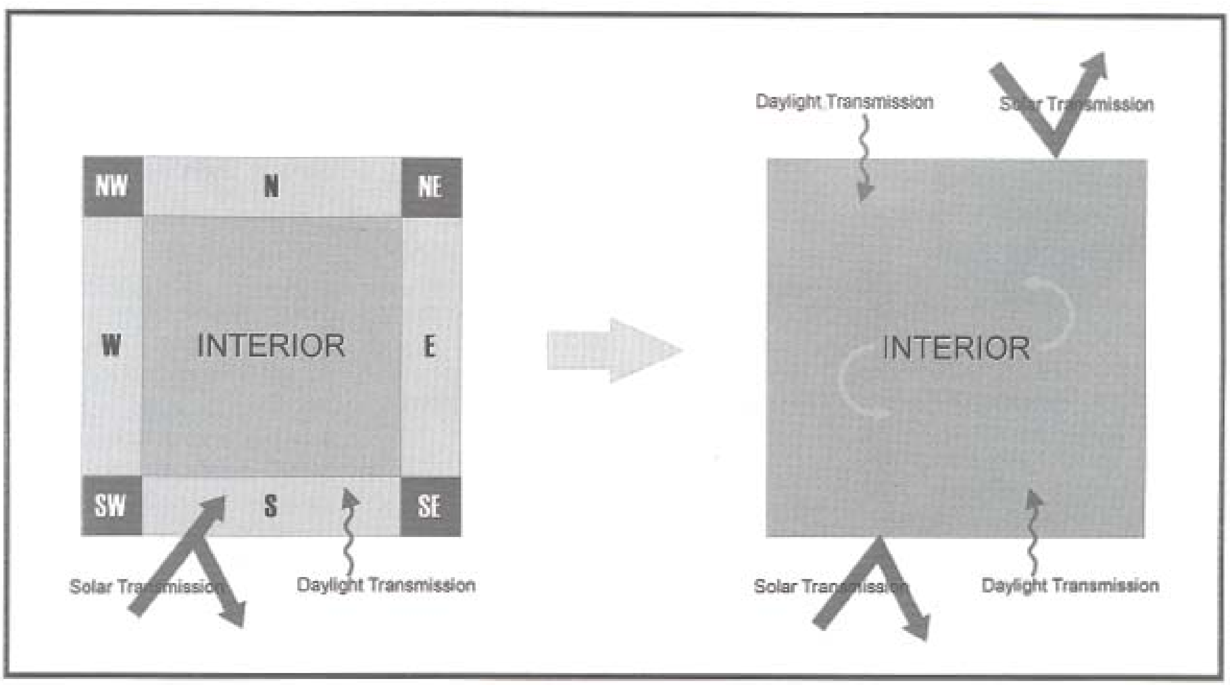
Just how much is 100 w/m2? Let's take a typical office building:

Lights @ 1.25 w/sq.ft.	= 15 watts/m2
People @ 1 person/150 sq.ft.	= 7.5 w/m2
Equipment @ 2 w/sq.ft.	= 22 w/m2
Total	= 44.5 w/m2

Therefore, a generous allowance for handling additional cooling loads exists within the "rule of thumb" operating envelope. That's not to say that the glazing and solar gain control around the perimeter zones can be allowed to climb - that would result in different thermal zones, requiring additional controls and system layout requirements. If the cooling loads in the building remain at similar average levels in all areas, then the radiant cooling system can operate with minimal sub-zone controls or other zoning design issues.

The most cost effective way to maximize the indoor temperature maintenance capabilities and the energy efficiency of a radiant cooling/heating system is to integrate it with the structure of the building, so that the building mass can act as a thermal storage element.

GRAPHIC 1



> **...these features do not need to cost "extra" compared to conventional building approaches.**

A concrete structure is an ideal case. Plastic hydronic piping can be cast into the slab to carry cool or warm water. The exposed slab would also be the finished ceiling in the space, to act as the overhead cooling/heating radiant source. Lighting could be accomplished with fixtures attached directly to the slab, or suspended using up-facing reflectors to make the ceiling a diffuse light emitter (providing less glare and more even lighting - ideal for heavily computerized areas to reduce computer screen reflections). *(SEE GRAPHIC 2)*

The perimeter glazing details could incorporate light shelves to direct more daylighting further into the building via reflectance from the slab ceiling. These shelves would enhance the overall energy efficiency of the building, because electrical lighting loads can be reduced to account for the daylighting.

The radiant slab concept allows the cooling load to be "offset" at night due to the thermal mass of the slab. Since the radiant slab only requires 64-65°F water to maintain the cooling capability, a simple fluid cooler (cooling tower) can be run at night to "recharge" the slab for service the next day. There are huge areas of North America where the nighttime ambient conditions would allow radiant cooling systems to operate this way.

Radiant cooling/heating operates at the speed of light - radiant energy is "self compensating" since heat exchange only occurs when temperature differentials exist in the space. If no lights are on, and no people are in the space, no heat exchange takes place. As soon as heat sources appear in the space, the slab absorbs the heat instantaneously. The huge thermal mass of the slab can deal with "instant high loads" extremely well.

Testing of radiant slab systems show that an empty meeting room can be filled and used for a 3-hour meeting,

> **Good examples of radiant cooling are all around us...**

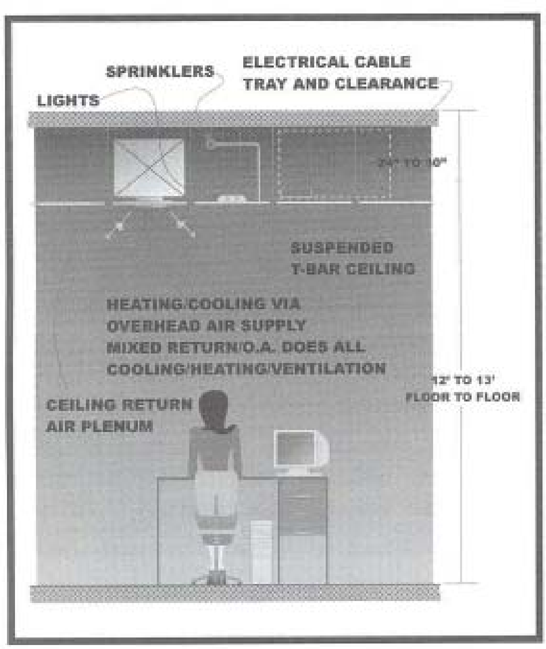
with the comfort conditions maintained perfectly.

When the indoor temperature can be maintained by a passive radiant system, the building air systems only need to supply the necessary ventilation air to remove indoor air pollutants. The generally accepted standards and operating statistics show that an average of 20 cfm/person of fresh/outdoor air, or 1 to 1.5 air changes/hour are needed to maintain healthy conditions inside the building. The key is to provide effective delivery of the ventilation air, while removing indoor air pollution at the sources.

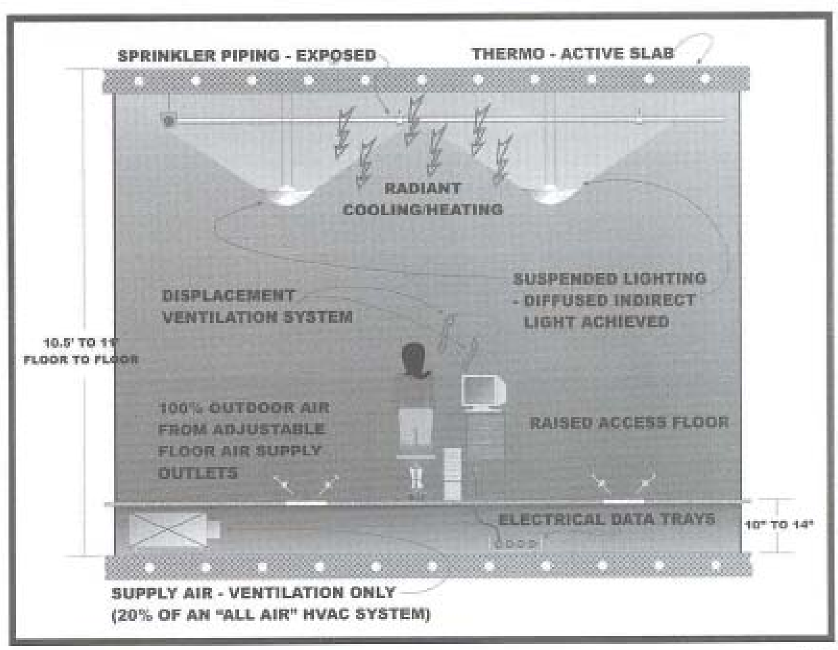
The most effective way to perform the ventilation in an occupied space is

GRAPHIC 2

Conventional System



Thermo-Active Slab System



to use a displacement ventilation supply air system. Since the overhead exposed ceiling slab is doing the cooling, the bulk of the building services would be best run in a raised floor. The raised access floor can be the supply air plenum allowing the 100% outdoor air used for ventilation to be supplied to floor outlets, or with the latest types of demountable partitions, to individual workstation desktop air outlets. *(SEE GRAPHIC 3)*

Displacement ventilation works by constantly replenishing a "pool" of fresh, filtered outdoor air at the floor level of the room. The heat from human bodies and equipment in the space causes buoyant air currents to draw the fresh air up where it stratifies at the ceiling level. As the warm air rises it collects pollutants, and high level exhaust inlet/ducts carry this polluted indoor air out of the building. Incorporating an air/air heat exchanger in a central ventilation/exhaust unit allows this system to be virtually energy neutral. Very little touch-up heating or cooling is needed to maintain the desired supply air temperature. The ventilation air temperature only needs to be within a few degrees of the desired room temperature, since this air is not doing any heating or cooling. This type of air system results in continuous flushing of the building with 100% fresh air, and exhaust terminals can be positioned to capture indoor air pollutants at their sources:

- photocopiers
- printers
- washrooms
- storage rooms

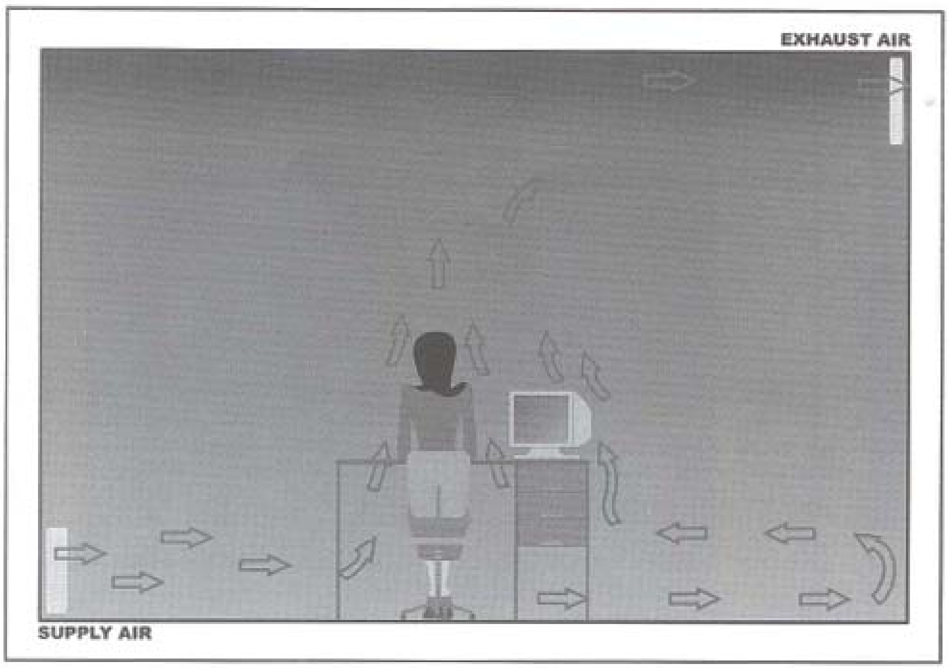
As mentioned earlier, high performance glazing is a <u>must</u> for this type of system to work. However, that does <u>not</u> preclude the use of open windows—in fact openable windows around the perimeter of the building are encouraged. The radiant slab system is essentially self-regulating, and since the perimeter transient thermal loads have been minimized due to the high performance glazing, the room temperature controls are minimal. However, any amount of personal control that can be provided to the building occupants will lead to more occupant satisfaction with the indoor air conditions.

Other possibilities that assist in enhancing indoor and outdoor air quality are:

- use low volatile organic compound (VOC) emitting furniture, paint and interior finishes

GRAPHIC 3

Displacement Ventilation Pattern



Displacement ventilation... system results in continuous flushing of the building with 100% fresh air, and exhaust terminals can be positioned to capture indoor air pollutants at their sources.

- use local materials so outdoor air pollution and energy consumption used to transport the building materials to the building site are minimized
- incorporate car pooling parking areas
- include alternative energy vehicle fueling stations for electric or natural gas powered vehicles

None of these features cost "extra" compared to conventional building approaches. In fact, a high performance building using a radiant slab/displacement ventilation system, and incorporating sustainable design features, can cost the same or less than a conventional building design. Such a high performance building will use up to 70% less energy, cause much less outdoor pollution/greenhouse gases, and have a much higher degree of indoor air quality and comfort.

Why aren't we pursuing this way of doing things? Barriers to implementing these radiant cooling systems in North America (which are becoming more common in Europe) are:

- perception that a green/sustainable building costs more than a conventional building
- lack of expertise in North America with radiant systems
- lack of incentives to improve on

the "tried and true" conventional "all air" systems approaches - engineering fees are commonly based on a percentage of the building construction costs, and many sustainable building approaches result in lower costs of mechanical and electrical systems, thus reducing potential fees.

- reluctance of building code officials to accept designs that go outside the bounds of conventional system approaches

All of these barriers are surmountable. There are numerous examples of how a sustainable building approach can result in a superior building project that enjoys a much higher degree of occupant satisfaction compared to conventional buildings. The design and operational information is available, and many of the buildings using systems described above exist, albeit mainly in Europe, but they have been operating for a number of years, with excellent track records. Good examples of radiant cooling are all around us - look at an open air concrete parkade for example: on a hot summer day, you can feel cooler inside the parkade, even though the air temperature hasn't changed, but you are surrounded by large areas of cool concrete that cooled off overnight, and take all day to warm up again. That cool concrete is providing radiant cooling.

This author has toured many of the European radiant slab buildings, spoken with the occupants, and reviewed the past performance of the buildings. There is no question that these systems do work and we should be looking at them for North American applications in order to reduce greenhouse gases, and improve our indoor comfort conditions. There are many examples of past radiant cooling installations in North America, but previous attempts were not as successful as hoped due to a lack of understanding of materials, cooling capabilities, and controls issues. A few good applications of building radiant cooling systems are now in operation in Canada and the United States, and these are being monitored for performance.

In North America, "buildings" contribute approximately 30% of the greenhouse gas emissions that we produce.[13] The increasing frequency of "sick building" litigation as well as the cost of lost productivity due to poor indoor air and comfort conditions are incentive enough for us building designers to "get with the program" and start designing better buildings.

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