European Green Building Technologies

A Report on Research Conducted for The Mechanical Contracting Education and Research Foundation

September 2008

YUDELSON ASSOCIATES

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Front cover: The 750,000-sq.ft. Lufthansa Aviation Center in Frankfurt, Germany, uses about one-third the energy of a conventional office building in Germany.

Photo by H.G. Esch, Hennef, courtesy of Ingenhoven Architekten.

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We conducted many interviews in the course of compiling this work; we greatly appreciate the time and expertise of these interview participants.

- Bill Watts, Max Fordham (London)
- Guy Battle, Battle McCarthy (London)
- Patrick Bellew, Atelier Ten (London)
- Terry Casey, Tridium (London)
- David Cook, Behnisch Architekten (Stuttgart, Germany)
- Andy Ford, Fulcrum Consulting (London)
- Alistair Guthrie, Arup (London)
- Christoph Ingenhoven, Ingenhoven Architekten (Düsseldorf, Germany)
- Mikkel Kragh, Arup (London)
- Maria Pons, Laing O'Rourke (London)
- Ty Saville, Somfy (London)
- Jürgen Lasar, Somfy (Rottenburg, Germany)
- Helmut Meyer, Transsolar (Stuttgart, Germany)
- J. Cramer Silkworth, Transsolar (Stuttgart, Germany)
- Tim McGinn, Cohos Evamy, (Calgary, Alberta)

Front cover: The 750,000-sq.ft. Lufthansa Aviation Center in Frankfurt, Germany, uses about one-third the energy of a conventional office building in Germany.

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EXECUTIVE SUMMARY

Continued challenges with the availability of fossil fuels and the impact of global warming are pushing building owners and developers toward projects that have a much higher level of energy efficiency. The challenge is that this efficiency needs to be provided, while at the same time supporting the overall building project goals including architectural, operational and occupant comfort. The result is the need for a "high performance" building where the building systems are pushed to deliver more, *without necessarily costing more*.

In the U.S., we are comfortable with the mechanical systems that are in broad use today. Other countries around the world, specifically selected European countries, are already long experienced in high-performance building systems using different concepts, technologies, products, systems. This report investigated several of these approaches, spoke with a number of systems experts, and looked at how European approaches could potentially be applied for use in North American markets.

The research consisted of a study of potential options, followed by in-depth research, and finally site visits to selected projects and interviews with European experts held in February, April and June, 2008. The results were interesting in a number of respects. We discovered several potential technologies that should be considered for use on projects in North America. Each of these technologies, however, also has challenges. Each must not only be properly designed, but must be carefully selected based on the project type, cost considerations and environmental conditions. In many cases, the systems we encountered used familiar components and climate-control mechanisms in different ways, but there is little that experienced mechanical contractors should find overly challenging. As with all climate control systems, each system must be properly commissioned, serviced and maintained to ensure operation in compliance with design intent.

We believe that mechanical engineers and contractors have much to learn from the European experience, and we're pleased to bring some of this experience to your attention.

INTRODUCTION

The green building movement in the U.S. and Canada has grown dramatically in the past few years, with projects registered under the Leadership in Energy and Environmental Design (LEED) system of the U.S. Green Building Council (USGBC) growing more than 50 percent in 2006, on a cumulative basis, and more than 75 percent in 2007 (Figure 1). New LEED registered projects in 2008 appear to be continuing the growth rate in 2007, with more than 4,438 new commercial construction projects registered in the first seven months of 2008 alone, suggesting more than 7,000 such projects will choose to begin pursuing LEED certification in 2008.[1] At an average size of about 100,000 sq.ft. and an average cost of $150 per sq.ft., such projects represent a new construction value of about $45 billion, close to 20 percent of the projected U.S. commercial and institutional construction market.

Along with this rapid growth has grown the impression that despite these large numbers, green building in Europe is still more advanced than in the U.S.[2] Some of this impression derives from a relatively few iconic buildings designed by leading European architects such as Foster and Partners (London) whose *Commerzbank* headquarters building in Frankfurt was hailed as the greenest skyscraper in Europe (it's also the tallest building in Europe, at 60 stories) when it opened in 1997. Other Foster projects including the German Reichstag (Parliament) in Berlin and the pickle-shaped "Gherkin" in London for Swiss Re have added to the impression.

In the past few years, leading European architects have begun designing large green buildings in the U.S. and Canada, using their engineering consultants from the Continent. One example is the Genzyme corporate headquarters building in Cambridge, MA, completed in 2004, which is the second-largest LEED Platinum building in the world. Designed by Behnisch Architekten with the help of Stuttgart, Germany-based "climate engineers" Transsolar, the Genzyme building is a masterpiece of natural ventilation, daylighting, natural climate control and energy efficiency in an urban high-rise office.

So we decided to investigate whether these achievements represented the work of a few outstanding individual firms or whether they were part of a larger trend that would soon find greater expression in the U.S. and Canada.

There were already good examples of European trends finding root in the U.S. A good example is the use of underfloor air distribution systems (so-called *displacement ventilation* approaches). These systems have considerable lifetime economic benefits, including energy savings, healthier indoor air quality and lower costs of office "churn" (changing work stations). They require considerable less fan energy than conventional overhead ductwork, since air is delivered through an underfloor space at very low pressure.

The author first became acquainted with such systems in 1997, when a mechanical engineering firm at which he was working designed some of the first such systems in the U.S., in Portland, OR. At that time, almost all of the information on such systems came from Germany; in fact, the manufacturers of the "floor diffuser" boxes were German. Since that time, hundreds of such systems have been installed in large open-plan office buildings in the U.S., despite their higher net first cost of $4 to $7 per sq.ft.

Another example of European technology that is making its way into U.S. practice is building-integrated photovoltaic panels, which were pioneered by another German manufacturer of building façades, Schüco.

One final example: the author worked from 2002 through 2006 at another Portland, OR-based mechanical engineering firm that designed what is currently the largest LEED Platinum-certified building in the U.S. (about 412,000-sq.ft.) This project set out to exceed the ASHRAE 90.1-1999

1 All data on LEED projects is courtesy of the USGBC staff, furnished to the author.

2 See for example, Nicholas Ouroussoff's influential New York Times magazine article, "What Do They Know That We Don't?" (May, 2007)

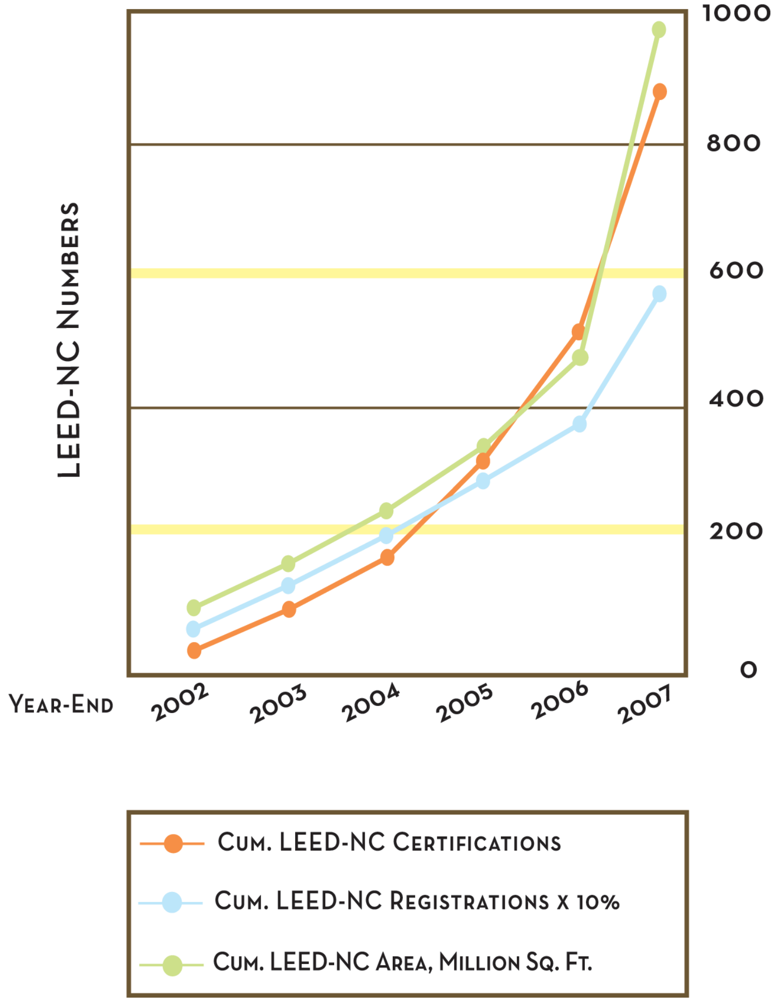


Figure 1. Growth of U.S. Green Buildings, 2002-2007, seen as LEED-NC Project Registrations, Certifications and Registered Project Area

standard (in effect for LEED projects when the design began) by 60 percent. The principal engineer for the firm looked at many different approaches to space conditioning and ventilation; one of the solutions was to install a large number of "chilled beams" to provide radiant cooling. The chilled beam technology that he found and specified came from Germany.

So, our investigation set out to discover what was happening "over the horizon" and to profile a few of the more important mechanical and systems technologies that mechanical contractors were likely to see showing up in U.S. projects, especially those with high-performance goals, such as LEED Gold or LEED Platinum. This is not a comprehensive view of European technology, but our best guess as to which technologies American and Canadian design engineers are likely to be using in the near future.

The purpose of the study is both to give North American designers and contractors a "heads up" about future technology changes and also to encourage them to go to Europe and see for themselves how these systems work. We also found that some of the leading engineers from the United Kingdom have already set up shop in the U.S. (language not being a barrier) and are actively including these approaches in their U.S. projects. These firms include Arup (formerly known as Ove Arup and Partners), the world's largest building engineering firm (with 10 U.S. offices) and Atelier Ten, a leading U.K. firm with an office in New York.

GREEN ENGINEERING IN EUROPE

American and Canadian engineers have learned a lot from the European experience with green and sustainable design. For quite some time, North American building engineering, especially for offices, has been stuck in a paradigm of using air-conditioning for both ventilation and space conditioning, resulting in excessive energy use and paradoxically decreased comfort.

Human comfort is based not just on temperature and relative humidity, but also on radiant temperature (the apparent temperature of surfaces), air flow, clothing and even controllability of systems. By removing the emphasis on radiant effects, dressing appropriately and having remote control of systems, we have effectively provided comfort in our buildings, but at a considerable energy and cost penalty, since most buildings are over-designed and over-ventilated. The last thing any design engineer wants to get is a call that the building just completed is "too hot."

At the same time, American workers have become accustomed to the carefully controlled environment, 73F plus or minus 2F, so that they can wear indoors whatever they please, no matter what the weather outside: wool suits and ties in summer, miniskirts in winter. This attitude would surprise most Europeans: they expect to wear warm, heavy clothes in winter and cooler, lighter clothes in summer. As a result, European designers have tended to rely more on radiant space conditioning, with a broader range of temperatures, typically with the opportunity for office workers to open the windows when the weather's nice outside.

With this background in mind, let's take a look at some current developments in European engineering. With a colleague, Paul Ehrlich, a professional engineer, I undertook a study of current developments in green building.[3] I also spoke with the presidents and partners of a number of German and English engineering firms, to get a broader perspective on their approach to low-energy design. One of the firms was Transsolar of Stuttgart, Germany, whose work is discussed in the next section. Another was Max Fordham, a longtime building services engineering firm with a sustainable design focus. Bill Watts is principal at Max Fordham in London. Watts is part of a large group of U.K. engineers trying to get buildings quickly to the zero-carbon level by focusing on high degrees of integrated systems and structure, along with carefully crafted renewable energy schemes.

One of the first things I noticed is that building services engineers or climate engineers in Europe appear to have a different relationship with architects than most mechanical and electrical engineers in the U.S. There is more of a partnership and less of a sub-consultant relationship. Partly this is cultural; partly it is a result of lower architectural and engineering design fees in the U.S.

One engineer, Patrick Bellew, president of Atelier Ten in London and one of the U.K.'s best known mechanical engineers, told me that engineers in the U.K. get about one-third more in fees; factoring in lower wages there, engineers have about twice as much time to spend on a project than in the U.S. Inevitably, this extra time will be reflected in greater time to study site dynamics, climate and other factors before beginning design and to participate in more iterations of architectural design.

In the U.S., the prevailing attitude of many building engineering firms is: "I only get paid to design the project once; when the architect has a final design concept, then we'll start our engineering work." As a result of this attitude (and it's based on hard experience), there is less of integrated design and more of a "serial" design approach, resulting in more separate systems with greater energy use and higher initial costs. I think there are also some cultural factors at work; basically, building engineers seldom study architecture, whereas all architects have to take at least one course in building systems. Nevertheless, their education and career paths are markedly different, making integrated design processes more difficult.

3 Paul Ehrlich, PE, is principal of Building Intelligence Group, LLC, www.buildingintelligencegroup.com

David Richards, a director of Arup (engineers and planners) in London, starts each project with six sustainable goals:[4]

1. Carbon-neutral
2. Water-neutral
3. Use of sustainable materials
4. Flexible design to adapt to future climate change
5. Make a positive contribution to the local community
6. Sustainable operations, including monitoring.

In Richards' view, every project needs a sustainable strategy, starting with these six objectives, then proceeding to specified outcomes that can be measured. From the outcomes, the team will then develop specific design themes and create a sustainable design plan. He thinks that engineers in the U.S. have 50 percent less time to think on projects, because of the fee structure and instead prefer to wait until an architect has mostly finished schematic design to step in and start fixing things. (Having spent seven years in New York City at Arup's office there, Richards is well qualified to expound on the differences in design philosophy and practice between the U.S. and the U.K.)

Andy Ford, president of Fulcrum Consulting, one of the U.K's premier engineering firms,[5] says,

> In terms of buildings, right now we're looking at long-term thermal storage. We're looking at seasonal thermal storage and ways of applying it directly to building construction. That covers such things as normal ground source heating and cooling. We're looking at what actually happens and how to promote that happening more effectively – how heat flows through the ground; how to get what happens naturally (the sun shines on the surface and it conducts heat into the ground); how to enhance that and control the temperatures you get within the ground better so you can then use them to heat and cool buildings. You can do that by pipe work with water flowing through them and you can do it by earth tubes and ducts running in the ground. You can do it by direct access by drilling a well into the ground and accessing the aquifer as a heat store. Where we're going at the moment is using all of those and *probably most actively it's aquifer thermal storage because it's applicable to very large-scale schemes. We're looking at inter-seasonal storage of heat – storing winter's cold for use in the summer and summer's heat for use in the winter, basically.*
>
> We're doing another project, which is thinking about how you do that for the 1851 Commission. Essentially, there's a big chunk of central London and contains Imperial College, the Natural History Museum and various other famous buildings. They're all under one single landlord. That landlord was set up by the Great Exposition that happened in 1851. We're looking at how we can manage the heat flow from about 80 different buildings using storage to move it around to where it's most appropriate at any given time. The different buildings heat up and cool down differently according to the way they're made and the types of usage. You've got some buildings that just need cooling and you've got some buildings that need vast amounts of heating. What you traditionally do is pump in electricity to cool a building and throw away the heat that's generated and you put in lots of gas and oil to heat a building and throw away the heat that comes out the building. The idea is to store both of those and move them between the buildings.
>
> We've come from a science background with a view of trying to make things simpler rather than a purely engineering background, which is just applying traditional solutions. In essence, the experience of living in buildings -- in parts of the world that have got seasons -- is that you have to heat your building in the middle of winter and you might well have to cool your building in the middle the summer. But there are edges to those seasons, when the building doesn't seem to need anything. It's quite happy in autumn and spring to be comfortable and everybody is happy with that idea and there's no real climate control systems going on at all. The key is to understand why some buildings have a long period when that's the case and others have a short period. If that's the case, [then the task we have] is understanding the physics of heat flow through the buildings. It would be really interesting to extend it deliberately.

4 Interview with David Richards, Arup, London, June 2008.

5 Interview with Andy Ford, Fulcrum Consulting, London, May 2008.

What would happen to sustainable engineering design if more engineering firms hired outside their discipline and brought on board scientists of various stripes? I'm guessing that the field would rocket in importance and influence. Let's take a look at the philosophy and practice of one of the leading engineering design firms in the field of green buildings, Transsolar, founded by Matthias Schuler and based in Stuttgart, Germany.

TRANSSOLAR AND THE NEW SCIENCE OF CLIMATE ENGINEERING

If I had to single out one of the two or three most important developments in Europe over the past decade, something that would dramatically affect how North American architects and engineers approach sustainable design, it would have to be the development of "climate engineering" as a practical science for building designers. And that development can be attributed directly to one person, Matthias Schuler of Transsolar, a climate-engineering firm he founded in 1992 based in Stuttgart, Germany, with offices now in Munich and New York.

Transsolar's company statement says, "the purpose of climate engineering for building is to ensure the highest possible comfort for occupants with the lowest possible impact on the environment."[6] In particular, Transsolar seeks to go beyond just energy conservation considerations of the building envelope, "towards a more holistic design recognizing the interdependence of comfort issues and integration of all building systems and components, by addressing simultaneously daylighting, natural ventilation, air quality, air temperature, acoustics and the well-being of individuals working in the building."

In Germany in particular, and in much of Europe, considerable attention is paid to what's called "building physics," seeing the building as an active system of constantly shifting internal loads, external inputs such as outdoor air temperature and solar gain, moisture moving into and out of the spaces, and interacting constantly with all the materials in the space. Looking at the building as a complex system requires complex modeling tools as well, since there are indirect and synergistic effects going on all the time. Within the next five years, most architecture and engineering schools will recognize not only the importance of buildings in mitigating climate change but also the central role of building physics in the curriculum for both disciplines.

What Schuler and his partners have done is simple and ingenious. They've taken building services engineering (we call it mechanical engineering) away from specifying heating/cooling systems and back into the full range of "design for comfort" considerations. For example, most engineering systems are specified today using three variables: air movement, relative humidity and air temperature. The standard approach considers comfort to be achieved when temperature and humidity are located inside a specified range on a psychrometric chart.[7] Air movement is regulated to meet minimum ventilation codes for fresh air supply. Most often, the amount of cooling needed in a modern office building provides adequate ventilation air as well. There's nothing wrong with this approach; it does work, it provides rapid responses to changing conditions and a reliable supply of fresh air. The problem: it is very expensive in both equipment and energy use. In fact, it's impossible to design a low-energy building using just mechanical systems alone. And using mechanical systems alone "locks in" today's technology for at least 25 years, the approximate economic life of the equipment.

Schuler says instead, let's start with a person's physiology and psychology and consider how the body responds to surface temperatures, operable windows, direct and indirect solar gain through windows, individual control of systems, etc. Let's consider radiant heating and cooling first, exterior fixed and moveable shading, stack-effect natural ventilation, operable windows, façades that admit fresh air directly, and so on. Expressed another way, mechanical HVAC systems should be seen as a symptom of design failures elsewhere in the building, rather than the first place to start with engineering design.

His philosophy is expressed in this statement: "sustainability in buildings is not limited to merely minimizing the energy requirements for heating and cooling but should consider the entire scope of user

6 ECOLOGY.DESIGN.SYNERGY, Behnisch Architekten and Transsolar Climate Engineering, 2006, p. 71.

7 See, for example, http://ohioline.osu.edu/aex-fact/0120.html, accessed August 9, 2008.

comfort, i.e., from a thermal, visual and acoustic perspective." To do this requires early engagement of the climate engineer, preferably as part of the competition team. Schuler says, "we realized right from the start that it is only by exerting early influence on the architectonic design that noteworthy impact on the future energy consumption and user comfort of the planned building can occur."[8]

David Cook, one of Behnisch Architects' partners told me that their collaborations exemplify the essence of integrated design. When Behnisch gets a new commission, says Cook, they invite Thomas Auer (a Transsolar partner) over to have a cup of espresso in the kitchen (or on the back deck in good weather) and communicate the basic design approach to him. Then a few days later, Transsolar will come back with a few engineering concepts that work with that particular design concept; from then on, it's an iterative process in which the building systems and architecture are developed in tandem, not in sequence as is the case with most U.S. projects.[9]

Transsolar's approach is not just to give the architect a blank sheet of paper, but also to create a "climate of discussion" and define the design parameters from the beginning. That way, the architectural design stays informed about the building physics through the early design process, rather than producing a design that is really expensive to build and operate. When architects and engineers work together as equal partners in this way, great things can be achieved.

Meyer explained further the firm's approach:[10]

> Typically the design process here in Europe is kind of like reinventing the wheel. Projects start from scratch. There's the impression that you are doing something completely new. In the U.S., the approach for quite a lot of projects is using the same principles for the production of many, similar buildings. Therefore, I think the intent of the design process is different. I think even the money which is spent on the design process is higher in Europe then in the U.S. But I think, overall, project costs are really comparable.
>
> Here, the approach is that your building has to be integrated into the environment. Typically each city has a building development center, which defines quite a lot of requirements and rules for the buildings for example, that appearance of the building has to be in a certain range.

Transsolar believes that most U.S. buildings are over-ventilated, because the ventilation and space conditioning systems are the same. As a result, quite a bit of bad air is recirculated, to avoid losing so much of the coolness to the exhaust air stream. Transsolar prefers to use water as a heat transfer medium, instead of air, since water will transfer 1000 times as much energy as air for the same temperature difference.

Transsolar also believes in individual temperature controls wherever possible. Meyer points out that an automobile is a good example of awful thermal conditions – in the winter it's terribly cold until it gradually warms up, and in the summer it's beastly hot until the A/C kicks in – that we willingly put up with, because we have control over the temperature settings. The same is true in buildings; if we want workers and other occupants to put up with lower temperatures in winter and higher temperatures in summer, for example, then we must give them control over the environment through individual temperature controls, operable windows and other means.

Transsolar also practices thermo-active slab cooling (such as chilled ceilings) wherever possible, using radiant cooling, along with operable windows and a small radiator for cold winter days. Displacement ventilation, which provides one-pass air through a space from below, is used to provide enough ventilation air, even in a building without operable windows. The firm believes in using "active slabs" that provide both radiant space conditioning and thermal energy storage together (see Figure 2). The only real drawback of this system is that it has to be properly operated 24/7, since it won't respond as fast to changes in sunlight, outside temperatures and internal loads as a standard overhead ducted air conditioning system.

8 Thierfelder, 2003, book jacket quote.

9 On this subject, see my recent book, Green Building through Integrated Design, especially Chapters 3 and 4.

10 Interview with Helmut Meyer, July 2008.


Figure 2. Thermo-active slab

Transsolar says that the greatest advantage of a thermo-active slab is that it can use relatively high-temperature water for cooling and relatively low temperature water for heating. As a result, it's easier to operate the system with natural energies, particularly ground-coupled heat exchangers. During the cooling system, the heavy reliance on the thermal mass of concrete slabs provides a "thermal lag" that offsets peak cooling loads, so that the size of the cooling equipment can be reduced and operating efficiency improved (because the system is operating less of the time at partial loads).

Some of the basic design principles are deceptively simple, but hard for clients to grasp their merits:

1. No deep plan floors in buildings, since they don't give good outdoor views or daylighting.
2. Everyone has to have adequate daylighting; a daylight factor of two percent is minimal and three percent is preferred. If windows are five feet in height, then the interior office depth can't be much more than 33 feet (10 meters) between windows, far less than most U.S. office buildings. Room depth to facilitate adequate daylighting depends on both window height and ceiling height, along with reflectivity of the ceiling.)
3. All flat roofs have to be green. This gives a greater thermal barrier and reduces the urban heat island effect, which lowers the local microclimate temperatures and reduces cooling demand in the building (during the summer).
4. Double-skin façades have a great use in most northern climates, providing natural ventilation and better climate control. (There is clearly an initial cost penalty, and North American manufacturers may not be able to meet European tolerances for complex façades.)
5. Reduce the use of HVAC by substituting radiant beams; this also means there is no need for suspended ceilings in buildings (in fact, they work against this system) but it does mean floor coverings can be normal carpet, for acoustic control. In this case, there will be perimeter decentralized heating units, since the window zones are likely to be cold in winter.

There are a lot of subtle variations to Transsolar's approach. One important new project is a 690,000-sq.ft., 22-story headquarters office for Manitoba Hydro in Winnipeg, Canada designed by KPMB Architects, Toronto. The annual temperature swing in Winnipeg is more than 70C (126F), from minus 35C (-31F) in winter to plus 35C (95F) in summer. Winter air is completely dry, while summer air is humid (think Minneapolis in the U.S.) It's also a very windy region; Winnipeg has been described as the windiest large city in North America.

Quite a challenge for climate engineering! Thomas Auer's proposed solution is a 22-story "thermal chimney" (Figure 3) integrated with the architecture on the north side of the building, to promote natural ventilation. On the south side is a six-story chain of nearly 300 flat Mylar® strips, with water running down them. In the winter, the water evaporates inside the building, adding moisture to the dry air to make it more comfortable. In summer, the water is cooled, adding cooling to the building and condensing water from the humid air, to reduce humidity, also making the interior more comfortable. And, it's an art feature as well!

Consider some of the new design approaches on a project at Harvard, a new biosciences complex. In that project, 50 percent of the space is taken by research labs that need tight environmental controls. In this case, the design approach is to slow down the air movement, to reduce pressure drops in the ventilation system. The project will also use an enthalpy wheel, a technology that allows outgoing air to give up much of its heat or coolness to incoming air (depending on season), saving as much as 50 percent of air-conditioning costs.

At this Allston Science Complex (expected completion 2010), with a gross floor area of about 1.1 million square feet (100,000-sqm), Behnisch Architekten and Transsolar are teaming up to redefine the environmental performance of a state-of-the-art lab, with a goal of reducing primary energy consumption by more than 60 percent compared with a reference "standard" lab building. Progressive design standards at this lab include:

- flexible programming of occupancy
- use of geothermal sources, or ground-coupled heating and cooling
- wind turbines for power production
- natural ventilation
- advanced methods of heat recovery and reuse, including returning air from offices for use in the laboratories (to capture the energy benefits of the already cooled or heated air)
- roof gardens
- interior winter gardens
- rainwater recovery and reuse
- specific wind and solar strategies
- sophisticated façade systems
- daylight enhancement systems
- tempering of incoming air through an air duct in the ground.

Figure 3. Thermal Chimney design at Manitoba Hydro

Speaking of the design process for the Harvard lab, Transsolar's Meyer says:

> We introduced enthalpy wheels for total energy recovery. It was not possible to use them for lab exhaust due to the pollutants in the exhaust air. However, in the past couple of years, coding for enthalpy wheels was introduced, and that minimizes the risk of reintroducing contaminates into the make-up air. We reduced the number of air changes in general to the hygienic minimum [of about four ACH, which saves lots of energy]. We have natural ventilation for the workspaces, a high-performance façade and exterior shading for solar and glare control. The building is aiming for LEED Gold.

Many of the systems listed above are already in use individually or in groups, at various high-performance projects around the U.S. and Canada. What makes Transsolar's work unique and valuable, in my opinion, is the tight integration with the architectural design based on careful studies of the local climate conditions.

Schuler believes that the rapidly growing concern about climate change and minimizing energy use in buildings will have a dramatic change in how architects approach sustainable building. He believes that "the planning team should set itself "the target of sustainable building as a basic requirement" for any project, which will then result "improved comfort and reduced energy consumption." In 2003, he said that "the architecture of today should accept the fact that limited energy resources and climate protection are now [as important] a fact of life, as is the case with fire protection or universal access issues, and use this as a basis for creating new ideas."[11]

11 Matthias Schuler interview with Friedrich Dassler, in Intelligente Architektur 07-08, 2003, at page 38.

DRIVING FORCES IN EUROPE

Before we dive in to the specifics of various technologies, it might be useful to consider whether the extensive northern and Western European use of sustainable design and green technologies is due to specific cultural, climatic, political and economic factors that might not be found in the U.S., making comparisons relatively meaningless.

CLIMATE

1. Most of the innovative European technologies come out of Germany and the U.K., as well as Switzerland, Austria, Holland and Scandinavia. These countries tend to have cold winters and relatively mild summers, with less humidity than is found in the U.S. In that respect, engineers are designing for mostly a different climatic situation, in which heating energy use is far more significant than cooling energy use. Latitudes range from 47 in Zürich, to 50 in London and Frankfurt, to 59 in Olso and Stockholm. (The northern border of the U.S. is mostly at latitude 48, so most of central and western Europe is farther north than any major U.S. city; for example, Boston is at 42 degrees.)

2. The counter to this notion is the fully sealed, all-glass skyscraper office building, which requires air conditioning year-round for comfort, almost no matter what the climate.

3. The climate in the U.K. is quite mild, certainly by Central European standards, with no location more than 60 miles from the ocean. In that respect, London's climate is probably quite similar to the coastal zone of the western U.S., from San Francisco northward.

CULTURE

1. The lack of daylighting in most large floorplate, open plan offices would make European engineers quite uncomfortable. Daylighting of all workspaces is pretty much a cultural norm. As a result, European office buildings tend to be less "efficient" from a real estate viewpoint, with a lower ratio of net to gross leasable area, given that all buildings of a certain height need about the same amount of core space for elevators and restrooms.

2. For example, German building regulations require that a permanent workstation have direct access to fresh air and natural light; therefore, the maximum distance from a window is limited to 5 meters (16 feet), unless the ceilings are higher.[12]

3. Europeans don't seem to be as sensitive as Americans to temperature excursions in the workspace. They find somewhat comical Americans' insistence on wearing the same clothing in the office year-round and expecting the same 73F temperatures, with little variation. This expectation of year-round constant air temperature is a great hindrance in adopting natural ventilation and radiant space conditioning systems, which can't promise the "instant response" of overhead-ducted, forced ventilation systems.

4. We're beginning to see some movement on this front, especially since 2004 when ASHRAE published its "adaptive comfort" research and standards. However, one issue is that most office leases still specify rather narrow temperature bands.

5. When to open the windows to let natural ventilation into the building is a major stumbling block to wider adoption of such systems. In a visit to a Norwegian building with operable windows in 2002, I asked our tour guide who would decide when to open the window for each group of 30 people; the response was "the group's manager." Can you imagine an American manager even wanting the responsibility for making that decision?

12 Behnisch Architekten and Transsolar ClimateEngineering, "Ecology, Design, Synergy," exhibit catalog, 2007, p. 60.

6. European design engineers appear to garner higher fees, somewhere between one-third and one-half more, than their U.S. counterparts. This allows for more time to be spent in investigations and analyses, which in turn can (but does not always) lead to more innovative solutions.

POLITICS

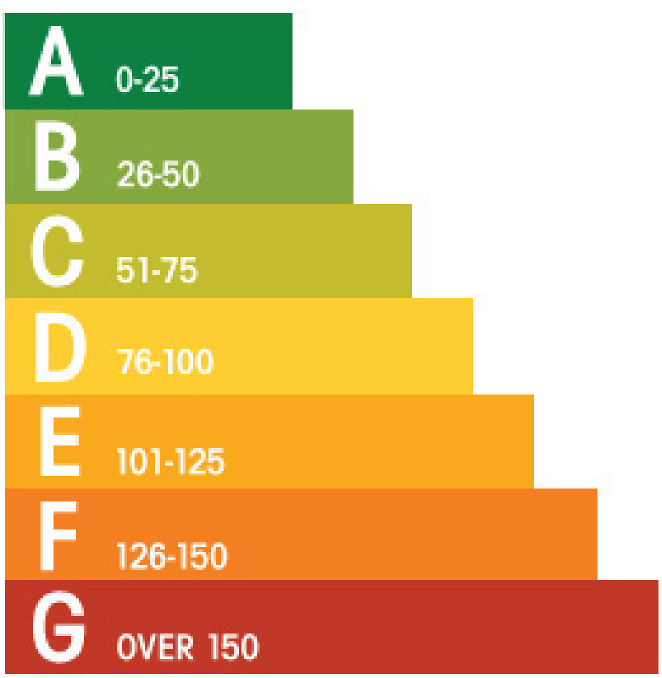
1. The European Union adopted its Energy Performance of Buildings Directive (EPBD) in 2002. Individual countries are responsible for implementation by 2010. The goal is to reduce energy use in buildings to help meet the "Kyoto" targets for greenhouse gas emissions. As one example, the German government wants to reduce greenhouse gas emissions 40 percent below 1990 levels by 2020. (By contrast, at the recent "G8 Summit," President Bush pledged only that the U.S. would meet 1990 levels by 2050.)

2. The most aggressive response so far to the EPBD has been in the UK, where the national government has pledged that all new public housing (a much larger component of housing construction than in the U.S.) would be "carbon-neutral" by 2016, all new private housing by 2018 and all new commercial buildings by 2019.

3. During 2008, the U.K. is implementing Energy Performance Certificates (EPCs) for all new commercial construction, which will publish the projected energy use of new buildings and give them a grade from "A" to "G," A being the best, essentially a "zero net carbon" building. We expect the simple task of grading the buildings will lead to a dramatically increased demand from commercial building owners, developers and operators for low-energy building engineering services in the U.K. In turn, this should spur innovation and adoption of new design approaches and new energy-efficiency technologies. In Figure 4, the "D" rating is just slightly better than the national average for building energy use, expressed in terms of kWh/sq.m. per year.

4. Other countries in Western Europe are required to follow suit in the next three years, so that the entire European Union will become a hotbed for building technology innovation.

Figure 4. Energy Performance Certificate Graphic



ECONOMICS

1. Energy prices have historically been higher in Europe, since governments have taxed fuels more than in the U.S. As an example, in April 2008 diesel prices in Germany were about $9.00 per gallon (€ 1.49 per liter). Because economics is a primary driver of behavior, one could ascribe a lot of European emphasis on low-energy solutions to economics rather than culture, but people we interviewed saw this approach as much a moral issue as an economic one.

2. The psychology of saving energy is more deeply ingrained in Europe than in the U.S. because of a long history of higher fuel prices. Of course, all countries are in shock with the three- and fourfold increase in crude oil prices that began in 2004, and energy conservation has become even more of a practical economic imperative.

3. Electricity prices in Düsseldorf, Germany in 2008 appeared to average about the equivalent of 17 cents per kWh, certainly higher than most locations in the U.S. Higher electricity prices make investments in energy-efficient technologies more attractive.

4. Economics drives most change in the advanced economies. Higher energy prices in the U.S. are going to drive us more toward European approaches to comfort engineering that place greater emphasis on radically improved energy efficiency without adding initial cost.

40 Grosvenor Office Building, London
Courtesy of HOK

DRIVING FORCES IN THE U.S.

Let's look at the forces driving sustainable design in the U.S., just to see whether we're subject to the same or similar forces that will drive innovation in climate control systems.

CLIMATE

1. The U.S. has a far greater diversity of climate zones than most of northern and western Europe, where the greatest amount of green design and green engineering innovation is taking place. Therefore, we are unlikely to be able to use European approaches throughout the U.S., without significant adaptations, especially for the hotter and more humid regions.
2. Global warming will cause two things to happen. First, we'll have to design in general for warmer climates, or at least "future proof" our buildings for this possibility. Therefore, figuring out how to meet the goals of both comfort and economics are going to be challenging.

CULTURE

1. As the U.S. culture continues to become more diverse, there is an opportunity to change the behavior of building occupants, to accepting greater temperature swings in the office workplace.
2. The best way to do this is with occupant education and with building systems that work autonomously or anonymously (a green light for example as a signal to open windows during the fall and spring "shoulder" seasons.)
3. Designers and contractors must engage with building occupants before imposing new climatic regimes on the building, to get their assent and to educate them as to their operating responsibilities.

POLITICS

1. The shock of high oil, gas and coal prices is likely going to drive political change toward mandating higher levels of building energy efficiency, along with providing incentives for making this change.
2. There is every likelihood that following the 2008 elections, the next President and the next Congress are going to grapple seriously with domestic energy prices and building practices; mechanical contractors and engineers are in a unique position of offering solutions to building energy use that have positive life-cycle costs.
3. States are unlikely to wait for federal action. Already California has enacted far-reaching legislation (AB 32) to control greenhouse gas emissions. More than 20 states already require LEED Silver or better performance from their own buildings.
4. More than 700 U.S. mayors have adopted the U.S. Conference of Mayors' Climate Challenge, committing their cities to reducing greenhouse gas emissions below 1990 levels by 2012. They need to cut building energy use dramatically to have a chance of even approaching these goals.

ECONOMICS

1. Economics is driving architects, building owners, engineers and contractors to seek out high-performance building solutions, an approach that will inevitably popularize European design approaches.

2. There are an increasing number of projects that are demonstrating high levels of energy savings on conventional budgets[13]; this will increase demand from owners and developers for engineers and contractors to achieve the same results, again driving design and construction toward European approaches and toward integrated design methods.[14]

3. The life-cycle costs and benefits of high-performance buildings are shifting as energy prices rise and the costs of achieving superior results continues to fall. Innovative financing methods are arising to fill the gap, ranging from the established energy service companies (ESCOs) to more innovative municipal and nonprofit financing, such as that found in the Clinton Climate Initiative (CCI.)[15]

4. The "jury" has now reached a definitive verdict: LEED certified and ENERGY STAR-rated buildings get higher rents, greater occupancy and higher resale values than their competitors.[16] This will drive the rapid adoption of such buildings throughout the U.S. and Canadian commercial sectors.

5. European buildings are expected to last much longer than American buildings, up to 100 years. As a result, budgets tend to be larger, systems are more robust and projects are allowed to take much longer from initial design to occupancy than in the U.S.

The basic conclusion is that we are going to see dramatic changing in building ventilation, space conditioning, climate control and similar systems over the next fie years. Many of these technologies, systems and products will derive from current practices in Europe, especially in Germany and the United Kingdom. Progressive mechanical contractors should begin preparing now for the expected surge in new designs and specifications from consulting engineers and requests from building owners and commercial developers.

13 See for example, "Engineering a Sustainable World," the story of the Oregon Health & Science University's Center for Health and Healing, the world's largest LEED Platinum certified building as of mid-2008, obtainable through Interface Engineering at www.interfaceengineering.com.

14 See, for example, my forthcoming book: Jerry Yudelson, Green Building through Integrated Design, 2008, New York: McGraw-Hill Professional, in press.

15 See the information on the CCI at www.clintonfoundation.org.

16 See, for example, the work of Professor Norman Miller at the University of San Diego, with colleagues Jay Spivey and Andy Florance of CoStar, "Does Green Pay Off?" in the Journal of Real Estate and Property Management, forthcoming, July 2008, 21 pp.

WHAT CAN WE USE TODAY?

We put this question to Tim McGinn, an engineer and principal at Calgary-based Cohos Evamy architects and engineers. Tim is one of the leading engineering practitioners of sustainable design in Canada and also a national speaker for ASHRAE. Here's his list of ten technologies and approaches that might have good transferability from Europe to North America:[17]

1. Design briefs concentrating on low-carbon design rather than solely a low-energy design, where the low-carbon design would include reducing embodied energy.
2. Use of earth tubes for preheating/precooling outdoor air.
3. Decoupling of ventilation and cooling, predominantly using displacement ventilation with radiant cooling (chilled ceilings, radiant-slab systems for low-temperature heating and higher-temperature cooling).
4. Increased incidence of using extensive thermal mass in thermally active building systems, including slabs.
5. Mixed-mode (fan-assisted) natural ventilation through central stack atrium also used for daylighting.
6. Chilled beams (to a limited extent in the right applications).
7. On-site use of renewable energy from wind and solar, to geothermal, and moving toward cogeneration/tri-generation systems with biomass fuel.
8. District cooling and heating to allow for more effective application of renewable energy towards a low-carbon approach.
9. A well developed market that can support equipment manufacturers providing space-effective, modular packaged systems that provide high efficiency and reliability (for such applications as gray-water reuse, rainwater reuse, heat recovery ventilation, solar domestic water packages, integrated boiler heating systems).
10. Exterior active solar control systems, such as moveable shades and shutters.

Every one of these systems can be engineered and built in the North American climatic and cultural conditions. None of them requires new technology. Many of these approaches are already being used by more determined green architects and engineers, for example, underfloor air distribution systems, light shelves and displacement ventilation systems. However, one cannot say that they are "mainstream" technologies yet in any way.

For the balance of this report, we're going to concentrate on an in-depth examination of three approaches: radiant heating and cooling systems, active façade systems and the user interface with building controls, along with systems integration. There's a lot to learn from a detailed examination of these three systems.

17 Interview with Tim McGinn, September 2008.

OVERVIEW OF TECHNOLOGIES

Our research examined in detail three European building system technologies and their status of or potential for adoption in North America. In this report, we describe each building system technology conceptually, with considerations for design and application. We include challenges and impediments presented by the North American, and in particular, the United States' markets. Finally, we reference and picture examples of both European and North American buildings employing the technologies to illustrate the technologies in use.[18] Here, we address three important building system technologies:

- Radiant heating and cooling
- Active façades
- Building system user interface and system integration

RADIANT HEATING AND COOLING

Radiant heating and cooling systems rely on the distribution of hot or chilled water throughout a building structure as opposed to more conventional North American systems that rely on the distribution of cool or hot air using ductwork. As the name suggests, radiant systems directly heat or cool the occupants through radiative heat transfer as opposed to convection or other means. Depending on the type of radiant system applied in a given building, it may also take advantage of the thermal mass of the building structure. Radiant heating and cooling systems found application in ancient times in Roman and Middle Eastern structures.

When applied in the U.S. radiant systems are used almost exclusively for heating, and are becoming increasingly common in residential and are even selected commercial projects. In Europe radiant heating systems are used broadly for both residential and commercial applications; in certain areas they are also being used for cooling as well.

CONCEPT

Radiation presents the most significant heat transfer mechanism between the human body and its surroundings. Other means in order of magnitude include convection, conduction, and perspiration. Therefore, radiant systems are generally thought to provide the best environment for human comfort. In both radiant heating and cooling systems, the preferred installation location is overhead in or on the ceiling where it "mimics the overhead sun and clear night sky effect that we have been subject to for millions of years of evolution." (See Figure 5).

The most important caveat on radiant cooling and heating systems is that they do not provide for ventilation, and a complementary outdoor air system is typically required for ventilation purposes. Furthermore, radiant cooling systems provide only sensible temperature control, and do not account for latent, or humidity, control. In the case of radiant cooling systems, the potential for surface condensation presents a significant concern, and depending on climate, humidity management may require a separate, complementary system to control moisture levels, as well as a commitment to a sealed building.

18 This section is largely the work of Paul Ehrlich and Jeff Seewald of Building Intelligence Group.

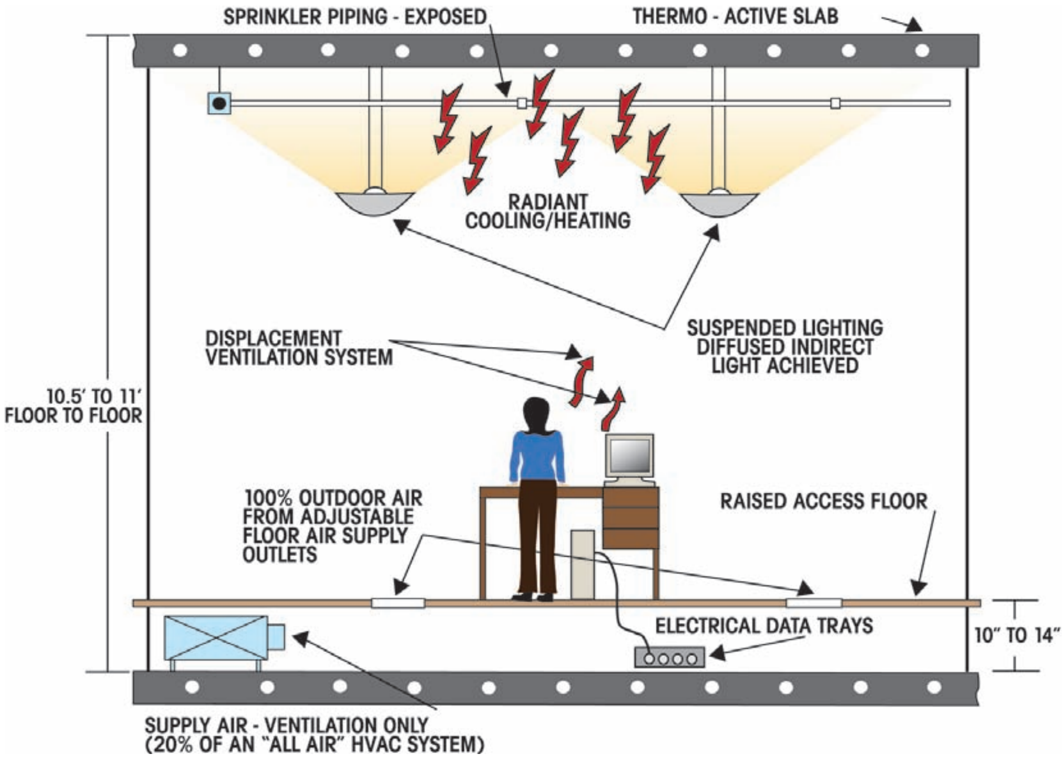


Figure 5. Radiant heating/cooling concept[19]

There are three common physical means of facilitating heat transfer between the water and the building occupants:

- **Panels and Beams** Metal panels or beams containing tubing are surface mounted, embedded on floors, walls, or ceilings, or suspended from ceilings. (See Figure 6 for a photo of an active chilled beam, with integral sprinklers and lights.)
- **Slabs (Embedded Tubes)** Plastic tubes are embedded in the structure to provide the conduit for water, while the structure acts as thermal storage and radiant surface. This is typically done with a high thermal density concrete slab (sometimes called an active slab) in either the floor or ceiling. Tubes can also be run below other flooring materials including wood floors and carpet using special sub-floor or insulating panels. This option is less effective since there is more insulation and less mass then the use of a concrete slab.
- **Capillary Tubes** Mats containing small closely spaced tubes are embedded in plastic, gypsum, or plaster on walls and/or ceilings. The end result is similar to a slab. This type of installation is more common in smaller installations, including residential installations.

In all three methods, a mechanical system is responsible for cooling or heating the water. Such systems include:

- Chiller or chiller plant
- Heat pumps, including ground source heat pumps
- Boiler or boiler plant
- Cooling tower
- Well water or other ground water

19 Adapted from Consulting-Specifying Engineer magazine, accessed June 30, 2008, www.csemag.com/article/CA6492841.html. Adapted with permission of CSE magazine and Geoff McDonnell.

Figure 6. Active Chilled Beam

One reviewer of this report, Professor Mike Feutz of Ferris State University, commented:

> "The radiant heating and cooling systems involve piping or tubing and a terminal device that is a bit different than we're used to, but to an MCAA contractor, the methods of routing the pipe/tubing will be familiar and the new terminal devices will be easy to learn to install."

BENEFITS

Radiant heating and cooling systems excel in energy efficiency and human comfort.

- Because nearly half of the heat transfer between human beings and their surroundings occurs via radiation, radiant heating and cooling systems are known for superior human comfort.
- Radiant systems are virtually silent.
- Decoupling sensible temperature control from ventilation allows for potential improvement in indoor air quality, with elimination of air recirculation.
- Radiant systems generally use less energy than forced air systems (with one reference estimating a 30% average savings, and a range of 17% to 42% potential energy savings in North American climates).[20]
    - A building constructed using thermo-active slabs may consume up to 60% to 70% less energy than an equivalent conventional building with an "all-air" HVAC system.[21]

20 Moore, Baumann, & Huizenga, 2006
21 McDonnell, 2007, Selecting Radiant Ceiling Cooling and Heating Systems

APPLICATION

- **Radiant versus All-Air Systems** As stated above, radiant systems offer potentially significant energy savings as well as substantially enhanced human comfort and indoor air quality improvement. While there is a perceived first cost disadvantage to radiant systems, their application may result in equal or lower first costs when all affected building systems and design elements are considered.

- **Panels or Beams or Slabs** When choosing the means to deliver radiant heating and/or cooling, there are a number of factors to consider. Note that on some projects radiant slabs are combined with radiant panels or beams. In this application the slab is used as the primary source for heating / cooling and the beam or panel is used for adding in additional capacity as well as for making more rapid changes to the ambient air temperature.

Table 1 summarizes the considerations for panels/beams and slabs.

Note that on some projects radiant slabs are combined with radiant panels or beams. In such an application the slab is used as the primary source for heating / cooling and the beam or panel is used for adding in additional capacity as well as for making more rapid changes to the ambient air temperature.

Schüco façades provide both control of solar gain/glare and the potential for building integrated photovoltaics. Photo courtesy of Schüco.

Table 1: Considerations for Different Means of Delivering Radiant Cooling and Heating[22]

Panels and Beams	Slabs
• Low mass and thus very little thermal inertia or associated risk of overcooling/overheating • Relatively high cost per unit active surface • Typical panel surface area installed is on the order of 50% of total ceiling area • Lower cooling-mode surface temperatures of 56–59°F (13–15°C) in keeping with smaller • Installed surface areas need to be calculated, to achieve the results desired. • Higher sensible cooling capacity on the order of 30 Btu/hr-ft2 (~9 W/ft2 or 95 W/m2) active surface, not including associated ventilation systems or strategies • Lower cooling-mode ventilation supply air temperatures in the range of 44–55°F (7–13°C) • Higher heating surface temperatures up to 92°F (33°C) for spaces with normal ceiling height • Surface area required is sometimes reduced by increasing convective heat transfer, either through the design of the radiant panel itself or the design of airside systems • Passive chilled beam variants can increase cooling of the air by inducing convective currents, but, given the added buoyancy of warm air, this detracts from heating effectiveness and is thus better suited to internal-load-dominated core zones • Perforated radiant panels and other designs offer options for acoustic damping; many can also be integrated with a standard T-bar drop ceiling of acoustic tiles • Faster response is better suited to buildings with greater variation in skin load loads or spaces, such as conference rooms, with highly variable internal loads • Use in mixed-mode buildings is typically either as a supplement to natural ventilation or for separately zoned or seasonal (i.e., non-concurrent) operation • Generally more suitable for retrofit applications and for providing supplementary space conditioning in hybrid systems or spaces where loads are greater than originally anticipated • Operation may address loads primarily with either radiant exchange or conditioned ventilation air depending on design strategy • Condensation avoidance tends to depend on dehumidification, sensors, and controls	• Lower cost per unit surface area • Larger active surfaces as a function of low cost and integration with structure • Surface temperatures of 64–75°F (18–24°C) for the entire cooling-to-heating range • Relatively lower sensible cooling capacity on the order of 24 Btu/hr-ft2 (~7 W/ft2 or 77 W/m2) active surface, not including associated ventilation systems or strategies • Ventilation supply air is normally just below space temperature • Better suited to buildings with high-performance envelopes, moderate climates, or use with natural ventilation and/or low-energy cooling (heating) sources • Operation most often addresses loads first with radiant exchange and secondarily with conditioned ventilation air (except during airside economizer operation or natural cooling in mixed-mode buildings) • Option for "constant-temperature" slab and pre-cooling strategies • Can be used to remove solar loads directly from receiving structural elements • Additional low-mass hydronic or electric radiant panels are sometimes used to "tune" individual spaces according to differences in load, occupant preferences, or transient loads • Condensation avoidance tends to depend more often on robust design strategies than on controls, although controls become more important where dehumidification is required

22 (Moore, Baumann, & Huizenga, 2006)

CONSIDERATIONS

General application considerations for all radiant systems are as follows:

- Due to increased complexity relative to forced air systems, radiant heating and cooling systems require expert installation and more coordination across building design disciplines and trades. For example embedding tubes into the structure requires careful design around structural elements and requires that the tubes be properly installed prior to the pouring of concrete. Caution also must be taken to avoid job site damage to these systems.
- Due to potential for surface condensation, radiant cooling systems should only be applied in arid climates, or with a secondary system to provide de-humidification and latent cooling. Care needs to be taken in both the design and installation of the mechanical system as well as the proper design and installation of the building envelope. Any radiant cooling system installed in a humid climate would need to be in a sealed building where humidity can be tightly controlled mechanically. If present, operable windows should be closed when ambient conditions present high humidity.
  - Radiant cooling system surfaces must not fall below the space dew point temperature.
  - In humid climates, radiant cooling systems present additional complications and cost due to this issue.
  - Humidity must be managed using a system that conditions ventilation air, such as a dedicated outdoor air system.
- Radiant systems respond slowly to transient conditions relative to their forced air counterparts.
- Radiant systems work best when the building is also designed to minimize transient loads, especially high solar gains and other cooling loads.
- Air filtration also requires separate air moving equipment.
- While radiant heating works well in any climate with a heating requirement, radiant cooling is very climate sensitive. In Europe radiant cooling is primarily being used in relatively cool, dry climates such as those found in Germany. More humid areas (such as England) are not seeing broad usage. Arid climates are ideal for radiant cooling systems.
- Water piping is considerably smaller than ductwork.
- Water can be as warm as 65° F (18.3° C) and still provide cooling allowing the use of alternate cooling technologies such as evaporative coolers in place of conventional refrigerant based chillers.
- Water distribution via pressurized pipe uses less energy than air distribution via ductwork.

CHALLENGES AND IMPEDIMENTS

Radiant heating and cooling systems present a variety of challenges and impediments when it comes to use in commercial buildings in the United States:

- The design community of architects and engineers in the United States is not generally familiar with radiant systems, especially radiant cooling systems.
- Likewise, the construction community is also not generally familiar with radiant systems, and current methods of building construction are deeply embedded.
- Humidity management and surface condensation potential present unfamiliar territory.

- An integrated design approach is necessary, requiring coordination and collaboration across building design disciplines and trades. This is counter to the conventional "silo" approach in the United States, where each discipline pursues its approach in relative isolation.
- Common modeling and design tools, such as DOE-2, BLAST, and TRNSYS, do not all account for radiant heating and cooling systems.
  - For example, DOE-2 only accounts for radiant heating floor panel systems.
  - TRNSYS does support modeling of chilled ceilings, but like the other modeling tools, learning and use requires a substantial time investment.
  - EnergyPlus, a newer energy-modeling tool (based on BLAST and DOE-2.1E), does allow for modeling of radiant heating and cooling systems.
- There exists a common perception that radiant systems are more expensive from a first-cost perspective.
- Some of the suppliers of radiant systems manufacture products in Europe, and it is costly to import these products into the United States.

KEY SUPPLIERS

Table 2 lists (primarily European and non-US-based) suppliers of commercial radiant heating and cooling systems and system components.

Table 2: Suppliers of Radiant Heating and Cooling Systems and Components

Company	Radiant Heating/Cooling Product(s)
DADANCO	Active chilled beams
Halton	Active and passive chilled beams
KaRo KaRo Systems	Capillary tube mats
proter imex srl	Radiant cooling ceiling panels
SABIANA ENVIRONMENTAL COMFORT	Radiant heating panels
Swegon ENERGIZING INDOOR CLIMATE	Radiant heating and cooling panels and beams
TROX® TECHNIK The art of handling air	Active and passive chilled beams
uponor	PEX tubing
zehnder group	Radiant heating and cooling panels

CONTROL IMPLICATIONS

Note that in addition to the radiant heating and cooling exchange media, a major component of radiant heating and cooling systems is the control system. DDC control systems can be readily utilized to control radiant heating and cooling systems. However most controls engineers and contractors have very limited knowledge and experience in controlling these applications. Proper consideration needs to be given to the thermal reaction times, sequencing and temperature reset. Building automation and controls are available from a wide range of providers, and many systems can be adapted and programmed to accommodate radiant heating and cooling systems.

VENTILATION

While radiant systems can be used as the primary source for comfort heating and cooling, proper ventilation is still required. Depending on the outside ambient conditions caution needs to be taken to properly pre-condition ventilation air. The use of a dedicated outside air system (DOAS) that provides heat exchange as well as de-humidification are a good idea. The delivery of ventilation air into the space is often done using a diffusion based system with the air being delivered either through floor mounted diffusers or registers. Ventilation can also be delivered through the ceiling, often coming in through perforations or grills in radiant panels.

In humid climates, radiant cooling alone cannot provide for latent cooling and de-humidification. In this case, additional cooling using air handlers or fan coils is required. For these installations, this secondary air-handling system can also deliver ventilation air.

BUILDING EXAMPLES / CASE STUDIES

We visited several projects in Europe that are utilizing radiant heating and cooling. Several of these projects are still under construction and provide a good study of installation techniques. Others were completed and allowed for observations of finished installation and aspects of comfort.

Embassy Court, London, England

Embassy Court is a new development of luxury apartments (condominiums) located near to Abby Road Studios in London. This project is a re-development of a brownfield site. The project has 25 apartments that will sell for up to $22 million USD.

Systems:

This is a design build project with a focus on energy efficiency and sustainability. The project is using a central heating / cooling plant that has a series of ground source heat pumps. Heat is rejected to the earth using tubes that where embedded in the structural piers for the foundation. Since the building straddles the London Underground (subway) the pier design did not allow for enough surface area and several additional dedicated bore holes used just for the ground source system where required. The centrally located ground source heat pumps are used in a changeover system providing either hot or chilled water.

Each apartment has fan coils located within the walls in the bedrooms and living rooms. The fan coils are able to provide heating as well as latent and sensible cooling. Radiant tubes are installed under all floors. For this project the tubing is not placed in the structural slab, but either in a concrete top coat for use below hard surfaces such as tile or stone, or in an insulating panel as part of a floating floor system for use below hardwood or carpet.

The apartments each have a dedicated exhaust fan system and bring in make up air through the exterior wall.

Heating is provided using a combination of the fan coils along with the radiant tubing in the floors. Cooling mode operates much like heating, with one exception. To keep the occupants from getting "cold feet", bathroom floors are used for heating only and not for radiant cooling.

Notes: It was interesting to note some of the job site considerations. Even though the project was nearing completion, the entire building was shrouded in scaffold and tarps to limit noise and dust for the neighborhood. Also the site was secured including an automated system to verify worker identity using facial recognition.

Figure 7. In-floor tubing for radiant heating and cooling

Figure 8. Manifold for radiant heating and cooling

Figure 9. Tubing mounted in raised floor for use under carpet or hardwood

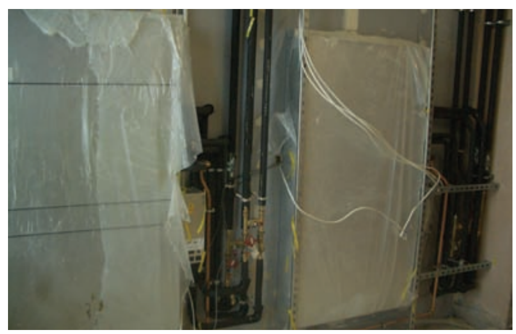


Figure 10. Roughed-in fan coil units

Figure 11. Central plant using water source heat pumps

Figure 12. Construction site entrance – turnstile with facial recognition to verify identity and safety gear prior to entry to site

Trumpf International –Ditzingen, Germany

This project is part of a campus for Trumpf International, a manufacturer of high-precision laser-cutting systems used for manufacturing. The building is approximately 87,000 square feet and is used as an office building. The project was designed to provide an open office space that would provide a collaborative environment. The site faces a major highway, and noise was a big concern.

Systems:

The project uses a double façade to provide for both improved energy efficiency as well as acoustic isolation from the road noise. The exterior wall of the façade is fixed glass with operable windows in the interior wall. The top and bottom of the façade is open allowing for ventilation. The heating / cooling plant is fairly conventional. The chiller utilizes an air-cooled condenser with a water spray on the outside surface. Radiant tubes embedded in the structural slab that forms the ceiling provide space heating and cooling. Piping was stubbed out for the future addition of radiant panels if capacity needs to be added. Air handlers provide ventilation as well as humidification and dehumidification. Diffusion ventilation is used with delivery coming in under the floor. The result of this design is a very quiet and comfortable building with dramatic architecture.[23]

Figure 13. Trumpf International Office Building, Exterior View

23 www.aia.org/siteobjects/files/trumpf_administration_building.pdf, accessed September 14, 2008.

Figure 14. Office space with thermo-active ceiling slab and ceiling panels reserved for additional capacity

Figure 15. Convertible ceiling panels reserved for additional cooling/heating capacity

Figure 16. Air handlers

Figure 17. Ventilation delivered under the windows

In North America, there are relatively few buildings that employ radiant cooling technologies, but a few examples include:

- 250 South Wacker, Chicago[24]
- City of Vancouver National Works Yard[25]
- Glen Eagles Public Safety Building[26]

EXPERT RESOURCES

Experts on radiant heating and cooling systems frequently cited in references reside with the following organizations in North America:

- Lawrence Berkeley National Laboratory (Berkeley, California, USA)
- Omicron (Vancouver, British Columbia, Canada)

24 http://250southwacker.com/acb.html, accessed September 14, 2008.

25 www.metrovancouver.org/buildsmart/resources/Pages/CaseStudies.aspx, accessed September 14, 2008.

26 www.omicronaec.ca/gallery08.php, accessed September 14, 2008.

ACTIVE FAÇADES

An active façade comprises any side of a building where the optical and thermal properties may change dynamically in response to local climate, occupants' preferences, ambient lighting, and/or utility request as part of a demand response program. Such changes are typically accomplished using one or more of the following mechanisms:

- Automated/motorized shades and/or blinds
- Switchable windows/glass
  - Electrochromic
  - Thermochromic
  - Photochromic

Active façades may also be adaptations of static façades or incorporate features of static façades. These static façades and their features include:

- Double façades, ventilated and unventilated
- Day-lighting, using sunlight redirection, light shelves and/or overhangs
- Solar control, using selective glass (spectral or angular)
- Integrated electrical generation using photovoltaic cells

Lastly, a building automation and energy management system typically initiates and coordinates action of the active façade.

CONCEPT

As described above, active façades employ a combination of mechanisms to produce a building façade that changes its optical and thermal properties dynamically in response to various inputs. Common applications take forms that include:

- Single façade with external light-deflecting sun shades
- Single façade with integrated shade or blinds
- Double façade, ventilated, with interstitial shading

See Figures 18[27] and 19[28].

27 Adapted from Ventilated Double Façades - Classification and Illustration of Façade Concepts (Belgian Building Research Institute)

28 Adapted from Performance of a transparent active façade in terms of thermal comfort: Experimental assessments. (Asociación Técnica Española de Climatización y Refrigeración)

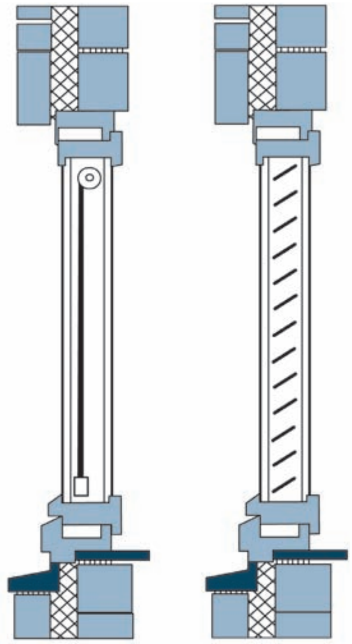


Figure 18. Single façade with integrated shade or blinds

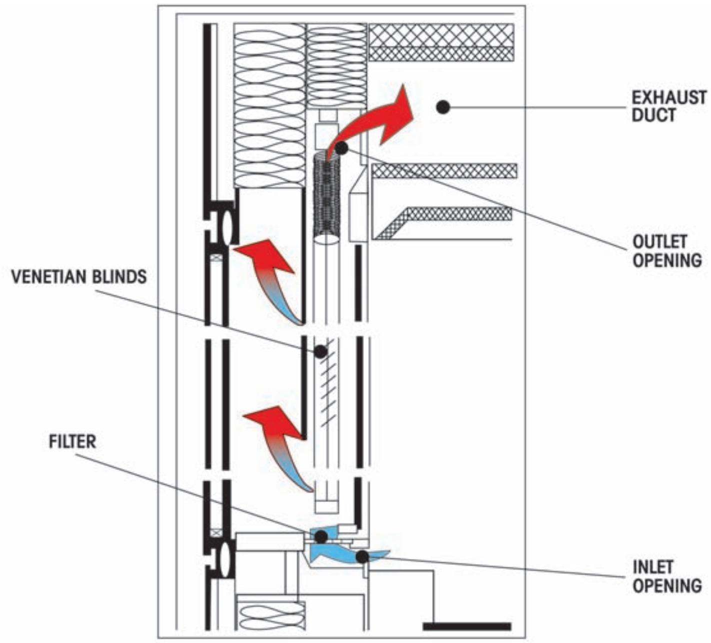


Figure 19. Double-ventilated façade with integrated shade

BENEFITS

The application of active façades is often driven by the desire to produce naturally lighted spaces within a building while minimizing solar thermal loading and glare, and compounded by rating systems and codes that impose requirements for daylighting. Benefits of active façades include positive impacts on energy and occupant comfort.

- Solar control, admitting or deflecting heat
- Day-lighting control and natural lighting
- Glare reduction
- Reduced energy consumption through active load management and/or integration with demand response

APPLICATION

Active façades often employ combinations of technologies. For a given building design, the combination is usually somewhat unique. Such combinations may include:

- Double façades, with or without ventilation
- Interior shading
- Exterior shading
- Integrated photovoltaics
- Switchable glass

In Europe there are many factors that are driving changes in façade design and the use of active components. These include:

- As in the U.S., many European architects are designing projects with a high percentage of clear glass. The use of shading is required to reliably cool these projects.
- In Germany there are strict work rules that require all office space to be located in close proximity to daylight or a skylight. As a result, offices are typically designed with a high amount of glass. Often this goes further to include operable windows or other forms of natural ventilation. The use of an active façade allows for natural ventilation even for projects that may have extreme wind, ambient noise, etc.

CHALLENGES AND IMPEDIMENTS

Active façades present a variety of challenges and impediments when it comes to use in commercial buildings in the United States:

- Active façades are not a mainstream building technology, and the design community of architects and engineers in the United States is not generally familiar with radiant systems, especially radiant cooling systems.
- An integrated design approach is necessary, requiring coordination and collaboration across building design disciplines and trades. This is counter to the conventional approach in the U.S. of each discipline working in relative isolation.
- In the United States, engineers with façade expertise are not involved early enough in the design process (by architects).
- Some of the technologies employed are quite costly. For example, switchable glass is very costly compared to more conventional glass.
- Developers in the United States often demand less than a three-year payback on building systems based on energy costs alone; whereas, European counterparts may take a longer-term approach.
- In many European Union countries, there are codes that require access to daylight and fresh air. This is generally not the case in the United States.
- In the United States, no engineering discipline is responsible for shading and blinds. Consequently, this item is often neglected. In Europe, it is often the mechanical engineering discipline that is responsible for solar control systems, including shading and blinds.
- European populations emphasize the value of a healthy work environment much more so than in the United States.

KEY SUPPLIERS

Table 3 lists (primarily European) suppliers of active façade systems and system components. Active façade systems are typically assembled from a combination of systems and components that include windows/glazing, interior and exterior shades and blinds, light shelves, and other components that are also used in static façades.

Table 3: Suppliers of active façade systems

Company	Active Façade Product(s)
elero	Actuators/drives for active façades (exterior sun shades)
comar ARCHITECTURAL ALUMINIUM SYSTEMS	Shading elements.
somfy	Shading, actuators.

CONTROL IMPLICATIONS

The control of active façade systems typically have both automated and automatic elements. On many systems the occupants are able to manually open and close windows on the inner façade layer as desired. Since these windows are protected by the outer façade there is little impact from weather or risk of intrusion. Systems also are using active control elements. This includes systems to automatically open and close windows, vents, and dampers based on temperature, weather conditions, and to react to emergency situations such as fire.

The blinds used in active façade systems also require control. On many installations the blinds used either on the exterior of the building or within the layers of the façade are controlled in an automated fashion based on the position of the sun and the amount of sunlight present. On a sunny day, it is not unusual for "big brother" to have the blinds closed for several hours a day. This allows for a dramatic reduction in solar gain, but requires coordination and training for the occupants to make them comfortable with this concept. Often the user is allowed to either override the automatic operations of the blinds, or to control a second set of blinds that are provided solely for glare control. The control of blinds is typically done independently of the control of interior lighting.

BUILDING EXAMPLES / CASE STUDIES

Examples of active façades can be found in many buildings throughout Europe. There are many variations of these systems from fairly basic external blinds to sophisticated double façade systems. Here are some examples:

Lufthansa Aviation Center – Frankfurt:

The Lufthansa Aviation Center was constructed as a headquarters and operations center for the German airline, by Ingenhoven Architekten, Düsseldorf. The concept was to design a sustainable facility with an open environment. The project was designed to work with a challenging site, which is located between a major highway and an airport runway. As a result, the building was designed to meet strict height restrictions and constructed in a manner that offered lots of light and air, yet was not impacted by the noise of passing planes, trains and automobiles. The resulting project is very impressive and features a six-story building that houses 1,800 employees. The building is sited so that it can eventually be doubled in size with a future addition. The project is designed to be like a comb with a long central core and office wings that come out at right angles. Between the office wings are enclosed, but un-conditioned garden areas. The building has over 500,000 square feet of glass and all offices (per German standards) are within a short distance to daylight.

Systems:

The building is designed for a high level of comfort and energy efficiency. Chilled and hot water are provided by the airport's central plant. Ventilation air for the building is brought in through several large inlets located at ground level. This air is brought through a subterranean tunnel located 30 feet below the building. This is used to capture ground temperature as a source of pre-heating in the winter and pre-cooling in the summer. Conditioned air is then brought in under the floor in a diffusion based delivery.

The exterior walls of the office wings utilize a double façade that is open at the top and bottom. This façade provides for improved insulation as well as for acoustic and wind isolation. The interior portion of the façade is triple glazed and the exterior portion is single glazed. Between the two walls of the façade are blinds that are mechanically controlled based on sun intensity and position. These are used to capture solar gain and to isolate it from infiltrating the interior of the building. A second set of roller blinds is provided for all interior windows. These are manually controlled by the building occupants and are used for glare control and privacy.

Between the office wings are enclosed gardens that form an atrium. The exterior walls of the gardens have a single façade and mechanically operated external windows. The windows as well as vents mounted at the ceiling are used as part of an automated sequence to naturally ventilate the atriums and to control the temperature. The office wings have operable doors that open into the atriums for natural ventilation of the office areas. The building also features automated lighting control with daylight harvesting.[29]

EXPERT RESOURCES

Experts on active façades frequently cited in references reside with the following organizations in North America and Europe:

- Arup
- Belgian Building Research Institute
- Lawrence Berkeley National Laboratory (Berkeley, California)

29 http://lac.lufthansa.com/en/index.php, accessed September 14, 2008.

Figure 20. Lufthansa Aviation Center employs single and double- façades with mechanisms for natural ventilation and shading

Figure 21. Doors allow for natural ventilation of the office areas, and automated blinds control solar gain

Figure 22. Operable vents in garden / atrium area

Figure 23. Mechanical roof vents in garden / atrium area

Figure 24. Outdoor air inlets – used for pre-conditioning of makeup air

BUILDING SYSTEM OPERATOR USER INTERFACE

The building system operator user interface allows building operations staff to understand what is going on in their building. Present technology for such operator user interface allows for delivery of the user interface in three form factors:

- Workstation software-based user interface
- Web-based user interface
- Kiosk-based user interface (built into equipment in the form of keypad/screen or touch screen)

The user interface also accommodates key tasks performed by building operators and energy managers:

- Status
- Troubleshooting
- Systems management (For example, scheduling)
- Analysis and energy management

In North America, most controls and automation systems are used primarily for active temperature control and troubleshooting of comfort problems and the user interface reflects this usage model. In Europe, systems are used for control but also as tools for building operation and analysis and include many more inputs that are used for metering, display and operations. We discovered that in Europe, as in the United States, there is a broad variation in how systems are designed and applied. On both continents, there is a range of systems applications, with the most advanced and highly integrated systems employed on large, prestigious, and sophisticated building projects. The user interface is obviously a critical issue for improving the energy performance of existing buildings. If existing buildings are retrofitted with systems and controls that reveal the performance of the building, they enable the possibility of continuous performance improvement.

CONCEPT

Given the acceptance of the idea that there is a range of use of integrated building systems and user interface, we can focus on the concept of an integrated system. In order to achieve an integrated user interface, systems must be integrated on a common infrastructure, allowing the building system user interface to represent more than just temperature control and HVAC systems. Systems represented in the user interface may include lighting, access, security, and fire and life safety for example. Furthermore, such integration creates the opportunity for cross-optimization of systems. For example, cross-optimization of access and HVAC systems enable ventilation based on real-time occupancy.

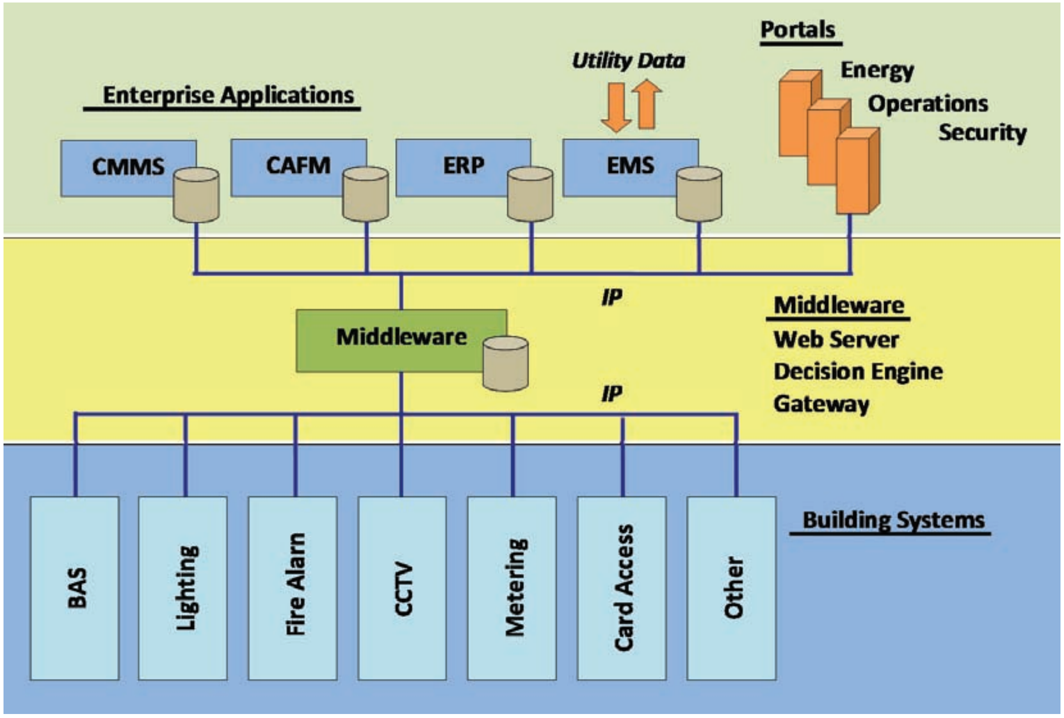


Figure 25: System architecture diagram for integration of building systems and user interface

BENEFITS

- **Operational Efficiency and Effectiveness:** One system with one highly accessible user interface enables a building management staff to achieve comfort and expertise across all systems, and to work flexibly with greater mobility. Up-to-date and advanced systems enable analysis and troubleshooting. Thus, the building management staff can improve their overall efficiency. Building operational issues and problems can be addressed faster, more consistently, and with greater effectiveness, resulting in improved comfort and reliability. And, one system with a single common user interface reduces overall training needs.

- **Energy Cost Savings:** Greater opportunity for energy cost savings comes with increased awareness of building system performance and issues, and timely resolution of such issues in real time. Building performance can also be measured and recorded over time. The resulting data can be used to better understand the opportunities for potential improvements. Building performance and energy usage reduction projects can be prioritized accordingly.

- **More Options Combined with Material Cost Savings:** Material cost savings can be achieved by empowering building owners with options when selecting building systems based on open standards. Because solutions are based on open standards, individual building system selections can be made independently when working with a multiple-building enterprise.

- **Broader Audience:** Data normalization and transparency allows systems to be accessed and used by a broader audience, and to serve a wider range of purposes.

KEY SUPPLIERS

Key suppliers of integrated building systems and user interface include many global companies, including the following:

- Automated Logic Corporation (United Technologies)
- Delta Controls
- GridLogix
- Richards Zeta
- Honeywell, including a number of companies acquired by Honeywell in recent years, including Alerton, Trend and Tridium.
- Johnson Controls, Inc.
- KMC Controls
- Reliable Controls
- Siemens Building Technologies
- TAC (Schneider Electric, Andover, Invensys)
- Trane

The Uptown München office building uses portholes in the glazing to provide natural ventilation even at the 38th floor.

Architect: Ingenhoven Architekten. Photo by the author.

SUMMARY

The building system technologies examined here are all great technologies, but they are not universally applicable. Radiant heating and cooling systems as well as active façades find more popular use in Europe, where the engineering and design community presents a more progressive approach to building system technologies. However, interest in such systems in the United States and in North America is growing. Around the world, building system integration and operator user interface continues to be an area of interest and growth, especially for high-end projects and multiple building environments. In all cases, any building and its design team must consider many factors when evaluating the use of building system technologies, including:

- Overall Building Design: The purpose and intent of the building must be considered as well as the architectural design.
- Climate: Climate is a major determinant in what types of systems are viable and will best serve a building and its occupants. For example, heating and cooling systems that work well in the moderate climates of Western Europe may not work as well in the more extreme climates in parts of the United States.
- Economics: The economics of a given building project are of course a key element in the design process and must be factored into many decisions.

KEY CONSIDERATIONS AND CHALLENGES

Some key considerations arise in comparisons between Europe and the United States with regard to potential adoption of progressive building system technologies.

Climate

- Europe, like the US, spans many climate zones. In Northern Europe, where there is a mild climate with limited cooling load, many innovative solutions are being applied. These same solutions are not being used in warmer southern Europe.
- While this climate difference is notable, it does not necessarily mean that the technologies examined are not workable or useful. Appropriate attention must be paid to the application of the technology. For example, humidity control must be diligently addressed when considering the use of radiant cooling systems in many parts of the United States. This usually requires a sealed building.

Culture

- In Europe there is a strong emphasis on exceptional design, both architectural and functional; whereas, in the United States, greater emphasis is placed on more practical design considerations and practices.
- Engineers are held in higher regard and command higher fees in Europe than in the United States. This allows for more time to be spent on all aspects of building design and engineering.
- In general, European culture takes a long-term performance oriented approach to buildings; whereas; the United States takes a more value-oriented approach with a shorter-term focus.
- Finally, European design teams are responsible for building performance, and buildings are labeled based on their performance. This labeling is often available to the public, and it is factored into the market value of the building.

BUILDINGS

Buildings cited in this document include the following:

Europe

- Embassy Court Apartments; St. John's Wood, London, United Kingdom
- Lufthansa Aviation Center; Frankfurt, Germany
- Trumpf Customer and Administration Building; Ditzingen, Germany

United States

- Loyola University Information Commons; Chicago, Illinois, USA
- 250 South Wacker; Chicago, Illinois, USA

Canada

- City of Vancouver National Works Yard; Vancouver, British Columbia, Canada
- Glen Eagles Public Safety Building; West Vancouver, British Columbia, Canada
- Manitoba Hydro Headquarters, Winnipeg, Canada

BIBLIOGRAPHY

Casey, T. (2008, April). Tridium. (Paul Ehrlich, Interviewer)

Dahle, D. (2006). *Energy and the Building Façade.* Retrieved from U.S. Department of Energy, Energy Efficiency and Renewable Energy: http://www1.eere.energy.gov/femp/pdfs/energy06_dahle_1a.pdf

Koene, F., & Bakker, E. (2005, August). *Validated Building Simulation Tool for 'Active Façades'.* Retrieved from International Building Performance Simulation Association: http://www.ibpsa.org/proceedings/BS2005/BS05_0533_540.pdf

Ford, Andy (2008, April). Fulcrum Consulting, London. (Jerry Yudelson, Interviewer)

Kragh, M., & Guthrie, A. (2008, April). Arup. (Paul Ehrlich, Interviewer)

Lee, E., Selkowitz, S., Bazjanac, V., Inkarojrit, V., & Kohler, C. (2002, June). *High-Performance Commercial Building Façades.* Retrieved from http://gaia.lbl.gov/hpbf/documents/LBNL50502.pdf

Loncour, X., Deneyer, A., Blasco, M., Flamant, G., & Wouters, P. (2004, October). *Ventilated Double Façades - Classification and Illustration of Façade Concepts.* Retrieved from Belgian Building Research Institute, V2SF (Ventilated Double Skin Façade): http://www.bbri.be/activefacades/new/download/Ventilated%20Doubles%20Facades%20-%20Classification%20&%20illustrations.dvf2%20-%20final.pdf

McDonell, G. (2007, 10 19). *Selecting Radiant Ceiling Cooling and Heating Systems*. Retrieved from Consulting-Specifying Engineer: http://www.csemag.com/article/CA6492841.html

McDonell, G. (2007, November). Ten Things to Know About Radiant Cooling Systems. *Consulting-Specifying Engineer* , p. 58.

Moore, T., Baumann, F., & Huizenga, C. (2006, April). *Radiant Cooling Research Scoping Study.* Retrieved from Center for the Build Environment: http://www.cbe.berkeley.edu/research/pdf_files/IR_RadCoolScoping_2006.pdf

Oleson, B. W., & Liedelt, D. F. (n.d.). *Cooling and Heating of Buildings by Activating their Thermal Mass with Embedded Hydronic Pipe Systems.* Retrieved from The Chartered Institution of Building Services Engineers: http://www.cibse.org/pdfs/Embedded%20Hydronic%20Pipe%20Sys.pdf

Perino, M., Serra, V., & Corgnati, S. P. (2003). *Performance of a transparent active façade in terms of thermal comfort: Experimental assessments.* Retrieved from Asociación Técnica Española de Climatización y Refrigeración: http://www.atecyr.org/climamed/climamed2004/books/02/PERFORMANCE%20OF%20A%20TRANSPARENT%20ACTIVE.pdf

Plafferott, D. J., & Kalz, D. (2007). *Thermo-Active Building Systems.* Retrieved from BINE Informationsdienst: http://www.bine.info/pdf/publikation/themeninfoI07englinternetx.pdf

Poirazis, H. (2004). *Double Skin Façades for Office Buildings - Literature Review.* Retrieved from http://www.ebd.lth.se/fileadmin/energi_byggnadsdesign/images/Publikationer/Bok-EBD-R3-G5_alt_2_Harris.pdf

Pons, M. (2008, April). Laing O'Rourke. (Paul Ehrlich, Interviewer)

Saville, T. (2008, April). Somfy (London). (Paul Ehrlich, Interviewer)

Selkowitz, S. E. (2001, May). *Integrating Advanced Façades into High Performance Buildings.* Retrieved from Information Bridge: DOE Scientific and Technical Information: http://www.osti.gov/bridge/servlets/purl/787135-alON2j/native/787135.pdf

Stetiu, C. (1997, May). *Radiant Cooling in US Office Buildings: Towards Eliminating the Perception of Climate Imposed Barriers.* Retrieved from Lawrence Berkeley National Laboratory, Energy Performance of Buildings Group: http://www-epb.lbl.gov/thermal/dissertation.html

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