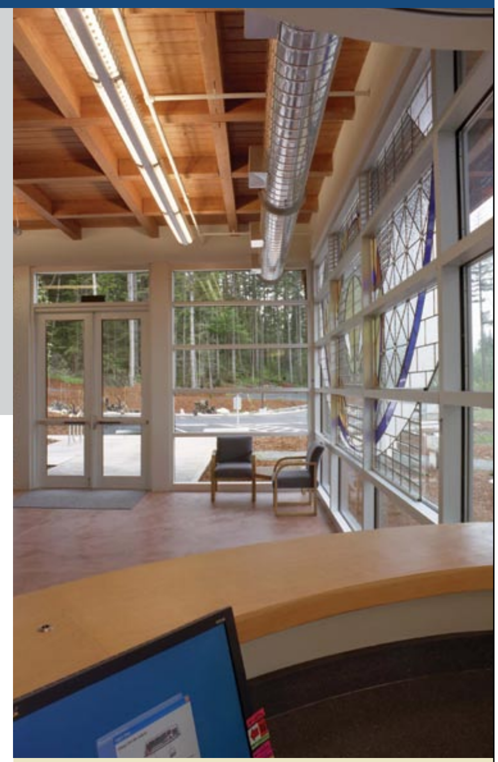
Creating Fire Stations with Safe and Healthy Environments

Technical Brief

What are the Key Criteria?



Headquarters Fire Station, Snoqualmie, WA. Image courtesy of TCA Architecture | Planning. The high-performance and healthy facility features chilled slabs integrated with natural ventilation, daylighting, and environmentally friendly materials.

During an all-day Eco-charrette, key strategies were identified for creating safe and healthy environments for firefighters. The strategies range from design to reduce workplace injuries and enhancing indoor air quality through materials selection to providing optimal thermal comfort for firefighters. This technical brief outlines these criteria tailored to the Seattle Fire Department. Thermal comfort is critical to firefighter health and safety, particularly when returning from events. One way to provide and significantly improve indoor air quality is to decouple ventilation design from heating and cooling. For example, flexible strategies similar to those used at Crosspointe Fire Station can be employed to prevent cross-contamination and improve indoor air quality.

Cooling-dominated climate is a climate that is warmer than human comfort standards for the majority of the year. In cooling-dominated climates, buildings are more often trying to cool off their occupants using their cooling systems than trying to heat occupants up.

Operative temperature is a measure of the thermal comfort in a space. A combination of 6 comfort parameters, as described by ASHRAE Standard 55. See "thermal comfort" sidebar on page 3 for more information.

City of Seattle Department of Planning & Development

Image courtesy of Fairfax County Dept. of Public Works and Environmental Services.

What are the key strategies for safe and healthy fire stations?

Currently, neighborhood fire stations in Seattle are not meeting the thermal comfort requirements of firefighters, particularly during summer months. Most neighborhood fire stations are not equipped with cooling or ventilation systems that are able to provide comfortable temperatures. During a half-day eco-charrette hosted to identify neighborhood fire station design strategies, firefighters in attendance suggested the following key criteria for health and safety:

(1) reducing possibilities for work place injuries,

(2) maintaining a comfortable, steady temperature in fire stations,

(3) providing the ability for rapid cooling for post-event recovery, and

(4) reducing toxins indoors

Reducing Workplace Injuries

Reducing work place injuries can be accomplished through focus on design that will minimize response times through paths of travel to the apparatus bays. For example, floor plan of the Crosspointe Fire Station in Fairfax Virginia was designed to maximize access to the apparatus bays. The floor plan has two corridors that run from the dorm areas directly to the apparatus bay to facilitate rapid response to events. Careful selection of materials and finishes will reduce slip hazards and obstacles in the path of travel (see Selecting Safe Materials in the sidebar on page 5).

Image: Samaha Associates
The Crosspointe Fire Station in Fairfax County, Virginia was designed to maximize access to the apparatus bays. The floor plan has two corridors that run from the dorm areas directly to the apparatus bay to facilitate rapid response to events.

Maintaining Comfortable Temperatures

Maintaining a comfortable, steady temperature was the number 2 key criteria for healthy and safe fire stations. This means paying close attention to the indoor *operative temperature* (see Thermal Comfort in the Sidebar). Operative temperature is a combination of environmental factors including air temperature and mean radiant temperature that influence occupant comfort. Providing acceptable thermal comfort requires providing an operative temperature that is acceptable to occupants.

Thermal Comfort inside Buildings

Traditionally, air temperature is the factor used to create comfort inside buildings. The main reason for this is that reliable thermostats were easy to manufacture when air conditioning was invented about 100 years ago. Since that time, significant research has shown that the temperature of the air around us is only 1 of 6 factors that contribute to how comfortable we are. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE) has been the main contributor to this research and recommends that the following be used to predict comfort:

1. Metabolic rate
2. Clothing insulation
3. Air temperature
4. Radiant temperature
5. Air speed
6. Air humidity

The combination of these factors is called the *operative temperature* of a space. Designing to the operative temperature instead of just the air temperature is not an exact science. In fact, the operative temperature has to include assumptions about the metabolic rate of the individuals in the building (i.e. what you had for lunch) as well as the wardrobe of the individuals or, in the case of, the uniform requirements. This technical brief gives estimates of these values based on information from SFD and tools available from ASHRAE. In the end, the *operative temperature* gives a much better indication of thermal comfort than just the air temperature.

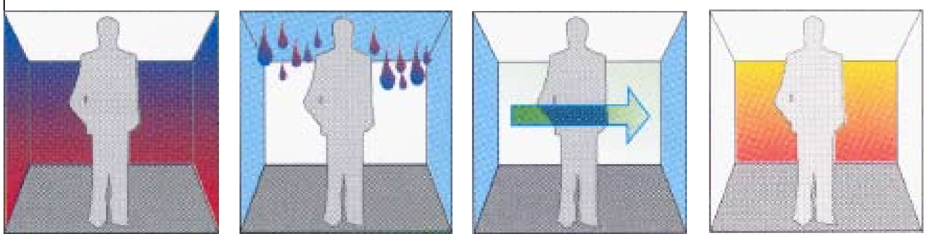
Provide for Post Event Recovery

The third key criteria is providing for rapid cooling in a post fire event situation. The radiant temperatures of floor, ceiling, and wall surfaces have a significant influence on occupant's perception of temperature and their thermal comfort. Therefore, the most effective way to provide ideal operative temperatures is to provide occupants ability to control several components allowing each individual to optimize ambient conditions depending on his or her core temperature. In professional buildings like fire stations, occupants should be given control over both air temperature and mean radiant temperature while maintaining energy efficient operation.

Washington State Code does not require any particular thermal comfort standards in fire stations. The prevailing national standard for indoor thermal comfort is ASHRAE Standard 55-2004 which bases thermal comfort on a prediction of comfort within a space. The standard defines six primary factors that are used to determine the operative temperature of a space (see Thermal Comfort in the Sidebar for more information). Of these factors, building conditioning normally affects air temperature and humidity. However, for optimal comfort, radiant temperature should be the foremost controllable factor in interior spaces [see figure 2]. Anyone who has sweated near a fire place in a cool ski lodge, or shivered near a large window during the winter in a heated room can attest to the how radiant temperature influences comfort.

Standard 55-2004 does not mandate how thermal comfort should be achieved; it prescribes a number of conditions that should be avoided to prevent occupant discomfort. If occupants perceive significant differences in the temperature gradient between walls or the ceiling and floor, they will often be uncomfortable. ASHRAE 55-2004 prescribes limits to radiant asymmetry. Radiant asymmetry is when wall, ceiling, or floor temperatures differ significantly. The standard also mandates limits for floor surface temperature, so that people's lower extremities are not uncomfortable (see Design Considerations section for more information).

Typically, fire stations do not include fully conditioned apparatus bays. All-air conditioning systems are impractical for apparatus bays because conditioned air is lost to the outdoor whenever bay doors are opened. Infrared heating is typically used for apparatus bay heating to overcome this challenge. Radiant systems are another effective system for apparatus bay heating or cooling. Radiant systems would provide comfort without significant wasted energy when air escapes to the outside.



Air	Humidity	Air Velocity	Mean Radiant Temperture
30%		20%	50%

Figure 2: Suggested percentage of influence to optimize thermal comfort.

Minimizing Indoor Toxins

The final key criterion is minimizing indoor toxins. To accomplish this goal, the fire station should first avoid introducing toxins where possible and, second, ensure that any toxins in the space are removed quickly. Some traditional construction materials include toxins that should be avoided (see Selecting Safe Materials in the Sidebar). In that same vein, dealing with the toxins released when buildings are burning is part of each fire station's mission. Keeping these toxins from spreading beyond the bunking room and apparatus bay are critical to keeping a healthy environment in the rest of the station. One way to effectively keep the toxins in their place is to completely separate ventilation air from contaminated exhaust air.

Many neighborhood fire stations in Seattle currently rely upon limited operable windows for ventilation and may not meet 2004 ventilation codes. Improving the ventilation and indoor air quality (IAQ) of neighborhood fire stations should be a fundamental driver for design teams. NFPA and WAC codes require effective ventilation in apparatus areas, including a Fire Apparatus Vehicle Exhaust System and appropriate means to clean, disinfect, and store equipment to prevent cross-contamination within the facility [4]. WAC 51-13-304 also prescribes minimum outside air ventilation rates for mechanically ventilated buildings. Systems designed in accordance with the ASHRAE Standard 62.1-2004 are permitted under the code and would be required to achieve a LEED rating.

Best practices for maintaining IAQ in fire stations include controlling carbon monoxide (CO) that is generated by fire trucks and present on bunking gear. CO control is accomplished through exhausting apparatus bays and bunking rooms. For added safety, CO alarms are installed in living quarters and will alert occupants if this gas is sensed. Designing gear rooms with high ventilation rates and free air circulation facilitates gear drying and contaminant removal. However, it is important that these high air flows are coupled with negative pressurization and external exhausts to limit the chance that contaminants will migrate into living quarters. It is also important to locate air intakes away from these exhaust air flows.

Healthy Air Quality Case Study: Crosspointe Fire Station

The Crosspointe Fire Station is expected to achieve a LEED-NC Silver rating. Fairfax County, Virginia has embraced green building to demonstrate their commitment to environmental protection, increase energy and water conservation in public buildings, and generate taxpayer savings. Fairfax County adopted LEED as the performance standard and as a measure of success. The Crosspointe Fire Station is one of their first two LEED projects and has been designed to achieve a Silver rating.

The design team took special precaution to significantly reduce or eliminate the introduction of contaminants into the living quarters. Contaminants come from several main sources: carbon monoxide and exhaust fumes from apparatus, diesel fumes from emergency generator, and carcinogens and particulate from gear after an event. A carbon monoxide removal system was installed. The system is attached to the exhaust pipes of apparatus, and disengages when the apparatus leave the bay. Fumes from apparatus are exhausted directly to the outside. The diesel generator was located on opposite side of building to the air intakes. The air exhaust is also located on the opposite side from air intakes. By locating the intakes away from sources of fumes, polluted air isn't circulated back into the building.

Another major source of contaminant is carcinogens and particulates that are a result of major fire events and are carried into the building on gear and clothing. A decontamination room is located next to the apparatus bay, where gear is stored. The ready gear rack room provides mechanical ventilation directly under the ready gear racks. Each locker has a vent located underneath that forces air up through the locker where gear hanging, both drying the gear and directing contaminants toward the ventilation exhaust. Entry grills and grates are located at the entry to the apparatus bays and between the apparatus bay and living spaces. The grills and grates have a pan underneath that can be cleaned as needed.

Higher than standard ventilation is provided into the living spaces, and all windows are operable. The building started with better indoor air quality by not introducing sources of emissions from paints, coatings, and adhesives such as volatile organic compounds and urea-formaldehyde resins. The building also went through a two week flush out prior to occupancy and all filters that were in use during construction will be replaced.

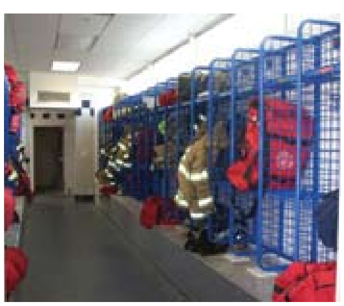
This project is slated to receive 13 out of 15 of the Indoor Environmental Quality credits in LEED.

Selecting Safe Materials

Many parts of a fire station are closely regulated. *The Seattle Fire Station Programming Manual* provides a detailed look at how these regulations apply to the neighborhood fire station program and includes information about slip-resistant surfaces, minimizing unnecessary finishes, and supporting fire fighter health through general advice on selecting safe materials. In addition, there are web links provided here that will help design teams select materials that will also minimize off-gassing. To increase indoor air quality, materials should be free of off-gassing chemicals such as urea-formaldehyde, solvents, and alcohols. The databases listed at the web addresses below can lead design teams toward non-toxic alternative materials that still meet fire station regulations:

(1) Oikos Green Building Source: http://oikos.com/

(2) Green Spec: http://www.buildinggreen.com/menus/



Images courtesy of Fairfax County Dept. of Public Works. The apparatus bay features a carbon monoxide removal system, and thedecontamination room ready gear rack is designed with a ventilation system that forces air up through locker both drying and directing contaminants toward ventilation exhaust.

Design Approach

Systems Approach to Meeting Key Criteria

To provide thermal comfort and improve fire station IAQ, the optimal mechanical systems for Seattle fire stations are a base radiant heating and cooling system with supplementary cooling in specific rooms and ventilation. This approach helps to minimize indoor toxins, provide fire personnel with control of their temperature for *post-event recovery*, and provide *steady, comfortable temperatures* on a 24-7 basis.

Also, the approach can meet ASHRAE 55 comfort standards and WAC ventilation requirements, allows high outside air ventilation rates, and takes advantage of free conditioning provided by Seattle's climate. In addition, this design approach allows the provision of higher ventilation rates to gear rooms and apparatus bays without significant impacts to energy efficiency.

Radiant heating and cooling systems are appropriate for remodels and new construction. Remodels can use radiant panels or embedded grid tubing. New construction can use those systems as well as slab embedded tubing.

The system outlined in this brief is synergistic with increasing envelope efficiency and reducing internal loads and is ideal when paired with a dedicated outdoor air system (DOAS). Other strategies that can be employed effectively with radiant systems in urban fire station are daylighting, façade optimization, and high-efficiency air filtration. Displacement ventilation or mixed mode ventilation systems may also be paired with radiant strategies.

Design Considerations

Design Parameters for Seattle Fire Stations

Using the ASHRAE fundamentals handbook the operative temperature for space types should be calculated from the space program. The "met" and "clo" values shown in Table 2 should be used as guides. Using these values, designers can calculate the Predicted Mean Vote (PMV) for space temperatures in fire stations (see To Learn More, top of page 7, for a list of calculation tools). Based on the Standard 55 methodology, the acceptable PMV Range is -0.5 to +0.5.

It should be noted that the PMV method was developed using assumptions for primarily sedentary office workers wearing office attire. Some of these assumptions may not be entirely applicable to firefighters, particularly if they are wearing bunker gear or returning from an event. Standard 55 does take this into account by noting that a person's thermal comfort is affected by recent environmental conditions so, in the case of a firefighter, being exposed to extreme heat during an event will continue to affect the person's thermal comfort as they return to the station.

Space metabolic and clothing values					
Space	**Metabolic Rate**	**met Value**	**Clothing**	**clo Value**	**Objective**
Apparatus Bay	light industrial work	3.0-4.0	Uniform or more when return from call	0.82 - 1.12+	Provide minimal comfort; prevent overheating
Office	sedentary	1.0	Uniform: underwear, t-shirt, socks, trousers, long-sleeved shirt, shoes	0.82	Provide thermal comfort
Lounge	sedentary	1.0	Uniform: underwear, t-shirt, socks, trousers, long-sleeved shirt, shoes	0.82	Provide thermal comfort; controllability for post-call cool down
Bunking Room	sedentary / sleeping	0.7	underwear, t-shirt, socks, trousers, long-sleeved shirt	0.72	Provide thermal comfort; controllability for post-call cool down
Beanery	cooking	1.6-2.0	Uniform: underwear, t-shirt, socks, trousers, long-sleeved shirt, shoes	0.82	Humid environment, provide adequate ventilation, provide thermal comfort

Metabolic and clothing value assumptions for Fire Station spaces.

Although Seattle is a not a cooling-dominated climate, overheating can be a life threatening condition for fire personnel. Due to comfort system limitations of current fire stations, SFD minimum uniform standards, and the safety and health threat of overheating; overheating during warm periods is the primary thermal comfort concern of SFD personnel. It was suggested by SFD firefighters that providing a constant operative temperature of 68-70 degrees should be a primary design goal.

Comfort System Comparisons					
System	**Benefits**	**Cooling Capacity**	**Response Time**	**Application**	**Limitations**
Air Conditioning	Design familiarity, response time	Variable	Instantaneous	remodel/new	Less efficient cooling,thermal discomfort with high cooling, maximum ventilation limited by to cooling delivered
Ceiling Panels	Response Time, ease of installation, thermal comfort	42 Btu/ hr-ft2	Similar to air system	remodel/new	Less efficient cooling, higher condensation potential
Mass embedded grid	Efficiency, can be used for remodel, thermal comfort	30 Btu/ hr-ft2	hours	remodel/new	Layout options limited
Embedded tubing	Efficiency, durability, thermal comfort	30 Btu/ hr-ft2	hours	new construction	Requires slab pour to install

Radiant Systems in Fire Stations

With a radiant design, the radiant system is used to control sensible loads. This allows for modulating ventilation rates because cooling capacity is decoupled from ventilation rate (i.e. air flows). The capacity of a radiant system depends on the type of system. The effective sensible cooling of panel systems is approximately 30 Btu / hr-ft2; for mass-embedded systems it is approximately 24 Btu / hr-ft2 [3].

A recurring concern expressed by designers is the potential for condensation with radiant cooling systems. There are several ways to deal with preventing potentially problematic water formation on cool surfaces. The most likely situations where condensation could occur with a radiant system are when ventilation air is very humid, or when a significant flux in occupancy raises the latent load of the space. To combat humid ventilation air, it is recommended that a dedicated outdoor air system (DOAS) be used to remove the space latent loads [2]. To prevent high transient occupancies from leading to potential condensation on radiantly cooled surfaces designers should ensure that the temperature of the cooled surfaces does not drop below the space dewpoint. This can be accomplished through careful design calculations, and backed up with BMS-controlled actions such as measuring the dew point and de-energizing the radiant panel pump if the dew point drops into a range where condensation might occur [2].

Radiant heating systems are technologically proven in a multitude of commercial and residential applications in the Pacific Northwest, and colder climates. If ceiling panels are used for radiant heating, designers should follow the guidelines in Section 5.2.4.1 of ASHRAE 55-2004 that prescribe limits for radiant ceiling panel temperature. Occupants are sensitive to radiant heat perceived on their heads, therefore if upper temperature limits are exceeded radiant ceiling panels can create thermal discomfort.

Operations and Maintenance

Radiant systems have been tested in a variety of applications for decades in North America and Europe. These systems utilized the same boilers, condensers, and pumps that are used in any hydronic heating and/or cooling system.

Radiant slab systems use cross-linked high-density polyethylene tubing that has a life expectancy of 100+ years based on accelerated testing predictions [3]. Radiant panel life expectancy has yet to be fully demonstrated in practice, but their established components and relative simplicity suggest adequate durability.

Maintenance requirements for radiant systems should be less than all-air systems due to their relative simplicity. However, if a DOAS or similar system is used for ventilation, maintenance requirements similar to an air-cooled HVAC system are likely.

St. Dana Building at the University of Michigan.

Radiant Systems Case Study: S.T. Dana Building

The St. Dana Building, School of Natural Sciences and Environment, University of Michigan, was a $25 million renovation of a 100-year-old historic building that achieved a LEED-NC Gold Rating. Project goals were to achieve the school's objectives for environmental preservation and sustainable development through the renovation, improve building comfort to enhance the learning and work environment, and demonstrate state-of-the-art environmentally conscious design.

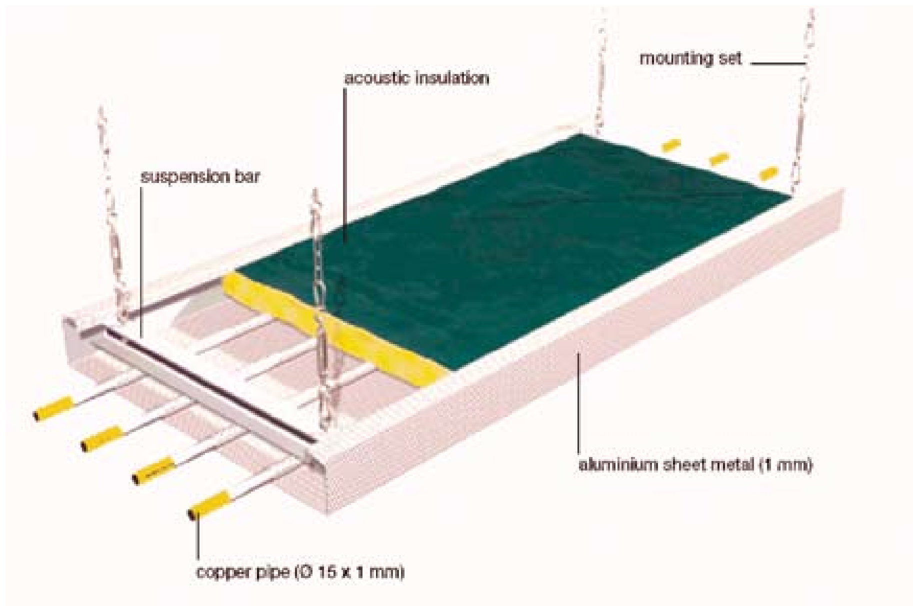
Completed in 2003, the renovation of this 110,000 square foot facility that includes classrooms, labs, and offices features 13,300 square feet of suspended radiant panels for cooling only plus a constant-volume overhead ventilation system. This project demonstrates the applicability of radiant cooling for retrofit applications, as well as the ability to provide cooling in an area with higher cooling needs than Seattle.

Prior to the renovation, the building did not have air conditioning. The radiant cooling system was selected because it was more energy efficient than a traditional forced-air system or wall-unit air conditioners. The system consists of copper pipes at the ceiling level covered with metal shrouds. Cold water runs through the pipes acting as a heat sink for warm air. This system is estimated to save 10% more energy than a traditional forced air system because water is about three times more efficient than air as a heat transfer medium.

For more information visit www.snre.umich.edu/about-snre/dana_building.php.

System Types

Ceiling Panels



Zehnder COMO radiant panel demonstrating a deck mounting configuration. Graphic courtesy of Zehnder.

Radiant ceiling panels provide radiant heating and cooling from above. They can be installed into a standard T-Bar drop ceiling, or can be suspended from the structural deck. The conditioning capacity of radiant ceiling panels comes from the mass of the water that runs through them. The panels themselves are relatively lightweight - weighing from 3 - 10 pounds per linear foot without water. The advantage of their limited mass is that they have a minimal response lag when thermostats are adjusted. As the water running through the panels gets warmer or colder, the radiant surface temperature changes quickly allowing immediate occupant control.

Other advantages of radiant ceiling panels are their applicability in remodel applications since they can be integrated with standard drop ceilings or easily suspended from an existing hard ceiling.

Potential disadvantages to radiant ceiling panels are that they are not as effective or efficient as embedded grids or piping because of their lower thermal mass. In addition, people are affected by the radiant temperature of floors more than ceilings, particularly in spaces with high ceilings. Finally the weight of suspended radiant panels, when filled with water, requires scrutiny to ensure compliance with seismic codes.

Grid Systems

A radiant grid system uses small diameter plastic tubes embedded in a substrate such as plaster or gypsum board or laid on top of a suspended acoustical ceiling. When embedded, a grid system has the benefit of the substrate's thermal storage. Plaster and gypsum have lower mass than concrete, so embedded grid systems are a hybrid between panel systems and embedded tubes.

The advantages of a grid system include their applicability for retrofit applications. The polyethylene tubes used in the system are flexible so that they can be routed around existing obstacles. In addition, embedded grid systems have less of a time lag than concrete-embedded tubes when occupants change building thermostats.

Embedded Tubes

Embedded tube systems are larger diameter plastic tubes that are embedded in poured concrete or another substrate. Embedded tubes take full advantage of the thermal storage of the massive materials in which they are embedded. Embedded tubes are rarely feasible on a retrofit project unless a new top slab is being poured. The advantage of embedded tubes is that they create a uniform heat that is stored in the slab for a long duration. The disadvantages are the challenge of incorporating them in retrofits and their slow response to user control because of the thermal storage of their substrate.

Heavy vehicle loading requires special consideration for apparatus bay applications. Measures such as thicker top slab, or higher strength concrete may be required if hydronic tubing is embedded in an apparatus bay slab.

Costs

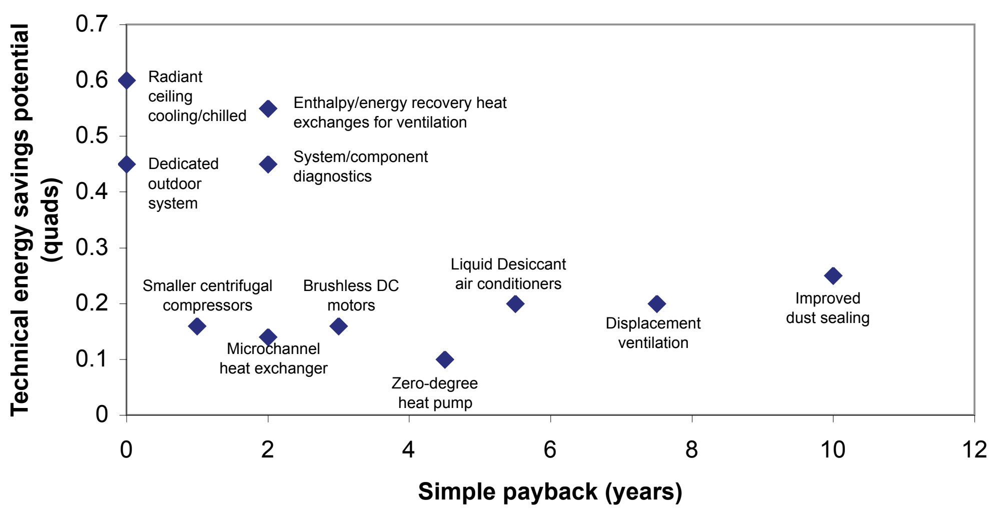


Figure 8: Energy savings payback for efficient HVAC technologies. Source: "Energy Consumption Characteristics of Commercial Building HVAC Systems Volume III: Energy Savings Potential" Roth, et al. DOE, July, 2002 http://www.eere.energy.gov/buildings/info/documents/pdfs/hvacvolume3finalreport.pdf

According to a 2002 U.S. Department of Energy Study, installation of radiant ceiling panels and a dedicated outside air system (with enthalpy heat recovery) are similar to installation of a conventional variable air volume system [5]. The report cited some variation in cost from several sources, ranging from lower first costs to a 2% cost premium for combined radiant and DOAS systems.

Conservative energy savings predictions from combined DOAS and radiant systems, derived from energy simulations cited in the report, are approximately 17%. Savings are derived largely from reductions in fan and motor loads. However, significant savings in first-cost and ongoing energy costs can be realized if duct sizes can be reduced in the case of DOAS systems.

Both first cost and energy costs would be increased if supplemental cooling, such as fan coil units, are provided in fire stations. If these units are used as intended for supplementary cooling the energy impacts would be moderate. However, without building management system integration, excessive occupant use could increase ongoing operations and maintenance costs, including energy efficiency. Therefore, control of supplementary cooling should be included in the BMS. One control strategy is to allow one hour of continuous operation at a time. The station's Locution alarm could reset the one hour time limit. This strategy would provide firefighters with the essential post-ever cool down but would keep the units from inadvertently being left on when firefighters are on a call or sleeping.

This approach is consistent with FFD's policy to maintain air temperatures that fall within ASHRAE standards in order to conserve energy. This temperature range will be set up in the heating/cooling control system. Firefighters will be given leeway within this temperature range.

To Learn More

[1] Dieckman, J., Roth, K., Brodrick, J. "Radiant Ceiling Cooling" ASHRAE Journal June 2004: 42-43

[2] Mumma, S. "Condensation Issues with Radiant Cooling Panels" ASHRAE IAQ Applications Fall 2001: 1-3

[3] Moore, T., Bauman, F., Huizenga, C. "Radiant Cooling Research Scoping Study" Retrieved from http://www.cbe.berkeley.edu/research/pdf_files/IR_RadCoolScoping_2006.pdf

[4] Department of Defense. "United Facilities Criteria (UFC) Fire Stations" 15 June 2006. http://www.wbdg.org/ccb/DOD/UFC/ufc_4_730_10.pdf

[5] U.S. Department of Energy. K. Roth et. Al "Energy Consumption Characteristics of Commercial Building HVAC Systems Volume III: Energy Savings Potential" 2002. http://www.eere.energy.gov/buildings/info/documents/pdfs/hvacvolume2finalreport.pdf

Radiant System Resources

"Present State of Knowledge about Radiant Cooling Systems" Retrieved from http://epb.lbl.gov/thermal/chapter2.pdf

Advanced Buildings Technologies and Practices, Natural Resources Canada, www.advancedbuildings.org/_frames/fr_t_heat_radiant_heating.htm

Thermal Comfort Calculators

(1) Human Heat Balance Calculator http://atmos.es.mq.edu.au/~rdedear/pmv/

(2) Comfort Calculator

(a) http://www.healthyheating.com/solutions.htm

(b) http://www.automationcollege.com/myfacilities/tools/comfortcalculator.asp

(3) Download - Free Windows Tool for predicting comfort

(a) http://www.squ1.com/project/pmvtool

(4) ASHRAE 55-2004 Section 5.2.1.1 includes a complete description of the calculations performed by the on-line tools. This description can also be used to manually calculate thermal comfort parameters.

Online Green Materials Selection

(1) Oikos Green Building Source: http://oikos.com/

(2) Green Spec: http://www.buildinggreen.com/menus/

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