Natural Ventilation and Cooling – Passive and Hybrid Systems for Fire Stations

Technical Brief

What are Key Concepts of a Natural Ventilation and Cooling System

Natural ventilation and cooling systems combine intelligent building design, ambient climatic conditions and natural air movement to provide a building's occupants with plentiful fresh air and comfortable conditions without the use of fans or mechanical air conditioning. A hybrid system adds supplemental cooling (typically radiant chilled slab, panels, or beams) to areas where passive cooling alone does not meet the cooling load. Typically in either passive or hybrid systems heat is needed to offset exterior heat losses and to temper ventilation air during the heating season. This technical brief outlines the key concepts for a natural ventilation and cooling system and addresses how it can be successfully incorporated to address the important needs of a fire station.

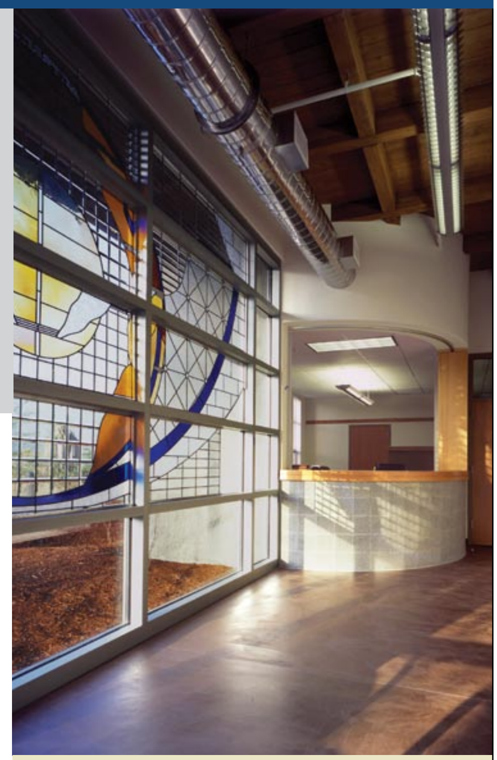


Image courtesy of TCA Architecture | Planning.

The Snoqualmie Headquarters Fire Station features an hybrid ventilation and cooling system that takes advantage of building orientation, passive solar design, radiant slab, and combination underfloor and overhead ducted systems to maintain a high degree of temperature control.

City of Seattle Department of Planning & Development

Goals and Benefits

A naturally ventilated and cooled building provides benefits to its users, its owners, and society as a whole. The following sections outline some of these benefits and the goals they can help achieve.

Societal Goals and Benefits

With the threat of climate change, many local, state, and national governments are taking action to reduce greenhouse gas emissions, and Seattle is aggressively leading the charge within the United States. As a result, the city is promoting sustainable development and greenhouse gas reduction policies. Using natural ventilation and cooling in lieu of a traditional mechanical system within a building can significantly reduce the energy required to operate a building and hence reduce carbon dioxide emissions.

A passive natural ventilation and cooling system does not require the energy normally needed to run fans, chillers, cooling towers, and pumps. A hybrid system requires some of this energy, but consumption is minimized because only supplementary cooling is provided and the building is still passively ventilated.

Building Owner and User Goals and Benefits

A naturally ventilated and cooled facility can help a building owner achieve many goals, from providing a healthy and stimulating working or living space to reducing operating and maintenance costs. Additionally, for projects going after LEED-NC certification, natural ventilation and cooling affects no less than 11 of the prerequisites and credits. Table 1, below, summarizes the impact of a naturally ventilated and cooled building with respect to the LEED-NC 2.2 rating system.

Table 1: Credit by credit impact of naturally ventilated and cooled building with respect to the LEED-NC 2.2 rating system			
LEED-NC 2.2 Credit	**Major/Minor Impact**	**Considerations**	**Notes**
EA Prereq. 2- Minimum Energy Performance	Major Impact	Significant influence on the overall energy consumption of the building	
EA Prereq. 3- Fundamental Refrigerant Management	Major Impact	No refrigerant required for system	A hybrid system will likely require refrigerants. Be sure to select CFC free options.
EA Credit 1- Optimize Energy Performance (Worth up to 10 Points)	Major Impact	Significant influence on the overall energyconsumption of the building	ASHRAE 90.1 2004 requires that energy model include mechanical cooling even if building does not, so full energy savings may not be credited.
EA Credit 4- Enhanced Refrigerant Management	Major Impact	No refrigerant required for system	A hybrid system will likely require refrigerants. Be sure to select appropriate options.
EQ Prereq 1- Minimum IAQ Performance	Major Impact	Design to standards in ASHRAE 62.1-2004 Section 5.1	
EQ Credit 1- Outdoor Air Delivery Monitoring	Major Impact	Requires CO2 sensors in occupied spaces	This credit is easier to achieve with natural ventilation compared to me chanical ventilation.
EQ Credit 2- Increased Ventilation	Major Impact	Follow path described in Carbon Trust Good Practice Guide & CIBSE App Manual 10	Thermal modeling air flows can be used to demonstrate ventilation effectiveness.
EQ 6.2- Controllability of Systems- Thermal Comfort	Major Impact	Operable windows can be used in lieu of climate controls for nearby occupants.	Typically easier to achieve with natural ventilation than with mechanical ventilation.
EQ 7.1- Thermal Comfort	Major Impact	Design to ASHRAE 55-2004 Section 6.1.1 standards	Typically more difficult to achieve with natural ventilation and cooling than with mechanical ventilation. Hybrid systems must comply with standards for full mechanical system.
EQ Credit 8.1- Daylight and Views- Daylight 75% of Spaces	Minor Impact	Location of operable windows in project may benefit daylighting.	
EQ Credit 8.2- Daylight and Views- Views for 90% of Spaces	Minor Impact	Location of operable windows in project may benefit occupant views.	

Other than the environmental benefits of natural ventilation and cooling, this system can also provide a superior living or working environment for building users. Despite the fact that naturally ventilated and cooled buildings cannot maintain as tight a temperature control as a typical mechanical system, studies have shown high levels of occupant satisfaction. This is because occupants are given control over their surroundings and have ample access to fresh, clean air. Recent research into this area is incorporated into the ASHRAE 90.1-2004 Adaptive Comfort model.

If it is too hot or stuffy occupants can open a window, and then close the window when the temperature drops. A certain level of user buy-in is required; when building occupants have direct access to ambient weather conditions they tend to dress appropriate to the natural climate. In the summer they might wear short sleeves, and in the winter they might put on a sweater. This adaptation allows a naturally ventilated and cooled building to expand the normal indoor temperature range without sacrificing comfort levels. In a fire station setting, where occupant dress is dictated by uniform policies, it becomes more critical that the occupants be able to control their environment. This can be achieved by shying away from automated window controls and allowing the occupants to decide when to open and close windows, or with the inclusion of a hybrid system that can maintain space temperatures via mechanical heating and cooling.

Even in a well designed passively-cooled building there may be a few times a year when outdoor temperatures have remained elevated for a prolonged period and thus the indoor temperature reaches a high level. It is up to the building owner and design team do decide if it is worth tolerating these "peak" periods to gain the benefits during the rest of the year, or if a hybrid system should be installed instead to add cooling during the peak periods. Thermal modeling software can help predict the amount of time that elevated temperatures occur to assist in this decision and building design in general.

One of the greatest advantages to a natural ventilation and cooling system is its simplicity. Although it is possible to design a complex, fully automated system, often the best designs rely on the building occupants to control their own conditions. From an operations and maintenance standpoint there is minimal effort required: no cooling towers, pumps, fans, piping, or duct-work. Again, a hybrid system would include some of this equipment, but overall, it would be a relatively simple system to maintain.

Finally, a natural ventilation and cooling system may open new design avenues not previously available. There is no duct work to be hidden in soffitts or drop-ceilings and less mechanical space is required. This may allow for increased usable space, greater floor-to-ceiling height, or remove ugly cooling towers currently being tucked away on the roof.

Applications for Natural Ventilation and Cooling

The following sections describe when and where natural ventilation and cooling systems are applicable and how they interact with other aspects of the building design.

Appropriate Climatic Conditions

Natural ventilation and cooling systems are most effective in climates where ambient temperatures and humidity levels naturally fall into comfortable ranges. Using historical Seattle weather data as reference, the ambient humidity or temperature appears to exceed acceptable levels approximately 1% of the time . Additionally, thanks to its seaside location, Seattle typically gets cool night breezes even during the hottest times of the year. This night-time cooling effect can be used to "flush-out" the heat that has been stored inside a building and pre-cool it for the next day.

Additionally, so called "micro-climate" issues should be considered during design. These can vary from foliage shading to the wind effect of surrounding buildings.

The combination of favorable climate and location makes Seattle an ideal location for the implementation of natural ventilation and cooling.

Appropriate Building Programming

It is important to know the intended building programming before the design begins. Building programming in this sense refers to the periods of occupancy in a building and the corresponding intended use. For example, the natural ventilation and cooling strategy for an office building with only daytime use would be very different from a 24 hour fitness facility. Nearly any type of building can take advantage of natural ventilation and cooling, but there are some conditions that greatly benefit or hinder a properly functioning system.

The following list of programming conditions should be considered and mitigated in the design and use of a naturally ventilated and cooled facility:

- Highly concentrated cooling loads (i.e. data centers): Typically, if these are in the design, an air conditioning unit will be included to serve only these spaces. Another option uses an exhaust fan to pull cooler air in from adjacent spaces. Such spaces may offer an opportunity for heat recovery.
- Security issues: If relying on using operable windows during unoccupied hours (i.e. night flushing), it is important to take into account security concerns. Typically 1st floor windows should not be left open at night, thus the design may require louvers at lower building elevations or may not make use of those openings.
- Occupant dress code: It is most beneficial if the users of the building are able to wear "seasonally appropriate" attire to maximize their comfort (i.e. short sleeves, sweaters, etc). If uniform requirements make this unacceptable than extra attention needs to be paid to giving the occupants a high level of control over their indoor environment. This can mean easy access to operable windows or using a hybrid system to more tightly control temperatures.

- High occupancy periods: For areas such as a conference room or dining area where, for short periods of time the space is fully occupied but that is not the typical condition, there may be a "recovery" period required for the space to flush out the built-up cooling load before it can be fully occupied again. If this is not possible, supplementary cooling may be required. If incorporated properly into the overall space design, a ceiling fan can make a space feel much more comfortable without adding mechanical cooling.
- Noise issue: To maximize the effectiveness of a natural ventilation and cooling system it is important to allow for free air flow across spaces, facilitated by unobstructed paths from one side of a space to the other. Depending on the floor layout and design this may mean there can be noise pollution from adjacent spaces or the outside environment. Sometimes a little "ambient noise" can be beneficial as with no mechanical system humming away in the back ground occupants may be more sensitive to surrounding conversations or noises.
- Indoor air quality (IAQ): Typically IAQ improves with a naturally ventilated and cooled building, due to the significant increase in fresh air. However, the design team should be aware of the surrounding environmental conditions, such as idling vehicles or allergenic-pollen producing foliage when planning a naturally ventilated building. Typically it is not possible to practically filter outdoor air in a natural ventilation and cooling system without a fan-assist. Because fire stations typically have large garage spaces and the potential for idling trucks, it is recommended that exhaust-extraction-systems (e.g., Nederman systems) be used to direct vehicle exhaust fumes out of the building, well away from any air intake.

Complimentary Design Techniques

There are many synergies between natural ventilation and cooling systems and other building design techniques. Often it is possible to take advantage of "double-duty" design to get several functions out of one building element, thus reducing costs and increasing functionality.

The following list is of design techniques that mesh with a natural ventilation and cooling design. It will not always be possible to include them all in a building, but as many as possible should be considered as part of the design:

- Operable windows: The key feature of naturally ventilated and cooled spaces is occupant control of windows (including operable louvers/dampers). Operable windows on opposite sides of a space allow for cross ventilation when a breeze blows. High and low combinations of operable windows create stack-effect ventilation, caused by temperature stratification and pressure differentials. Ideally a space should have both cross and stack ventilation.
- Radiant heating: Because there is no mechanical air delivery there are limited options in how to condition the space during the heating season. It is often reasonable to use radiant slab heating. If needed, supplementary perimeter heating can be added. Minimum ventilation air can be directed through a heating coil or radiator before entering the space. There can be significant cost savings in using radiant heating (either in-slab or over-head) to condition large open spaces (such as fire station garages) because rather than heating all of the air in the space (including the exhaust and make-up air), heat is provided directly to the occupants and work areas. Another advantage of in-slab radiant heating is that because there

is no ductwork or exposed mechanical equipment overhead or on the garage floor there is minimal risk of trucks or fire-fighting equipment colliding with the mechanical system. Garage space comfort requirements are also typically less stringent than other regularly occupied spaces. This enables the designer to design for a lower winter set-point temperature saving energy. In addition, providing a uniform floor temperature is less critical. These together allow the designer to specify less total embedded hydronic tubing in the floor slab (i.e. wider spaced tubing), reducing construction costs.

- Radiant cooling (hybrid systems only): In a hybrid system most of the cooling will still be passive, but during peak times radiant cooling can keep the spaces comfortable. If a radiant slab is used for heating it can be switched over during the summer months to provide cooling, though it has to be closely controlled to prevent condensation. Seattle is well situated for chilled slabs due to its dry summer climate and low humidity levels, thus slab temperatures can remain lower and more cooling effect is provided without risking condensation. Chilled slabs are very effective when used to prevent solar load striking a floor from heating the space. Figure 1, following, illustrates the use of hybrid natural ventilation and chilled slab system.

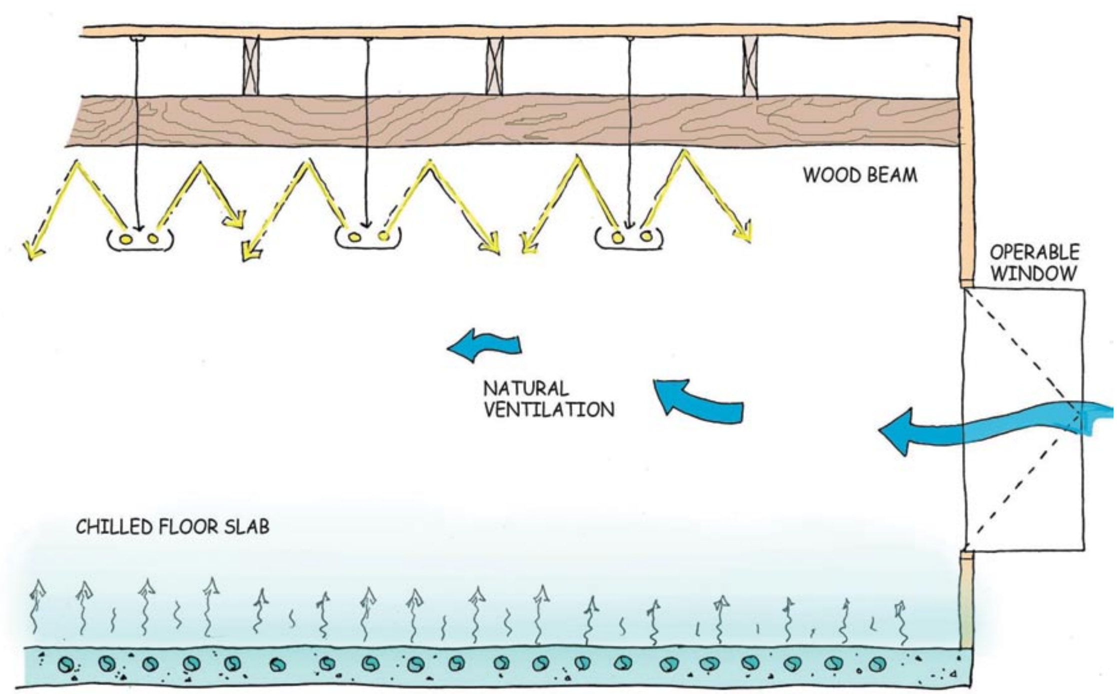


Figure 1: Hybrid system combining natural ventilation with chilled slab (Courtesy of Stantec)

- Shading: The best way to keep a space cool is to never allow it to get hot in the first place. Optimized shading can help counteract the increased solar gain caused by windows, and is crucial in any natural ventilation and cooling design.
- Thermal mass: This is one of the oldest yet most effective passive building design techniques. Buildings with heavy construction and exposed thermal mass (concrete, brickwork, rock, etc.) can greatly reduce their peak cooling loads by allowing the material in the building to store energy. During the night the building cools off (especially if assisted with night flushing), and then during the day it slowly absorbs the heat, resulting in a space that does not feel as hot. After

a long spell of hot days, the effect of thermal mass may become minimal if the building never gets a chance to cool down.

- Daylighting: This technique uses the natural sunlight, rather than electric lighting to provide light to a space. It can save significantly on electricity usage and reduce cooling loads. On the surface it seems that daylighting is counter-productive to a natural ventilation and cooling system. Daylighting requires sunlight, while natural ventilation and cooling prefer to have it blocked out. In reality these strategies can co-exist and benefit each other. This is because a key element of daylighting is glare control, meaning preventing direct sunlight from striking a surface. This also prevents direct solar gain. Often shading devices can double as daylighting features by allowing in diffuse light, or bouncing light off of the ceiling. Figure 2, following, illustrates the combination of daylighting with proper shading and natural ventilation.

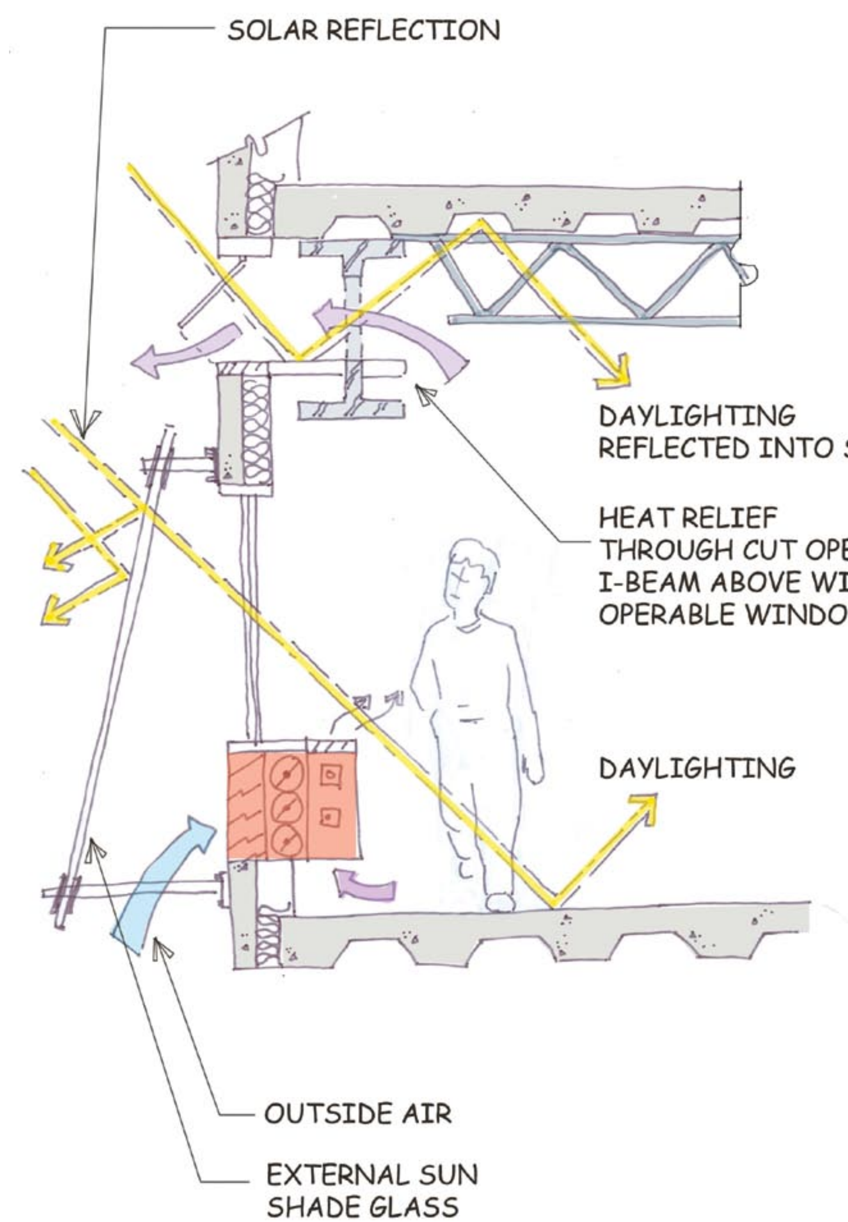


Figure 2: Illustration of daylighting used in combination with shading and natural ventilation (Courtesy of Stantec)

Regulatory Requirements

The 2003 Washington State Ventilation and Indoor Air Quality Code (Chapter 51-13) provides requirements for outdoor air supply flow rates for various types of facilities and occupied spaces. These requirements are normally achieved using mechanical ventilation. However, section 304.1 makes an exception to these requirements for naturally ventilated spaces that meet the requirements on the International Building Code (IBC), as adopted by the State of Washington.

The 2003 IBC section 1203.4 provides prescriptive requirements for quantity and location of operable area to provide ventilation air.

Alternately, naturally ventilated buildings can use thermal modeling to predict outdoor air flow into spaces and thereby meet the mechanical ventilation performance requirements of the ventilation code. See Section 4.3 of this report for more information on building simulation and modeling.

It is important to note that some high-contamination-level spaces, such as bathrooms, kitchens, and copy rooms must include exhaust even if the rest of the building is naturally ventilated. The make-up air for these spaces can be provided by natural ventilation.

Design Process and Strategies

The following sections outline key concepts that need to be addressed both before and during the design process. For thorough design guidelines, please refer to Further Resources section.

Pre-design Consideration

Before design begins it is of utmost importance to acquire complete buy-in from the building owner/operator. The design team and client need to agree on comfort standards for the occupants of the buildings. For example, if building occupants are given control over operable windows and are allowed to adapt their dress to weather conditions, usually the acceptable comfortable temperature range can be expanded without sacrificing occupant satisfaction. If possible, choose a standard, such as Section 5.3 or ASHRAE 55-2004 or the Bounding Comfort Parameters from LEED-NC 2.1 to guide the thermal comfort performance required of the design.

It is also important that the owner understand with a passive systems either the building users or maintenance staff will need to be educated on the proper use of the system to maintain comfort (i.e. opening windows for night flushing, closing windows in the winter to reduce heating requirements).

A 24-hour facility, such as a fire station offers excellent opportunity for incorporating natural ventilation and requires few design modifications. Sleeping areas can be treated much like in a typical house, as residents often leave their windows open at night during hot periods, which effectively pre-cools the area for the next day. Areas that are primarily un-occupied during the night can be flushed-out and pre-cooled for the following day. If there are work spaces that are occupied around-the-clock, supplemental cooling may be required during the day, as night-time occupants may not want to allow full flush-out during the night if temperatures drop too low. A significant advantage of 24-hour facilities is that security concerns may be lessened, particularly if there is always some one "on-duty." Obviously this needs to be evaluated on a case-by-case basis.

Another aspect of domestic living that could be advantageous for integration into a fire station is the concept of seasonal cooking. Even with full mechanical systems, a kitchen space is typically an uncomfortable environment, especially during hot summer months. Minimizing the amount of heat produced by a kitchen will only aid in keeping the whole station more comfortable, and may well help keep the cooks happier. This can be achieved by cooking less hot foods during the summer months (many households make this adjustment), or better yet, incorporating an outdoor cooking/grilling area that can be used during nice weather to help keep the cooking loads outside of the occupied spaces as well as provide a pleasant area for building occupants to unwind and relax.

It is a good idea to gather and analyze typical local weather data before design begins, including hourly ambient temperature, humidity, and wind speed and direction. Combining this knowledge with the thermal comfort criteria can lead to an initial assessment regarding the necessity of supplementary cooling.

It is also vital to involve all design team disciplines in these discussions. Successful natural ventilation and cooling systems often involve cost trade-offs between disciplines. For example, the mechanical system will likely be smaller and less expensive, but perhaps the structural budget will increase to provide more thermal mass, or the need for operable windows will drive the architectural design. The earlier the entire design team is aware of the intent of the building, the easier it will be to incorporate the necessary elements into the design.

When existing buildings are being renovated one should consider the form, structure and siting of the building. They may prove to be either a constraint or an opportunity for natural ventilation. For example, many older buildings in Seattle have high-mass structural components - masonry, concrete and brick. These provide thermal mass that can potentially enhance the effectiveness of a natural ventilation design. On the other hand, challenges are introduced if the existing building is oriented on a north/south axis such that the east and west façades experience large afternoon solar heat gains during the summer.

Design Options

Table 2, following, details some of the design options that can be combined to create a comfortable, naturally ventilated and cooled building.

Table 2: Natural Ventilation and Cooling Design Options

Option	Description	Design Considerations	Related Strategies	O & M Issues
Minimize Loads	Mitigate or prevent solar, conductive, and process loads.	High performance envelope, shading, avoid concentrated process loads	High occupancy space "flush-out" after use, daylighting to reduce lighting load.	None
One sided natural ventilation	Draw fresh air and vent relief air through openings along one exterior side of space.	Only appropriate in shallow spaces (i.e. private offices). Include high and low openings to create stack effect.	Ceiling fans to create air flow during stagnant periods.	None

Option	Description	Design Considerations	Related Strategies	O & M Issues
Two sided natural ventilation	Draw fresh air and vent relief air through openings on opposite sides of a space.	High and low openings on opposing facades create cross and stack air flow.	Clerestories, solar wells, ventilation chimneys, narrow floor plates, "I", "E" or "O" shaped floor plans	None
Occupant control	Allow building users to open and close windows to control space temperature.	Can be manual (operable window) or mechanical (switch-controlled damper).		Motorized windows require maintenance. Operable windows may present security risk.
Automated control	Automated windows or dampers controlled by temperature, wind velocity, or CO2 level sensors	Can be a primary method of introducing air or as fail-safe. A solution for areas high occupancy spaces. Requires more robust controls system.	Can be good way to implement night-flush.	Automated systems require more maintenance than passive systems.
Thermal mass	Reduce peak building space temperatures with exposed dense building materials (i.e. concrete) that absorb heat during hottest times and slowly release it during cooler periods.	Can be walls, ceilings, or slab. Finishes (carpeting, drywall, etc.) greatly diminish effect.	Radiant chilled slab can be combined with exposed floor to increase cooling effect.	Durable materials require less maintenance than alternate finishes.
Night flush-out	Introduce cool outdoor air into building at night to allow structure to pre-cool for next day.	Requires either automated system or early morning and evening occupants to open and close windows. Only effective if nighttime temperatures are cool.	Most effective when combined with thermal mass effects to store "coolth" into the next day.	Automated systems require maintenance. Passive systems may require custodial crew to be in charge of window control. Potential security issues.
Supplementary cooling	Add cooling to areas with peak loads to maintain comfort conditionings.	Optimal choice is radiant cooling rather than forced-air units. Ceiling fans can provide significant cooling effect without mechanical cooling.		Cooling systems require maintenance.

Design Tools and Calculations

In a traditional HVAC design, compliance with thermal comfort criteria can be demonstrated through peak load calculations, unit capacities and temperature set points. Thermal comfort compliance in a natural ventilation and cooling design can be more difficult to prove, as indoor temperatures are a function of frequently changing factors such as wind speed and direction, cloud cover, outdoor temperature, and occupancy levels. Some comfort criteria, such as ASHRAE 55-2004 are based on peak indoor operative temperatures, while others, such as the LEED-2.1 Bounding Comfort Parameters refer to the number of annual hours allowed at different temperature thresholds.

The best way to demonstrate compliance with the design comfort criteria is to conduct whole building thermal modeling. This requires software capable of performing dynamic hourly load, air flow and temperature calculations, including the effects of operable windows, and natural air flow, with the ability to use location appropriate weather files.

Thermal modeling is useful for much more than simply demonstrating compliance. It can be used to test different options or iterated to optimize the design. For example, the thermal modeling software can be used to find the optimal quantity and location of operable windows, or evaluate the effect of changing building materials.

Owner: Resort Municipality of Whistler, British Columbia

Architect: Hughes Condon Marler

Mechanical Engineer: Stantec

Project Cost: $CAN1,600,000

Project Size: 6,500 ft^2

Completion Date: 10/1/2004

Project Status: Completed

LEED® Status: Silver Certified

Case Study – Spring Creek Fire Hall

Spring Creek Fire Hall exterior (Courtesy of Stantec)

Project Description (provided by Hughes Condon Marler & Stantec):

Spring Creek Fire Hall is located on a steeply sloped mountainside near the Whistler Ski Resort in Canada. The 6,500 sq.ft. building is made up of three major components: a three bay truck storage, a hose/training tower and live/work quarters. This building is the first in the Whistler area to achieve LEED Certification. The primary and most visual response to the context and green agenda called for a mountain-like planted roof, which naturally retains excessive storm water and promotes summer cooling. Other notable green strategies incorporated into the design include: high energy efficient equipment, recycled/reused building materials, natural ventilation and construction waste management.

The Resort Municipality of Whistler in recent years instituted a community program entitled "Whistler. It's Our Nature" to promote and support a sustainable Whistler. This program encourages businesses, households and other organizations to practice sustainability, including using The Natural Step Framework as their sustainability compass.

In the Fall of 2001, the Resort Municipality of Whistler (RMOW) decided that Fire Hall No.3 had outgrown the small confines of its existing building and that a new fire hall would be needed. In keeping with the "Whistler. It's Our Nature" environmental sustainability plan they concluded that the new facility must incorporate sustainable design techniques and set a precedent for future municipal buildings. Working with British Columbia Buildings Corporation the RMOW also decided that this new building should become LEED registered.

The following are three significant design features that make this project sustainable:

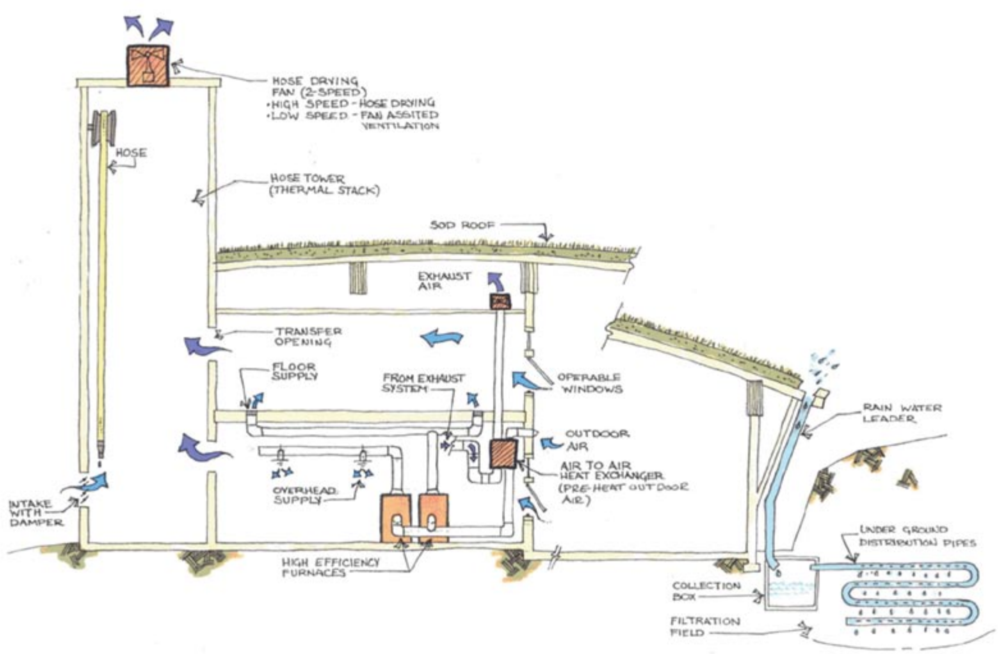
Energy Efficiency

Heating Season

To reduce energy use in the fire hall a high efficiency furnace was installed in the living area to provide heat. Infrared heaters were installed in the apparatus bay in order to heat only the equipment and occupants working on the equipment. An air to air heat recovery unit was installed for ventilation which will recover approximately 50% of the rejected heat from the exhaust air. The domestic water heater is a high efficiency heater that will also reduce the energy usage on the building.

Cooling & Shoulder Seasons

This building did not require an air conditioning system, and relies on natural ventilation and cooling during the warmer months. An air intake located on the lower level of the tower brings in outside air and acts as a natural stack effect for ventilation.



Spring Creek Fire Hall mechanical system cartoon (Courtesy of Stantec)

Green Roof

More than 50% of the total roof area on the fire hall is a green roof. This type of roof captures rainwater and returns a portion of it back to the atmosphere via evapotranspiration. It also reflects solar radiation in a natural way and helps reduce the heat island effect. The green roof on the fire hall provides insulating benefits, looks like its part of the natural local environment, has a longer lifetime than a conventional roof, and requires less maintenance than a conventional roofing system. The fire hall roof has been planted with local indigenous grasses and drought tolerant plants so there is no permanent irrigation required, which helps reduce water usage. These local plants require less maintenance than foreign plantings and minimize the use of fertilizers and pesticides. By using local plantings we hope to attract native wildlife, including birds, mammals, and insects, thereby creating a building site that is integrated with the natural surroundings.

Spring Creek Fire Hall green roof & Valley Trail (Courtesy of Stantec)

Alternative Transportation

The Valley Trail is a paved 20 km trail that runs from Alpha Lake Park at the south end of Whistler to Emerald Estates in the north, with branches to hiking and mountain biking trails. The trail is plowed in winter for walking, with a portion groomed and track set for free cross country skiing. This trail runs immediately adjacent to the fire hall's rear entrance and makes for a vital mode of transportation for people to get to the fire hall. Pedestrians can take the trail from the fire hall straight down the hill to the bus stop (just 200 ft away), located on the sea to sky highway which leads directly into the village. This bus stop is serviced by WAVE (Whistler and Valley Express) bus line on their Whistler Creek route and is also utilized by Greyhound bus lines on their Squamish to Whistler route. If building occupants chose to walk, run, or bike to the fire hall we have installed a secure bicycle storage area and changeroom/shower facilities. For those that still require a vehicle for transportation, parking is provided for 10 vehicles (which is only 50% of what local zoning laws require) with the priority space designated for carpool vehicles.

Case Study – Snoqualmie Headquarters Fire Station

Snoqualmie Headquarters Fire Station exterior (Courtesy of TCA)

Project Description (provided by TCA & Stantec):

Nestled among old growth timbers, the new 16,500 sf Headquarters facility thoughtfully embraces the site orientation, terrain, and on-site natural resources to accomplish an integrated sustainable design solution, which places operations first. Capitalizing on the sloped site, a terraced design defines the horizontal and vertical zoning of operational functions and allows for clear separations between a future City Hall, response activities and on-site training requirements.

Through an extensive collaborative design process the project incorporates an industry sponsored and monitored test site for pervious pavers, a rain garden incorporating the site found snags and timbers, shared parking with minimized drive widths and 83% native vegetation. Additionally, the facility's high performance, low impact features include chilled slabs with naturally ventilating chimneys and earth tubes, sun shading and daylighting strategies, environmentally friendly materials such as concrete masonry and 'cool' roofs and plumbing fixtures which promote water conservation. This facility maximizes design opportunities balancing fiscal responsibility, ecological health, and enhances the safety and welfare of the citizens of Snoqualmie.

Owner: City of Snoqualmie, WA

Architect: TCA Architecture

Mechanical Engineer: Stantec

Project Cost: $4,100,000

Project Size: 16,500 ft2

Completion Date: 2005

Project Status: Completed

Awards: Silver Medal- Station Style Award, 2005 Fire Chief Magazine

Mechanical Description

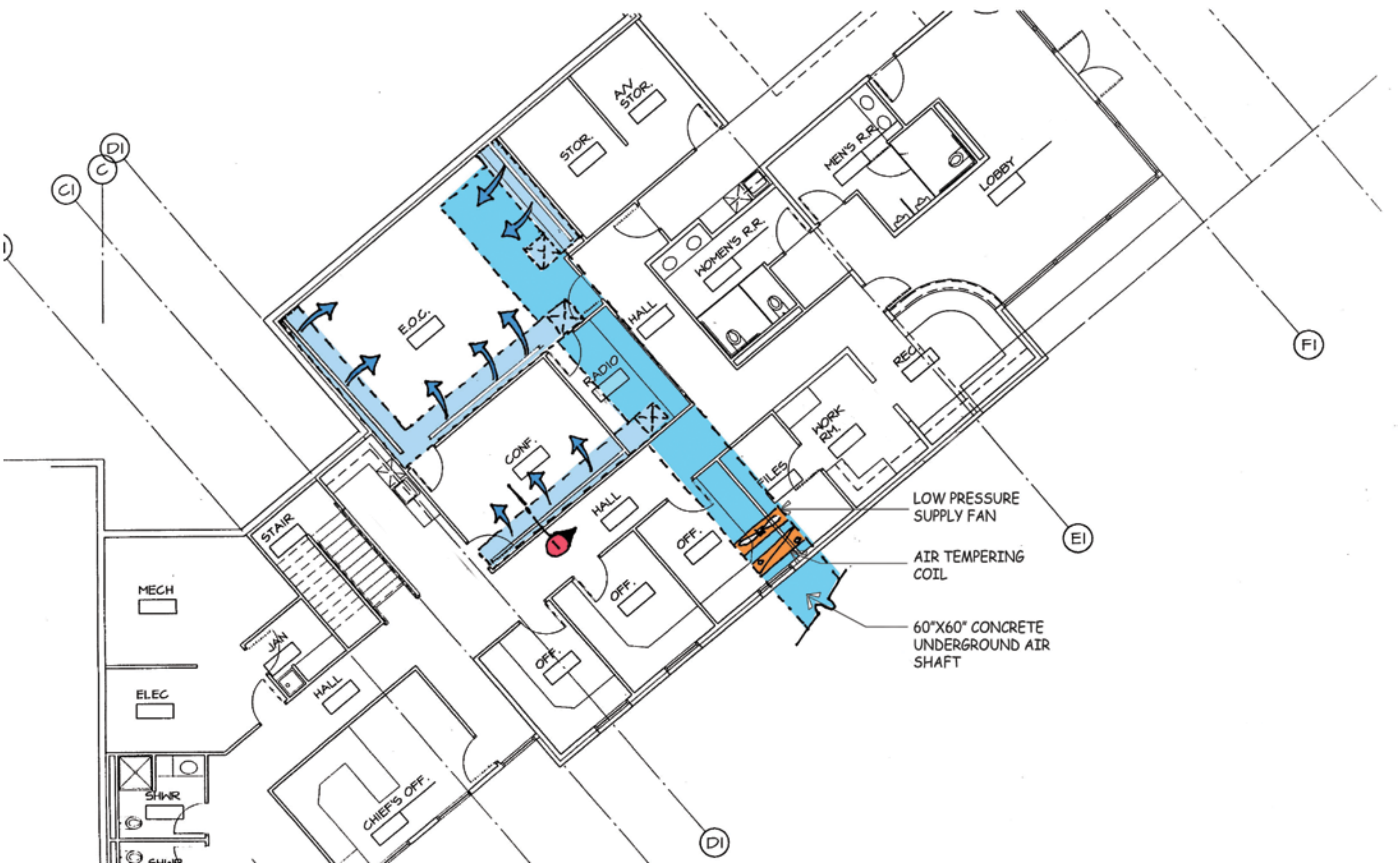
The Snoqualmie Headquarters Fire Station makes use of a unique hybrid system. The client requested that most occupied spaces maintain a high degree of temperature control. Depending on the needs of the space combinations of natural ventilation and cooling, radiant slab, under floor ducted, and overhead ducted systems were used. The following sections detail the mechanical systems used in several of the space types.

Apparatus Bay and Maintenance Work Spaces

These spaces used radiant in-slab heating and no mechanical cooling. Exhaust-extraction-systems are connected directly to the trucks to remove engine exhaust from the spaces. These systems include break-away fittings, so that the trucks can leave the bay during a fire-call without unhooking from the exhaust system.

Lower Floor Work & Conference Spaces

Because these spaces lack exterior windows, traditional natural ventilation was not an option. Instead, the primary source of supply air comes from an earth tube buried beneath the facility with an outside air intake located away from the building. A large fan pulls the air through the tube at a low velocity (around 300 feet per minute) so that the air has time to approach the ground temperature as it drifts through the over-sized earth-tube. During the summer this pre-cools the air and during the winter it pre-heats the air. If necessary, the air is tempered by a heating coil before being introduced into the spaces by in-floor diffusers. The floors also contain in-slab radiant heating and cooling. For times when the heating or cooling capacity from the earth tube or radiant slab is inadequate, an overhead ducted fan coil unit provides fully conditioned air.



Schematic of lower level earth tube and under floor air supply (Courtesy of Stantec)

Sleeping, Multipurpose, and Office Spaces

These spaces have exterior operable windows, and thus always have the option of utilizing natural ventilation and cooling if desired. For the majority of the year space heating or cooling is provided by an in-floor radiant system. For times when the radiant slab capacity is inadequate, an overhead ducted fan coil system can provide supplementary conditioning.

Incentives and Technical Design Assistance

Betterbricks (www.betterbricks.com), an organization that supports the design of energy efficient buildings, is funded by the Northwest Energy Efficiency Alliance. They have several incentive and assistance programs that will partially fund the "soft costs" of a naturally ventilated and cooled building. Soft costs can include building simulation and enhanced design services above and beyond the design costs of a "traditional" building.

Additionally, utilities such as Puget Sound Energy and Seattle City Light frequently offer incentive programs to offset the initial cost increase to install more energy efficient systems.

Cost Benefit Analysis

No formal economic studies were performed for the Stantec natural or hybrid ventilation fire station design case studies. Based on project experience, however, the relevant capital costs for a fire station should be very similar to other natural ventilation designs. Because of the 24 hour occupancy of a fire station, however, the life cycle costs will be different from most other building types.

The following sections give examples from an actual project of capital and annual energy costs for natural ventilation designs as compared to traditional systems. Dollar values in the examples should be considered an indicator of relative costs as not all of the data is current.

Capital Costs

Table 3, following, shows a sample capital cost comparison (in $/ft2) of a passive natural ventilation cooling system vs. a hybrid system vs. a traditional ducted VAV system. It is taken from a report for the classroom design of a university building in the Puget Sound region and was created by Stantec in May 2006. Capital costs for a fire station should not be significantly different (other than adjusting for increasing construction and materials costs).

The comparison illustrates some of the cost trade-offs involved with natural ventilation and cooling design. Notably, in this project, the architectural costs are higher but the mechanical costs are lower. In this case the hybrid system not only includes mechanical cooling, but also fully automated operable windows controlled by the DDC system. This is why the architectural elements in the hybrid system are more expensive than in the passive system.

One opportunity to further reduce costs of naturally ventilated high performance buildings that is not represented in Table 3 are local utility and other green incentive programs. Seattle City Light, Puget Sound Energy and Betterbricks all offer programs that can reduce the initial investment cost of energy conserving features in buildings.

Table 3: Sample capital cost comparison of passive natural ventilation and cooling vs. hybrid (including automated window control) vs. traditional systems (in $/ft2)

	Passive Natural Ventilation and Cooling Design (Perimeter Baseboard Heat)	Hybrid Natural Ventilation and Cooling Design (Heated/Chilled Radiant Slab)	Traditional Ducted VAV System
Architectural Items			
Windows	$4.90	$4.90	$2.40
Window actuators & wiring	-	$6.30	-
Window security & wiring	$1.50	Covered by DDC	$0.90
External blinds	$5.06	$5.06	-
Internal blinds	-	-	$2.16
Wiring for blinds	$1.60	$1.60	-
Relief chimneys	$3.50	$3.50	-
Ceilings	$0.50	$0.50	$1.50
Arch Sub Total	$17.06	$21.86	$6.96
Mechanical Items			
Central plant (Heat)	$3.00	$3.00	$3.00
Central plant (Cool)	-	$3.00	$3.00
Perimeter baseboards	$2.00	-	-
Radiant slab piping	-	$6.00	-
Ventilation air fin tube units	$0.15	$0.15	-
VAV boxes and ductwork	-	-	$6.60
Air handling unit	-	-	$3.50
Hydronic piping & pumping system	$2.50	$2.50	$5.00
Terminal unit controls	$2.50	$2.50	$5.50
Balancing	$0.06	$0.06	$0.18
Commissioning	$0.50	$1.00	$1.00
Mech Sub Total	$10.26	$18.21	$27.78
Total Cost per ft^2	$27.32	$40.07	$34.74

Annual & Life-cycle Costs

For the example in Table 3, overall construction costs on a square foot basis are lowest for the passive natural ventilation and cooling design coupled with perimeter baseboard heating. This system is expected to have the lowest annual energy costs, even though heating costs may be slightly higher than the hybrid natural ventilation case which has the more efficient radiant floor heating system. Conversely, energy costs are highest for the conventional system, primarily because of the fan energy.

Because of its lower capital and energy costs the passive natural ventilation design has easily the lowest life cycle cost of the three options. For those spaces where a passive system can be effectively implemented it therefore becomes the most economic choice.

For spaces that may need some mechanical cooling on the warmest days the choice between a conventional ducted overhead VAV system (initial cost = $34.74/ft2) and the hybrid natural ventilation system (initial cost = $40.07/ft2) becomes one of choosing between lowest first cost and lowest estimated life cycle cost.

The life cycle cost calculation for our example can be applied to a new fire station as follows: For a new fire station in Seattle with 24-hour occupancy, the baseline annual energy use intensity for spaces with a traditional ducted overhead VAV design that meets the current energy code would be expected to be about 60 kBtu/ft2; using current utility rates for natural gas and electricity, this comes out to $1.06/ft2 annually.

Provided the same fire station is designed instead to maximize natural ventilation cooling benefits, those spaces served by the hybrid natural ventilation system have typically been found to have energy cost savings of at least 25%. This equates to annual energy cost savings relative to the traditional design of approximately $0.32/ft2. Assuming fuel escalation averages 10% annually and a discount rate of 6%, the internal rate of return (IRR) on the additional capital cost investment for the hybrid natural ventilation system is 10.9% and positive cash flow occurs after about 10 years.

Further Resources

ASHRAE 55-2004: Thermal Environmental Conditions for Human Occupancy

ASHRAE 62.1-2004: Ventilation for Acceptable Indoor Air Quality

The Carbon Trust Good Practice Guide 237- Natural ventilation in non-domestic buildings: A guide for designers, developers, and owners.

Chartered Institution of Building Services Engineers (CIBSE) Applications Manual 10:2005, Natural Ventilation in non-domestic buildings.

International Building Code- 2003 Edition, as adopted by the City of Seattle

Washington State Ventilation and Indoor Air Quality Code- 2003 Edition- Chapter 51-13

Glossary

Comfort criteria: Agreed upon interior design conditions for project, such as maximum temperature or annual hours above temperature thresholds

Cross ventilation: Taking advantage of natural breezes to draw air across a space, requires operable windows on opposing facades of the building and unobstructed paths for air flow

Daylighting: The use of natural sunlight to provide light to a space rather than electric light, typically most effective when light is diffuse rather than direct-beam sunlight

Hybrid system: In this context, hybrid system refers to a natural ventilation system with supplementary mechanical cooling, usually used only to meet peak loads

Night flush: Opening up windows and dampers at night to purge hot air from building and allow fresh air to pre-cool building structure for next day, most effective when used in combination with thermal mass

Natural ventilation: Strictly, this only refers to providing fresh air to a building's occupants without the use of mechanical means (i.e. fans); it is often incorrectly used to imply natural cooling

Natural cooling: Keeping a space from overheating by introducing cooler outside air without the use of mechanical means (i.e. fans, chillers, etc.) often requires preventing air from entering spaces if outside temperature exceeds inside temperature, also known as natural conditioning or passive cooling

Operable windows: Refers to glazing or dampers that can be opened to allow outside air to enter a space

Operative temperature: The temperature that an occupant "experiences" in a space, including the effects of air temperature, air movement, and radiant temperature

Radiant heating/cooling: A cool surface will radiantly "pull" heat away from an occupant thereby cooling them, a hot surface will give up heat to a person radiantly, this allows for heating and cooling with out mechanically conditioning air

Stack ventilation: Using the natural buoyancy of hot air to create vertical air movement, typically involves high level venting through chimneys, vent shafts, or atriums

Thermal mass: Dense building materials such as concrete, brickwork, or stone that moderates space temperatures by absorbing heat during hot periods and releasing it during cool periods

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Printed on recycled paper.