Seattle Department of Construction and Inspections
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Tip 411
GREEN
Seattle Permits
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Natural Ventilation

May 15, 2009

What Is Natural Ventilation?

Natural ventilation is the use of a building's form, organization, and openings in conjunction with naturally occurring phenomenon, such as the wind or warm air buoyancy, to supply air to its occupants and to remove heat from both the occupants and the building. Forms of natural ventilation activated by the forces of gravity are called stack ventilation. Wind-driven systems are referred to as cross ventilation.

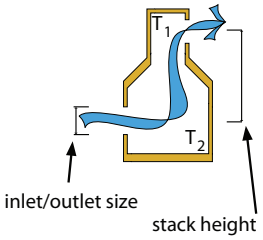
What Is Natural Ventilation?

- Supplying breathing air for occupants
- Reducing odors and pollutants
- Cooling people by moving air across skin
- Removing internal heat gains
- Cooling thermal mass at night to precool buildings for the next day

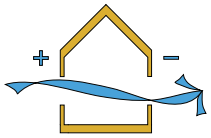
Why Should Buildings Be Naturally Ventilated?

- To reduce operating costs by decreasing or eliminating the power used to mechanically ventilate and cool.
- To reduce construction costs by allowing the downsizing or elimination of cooling equipment.

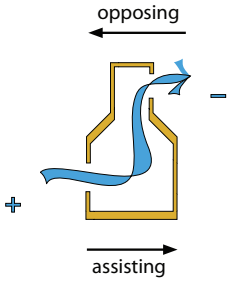
Types of Natural Ventilation



Systems that primarily rely on gravity are called stack ventilation. Stack ventilation through a space is a function of the vertical distance between inlets and outlets, their size, and the temperature difference between the outside air and the average temperature in the stack.



Wind-driven systems are referred to as cross ventilation. Cross ventilation airflow through a space is dependent on opening size, wind speed and direction, building shape, and opening location.



Cross and stack ventilation can work together. If the inlets for stack ventilation correspond to the high-pressure zones and the outlets to the low-pressure zones, then wind will assist the stack ventilation.

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- To reduce building energy use and thereby reduce the environmental impact caused by power generation.
- To potentially increase the productivity of building occupants due to real or perceived improvements in the indoor environment.

What Are the Goals and Benefits of Natural Ventilation?

Reduced Energy Use and Operating Costs

Natural ventilation can reduce building energy use and thereby reduce the environmental impact caused by power generation. Of the total energy used for all U.S. buildings, 7% is for cooling and 6.5% is for ventilation. Cooling energy use ranges from 1.3 kBtu/sf/yr for warehouses, to 8.9 kBtu/sf/yr for office buildings, to 17.4 kBtu/sf/yr for food service. Ventilation energy use for warehouses is 2 kBtu/sf/yr; for offices, 5.2 kBtu/sf/yr; and for health care, 13.3 kBtu/sf/yr (U.S. DOE, Energy Information Administration).

Increased Productivity

In addition, natural ventilation can potentially increase the productivity of building occupants due to real or perceived improvements in the indoor environment. Occupant benefits from natural ventilation are difficult to quantify, but the potential benefits due to increased productivity can be substantial. In fact, because salary and other personnel costs for occupants are typically several times greater than the cost of energy, even small increases in productivity (several studies estimate that productivity increased from 0.4% to 15% due to adding operable windows) can easily yield benefits that far exceed those from energy savings (Gurtekin-Celik, p.9).

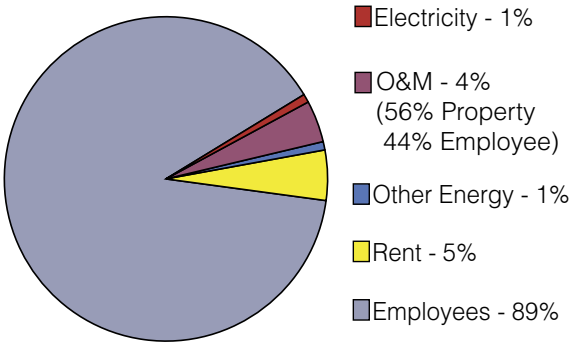
Thermal Comfort

The applicability of natural ventilation to a specific building depends on the limits of the occupant "comfort zone:" the range of temperatures, relative humidity, air speeds, and radiation amounts within which we feel comfortable. The comfort zone is affected by our activity level and clothing, and it also varies with age. In general, increasing physical activity and clothing lowers the temperature at which we feel comfortable. In general, elderly people prefer warmer temperatures.

The upper limit of the comfort zone often marks the point where natural ventilation is replaced by refrigeration as the primary means of cooling a building.

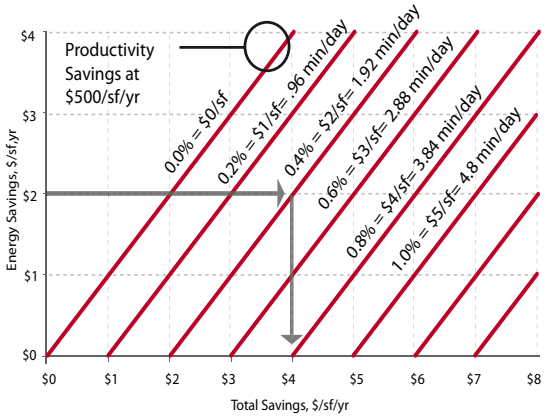
Employee Cost as a Percentage of Total Operating Costs

The argument that natural ventilation improves productivity is attractive because personnel costs far outweigh capital costs. For example, a recent evaluation of office buildings used by California state employees showed that personnel costs were ten times greater than space costs.



Benefits of Combined Energy and Productivity Savings

The vertical axis is energy savings, the diagonal lines show rates of productivity increases, and the horizontal axis is total energy and productivity savings. In the example, if the investment in ventilation saved $2/sf/yr in energy costs, and this resulted in a productivity increase of 1.92 minutes/day then the productivity savings would equal the energy savings, and the total savings would be $4/sf/yr.



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Adaptive Comfort

Current research indicates that the upper limit of the comfort zone for naturally ventilated buildings can be higher than that for mechanically cooled buildings. The higher acceptable limit has been attributed both to behavioral adaptations, such as decreasing clothing levels as temperatures rise, and to psychological factors, such as a relaxation of thermal expectations, a perceived control, and a greater diversity of thermal experiences in naturally ventilated buildings (de Dear). Using the adaptive comfort model, in the Northwest's relatively mild climates the upper limit of comfort can be 1°F to 2°F above the ASHRAE Standard 55 upper limit of 81°F at 20% relative humidity.

Is it Feasible to Eliminate Mechanical Cooling and Ventilation?

Climates such as Seattle's that have a large diurnal temperature swing are ideal for buildings that are thermally massive and ventilated at night. The cold nighttime temperatures can cool building mass, which is used in the daytime to reduce the need for mechanical cooling.

A building designed to use cross or stack ventilation and ceiling fans, and to have a low rate of heat gain (<100 Btu/hr/sf) can meet its cooling load with daytime natural ventilation for all but 1% of the year in Seattle. If that building were also thermally massive, it could meet its cooling load with night ventilation for all but part of one day of a typical year.

Can Natural and Mechanical Ventilation Be Used Together?

Mechanical ventilation makes sense as an assist to natural ventilation in many cases. It is a way to dependably introduce a high rate of outdoor air into buildings at a relatively low rate of energy consumption compared to air conditioning.

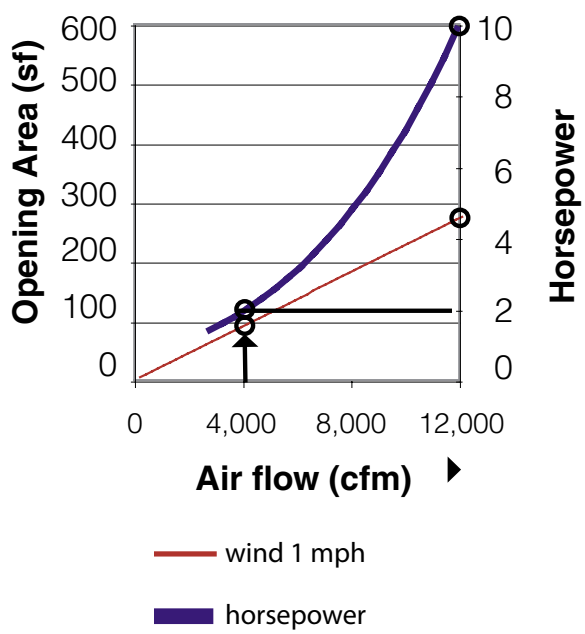
When natural and mechanical heating, ventilation, and air conditioning systems are combined, either one or the other is usually primary. This reduces duplication, which saves money and materials. Most often, natural ventilation systems handle the average conditions while mechanical systems take care of the peak conditions.

Coordination - Hybrid Systems

- Ventilation systems can be coordinated by location, for example with natural ventilation handling one part of the building and mechanical HVAC the other.
- If both types of systems are supplied for a single space, it is important that controls prevent natural ventilation inlets or outlets from being opened when mechanical heating or cooling is being provided. This can be accomplished by either letting occupants know when it is okay to open windows or by automatically shutting down the HVAC system when windows are opened.

Windows or Fans?

If the windows in a building are operable and are arranged to facilitate cross or stack ventilation, they can move a large volume of air. For example, used as inlets and outlets, windows with an opening area of 100 square feet each and with a wind speed of 1 mile per hour will create an air flow of approximately 4,000 cfm, roughly equal to what a 2 hp fan could move. To raise the cfm by a factor of 3 to 12,000 cfm, it would require an inlet or outlet window area of 275 square feet, or about 2.75 times the size of the original window. To realize the same increase in air movement with a fan would require a 10 hp fan, or about 5 times the original size.



Temperature Assumptions: Ti=80°F, To=77°F, and Δ H= neutral pressure level assumed to be 1/2 the stack height.

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- Natural ventilation and HVAC systems can also be used simultaneously for different purposes, for example with natural ventilation supplying outside air for people, while cooling is provided mechanically.
- Natural ventilation systems can also be augmented by ceiling or other local fans which increase air movement across people, making them feel cooler.

How Can Natural Ventilation Contribute to the City of Seattle's Regulatory Requirements?

Since the Seattle Building Code, the Seattle Mechanical Code, and the Seattle Energy Code do not require the installation of a mechanical system to provide cooling, the use of natural ventilation as the only means for comfort cooling is acceptable. If a mechanical refrigeration system is installed, Section 1433 of the Seattle Energy Code requires that an air economizer cycle be installed on that system. An air economizer cycle automatically modulates outside and return air dampers, which are capable of providing 100% of the design supply air as outside air to reduce or eliminate the need for mechanical refrigeration. Section 402 of the Seattle Mechanical code outlines basic sizing and operability requirements for natural ventilation openings.

- Section 402.1 specifies the openings for natural ventilation.
- Section 402.2 and 402.3 specifies the minimum operable area for natural ventilation to the exterior and through adjoining interior rooms without openings to the outdoors.
- Section 402.4 deals with below-grade openings for natural ventilation.

Important Code Implications

The same passageways created to naturally ventilate buildings have the potential to supply oxygen to a fire and to permit the fire to spread. The size and type of openings between interior spaces and the exterior permitted by code are a function of a building's occupancy, construction type, active fire suppression system, and location on the site.

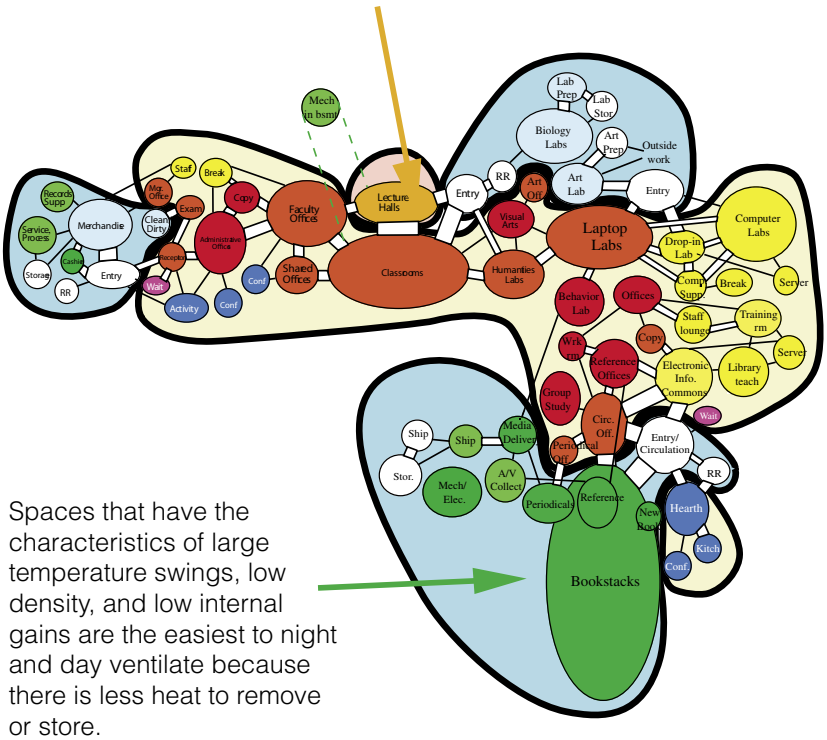
Cross ventilation outlets on the exterior that open to courtyards or public ways can be limited in size or not permitted depending on the nearness of other buildings.

Zoning for Natural Ventilation

The amount of energy used by a building is a result of the interactions of climate, building, and when and for what people use the building. Energy zoning is a set of activities intended to discover and develop strategies to take advantage of these interactions so that energy efficiency becomes an integral part of the building's program.

Spaces with similar heating, cooling, and lighting needs and occupant schedules can employ the same energy-efficient design strategies.
In energy zoning, spaces are categorized by allowable temperature range, internal rate of gain, and occupant density.

The most difficult spaces to naturally ventilate have a small temperature range, high internal heat gain, and high occupant density.



Spaces that have the characteristics of large temperature swings, low density, and low internal gains are the easiest to night and day ventilate because there is less heat to remove or store.

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Most of the restrictions on openings apply when the building is less than 20 feet from a property line or another building, although restrictions vary depending on the exterior wall size and the character of adjacent building walls. However, adjacent buildings that are within 20 feet can be substantially obstructions to the wind, limiting the effectiveness of cross ventilation for cooling.

Stack ventilation openings on the exterior have the same restrictions as those for cross ventilation. However, because atriums, malls, shafts, and stairwells play such an important role in creating a stack, the code restrictions on those elements are more important in determining the feasibility of using stack ventilation. When a design already has budgeted stacks that have large doors that are automatically closing fire assemblies, they can be cost-effective outlets for night ventilation of mass.

What Are Some Design Considerations for Natural Ventilation?

Site

Buildings should be oriented on sites so they can take advantage of microclimates — created by trees or water bodies, etc. — that provide cool air for inlets. On sloping sites, buildings should be located at the top of the slope, where winds are usually the strongest. If several buildings are to be placed on the site, they should be staggered or spaced apart (about five times the building's height). This may limit cross ventilation effectiveness in denser, urban areas.

Program

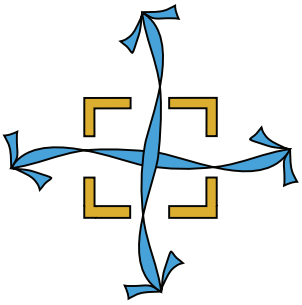
When a building's program is being developed, spaces should be grouped together that have similar criteria for allowable temperature swing, rate of heat gain, occupancy density, outside air, and time of use. This zoning means similar ventilation strategies can be used in one area, while others are used elsewhere, simplifying both building and mechanical design.

Buildings that are zoned for time of use can take advantage of unoccupied periods by relying entirely on natural ventilation. Zoning can reveal other compatibilities. For example, spaces that are daylighted need openings to the outside and are usually located on the perimeter, also a good location for openings for ventilation.

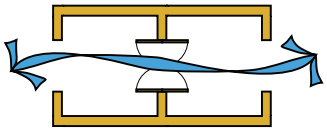
Space Types

Cross ventilation works well for spaces that extend from one side of the building to the other, like gyms or hallways, offering an unobstructed connection between windward and leeward openings.

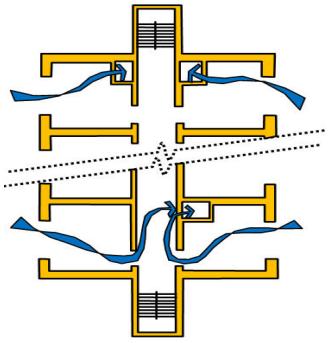
Space Type Strategies



Single Room Buildings
If there are openings on all four sides of a single room building, it will cross ventilate regardless of wind direction.



Multi-Room Buildings
Rooms arranged back to back with exterior circulation in buildings more than one story high can be night ventilated if opened to each other at night. The openings can usually be the size of one or two doors.



Double-Loaded Corridors
Probably the most common problem for natural ventilation is double-loaded corri-dors. They can be ventilated with a stack in each room, or the corridors might be used to conduct ventilation to common vertical stacks. Use of corridors may compromise egress requirements. Project teams considering this approach are advised to schedule a pre-submittal conference to present alternatives to discuss building code compliance.

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When a building is composed of many small spaces, the most straightforward way to naturally ventilate is to provide inlets and outlets in every space. Therefore, no cooperation is needed between occupants. In buildings more than one room deep and in all buildings with internal circulation corridors, the windward rooms can block the air movement to leeward rooms. Open office planning can be used to eliminate corridors, and if private offices on the perimeter are needed, they can be spaced apart to allow cross ventilation air to flow between them.

Inlet/Outlet Design

Cross ventilation is a valuable means of cooling during the day, but at night wind speeds are frequently low, so stack ventilation becomes an important strategy. Stack and cross ventilation strategies may also be used in the same building but in different rooms. For example, cross ventilation might be used in windward-side and upper-level rooms, while stack ventilation might be used in leeward-side and lower-level rooms that have little access to wind.

The rate of stack ventilation can be increased by adding a chimney to the outlet to increase the stack height. If the stack is south facing, it can be heated with the sun, which increases the average temperature in the stack and therefore the temperature difference with the outside air, increasing the ventilation rate.

Maximum cross ventilation occurs when both inlets and outlets are large and wind is relatively perpendicular to the openings. When openings cannot be oriented to the prevailing breeze, landscaping or wing walls that project into the air stream can be used to channel wind flow through windows parallel to the prevailing wind directions.

Construction Practices and Considerations for Naturally Ventilated Buildings

Operable windows and vents are readily available in the United States. Controls and vent opening operators are available but are not always designed or constructed for commercial building use. As the market for naturally ventilated buildings increases in the U.S., these products should become more available here.

Minimizing leakage is important in naturally ventilated buildings, and requires careful sealing around openings and surrounding wall systems. Improper installation of unfamiliar components can result in excessive air leakage around inlets and outlets, which can cause problems with condensation, energy loss, and drafts. Proper coordination of flashing and cavity water-proofing are also required to ensure effective envelope integrity. Turbine ventilators (often used to increase airflow) are prone to horizontal rain penetration and may require the construction of special barriers as well. Contractors should understand the proper handling and installation of these components prior to construction.

With naturally ventilated buildings, component installation must be coordinated among the members of the construction team. Because operable windows, louvers, and turbine vents are part of the building's cooling and ventilation system, there may need to be additional coordination between mechanical and envelope trades. This is especially true if the natural ventilation components are linked to mechanical components with control systems.

Design Tools and Calculations for Natural Ventilation

The tools and calculations used to design for natural ventilation are geared to three stages of the design process: analysis, design, and evaluation.

Analysis tools are used to understand the problem and its context. Design tools or strategies are form-generating — they concentrate on revealing the relationship between architectural form and both natural and mechanical ventilation. Evaluation tools are used to evaluate the performance of a design. Analysis tools are used primarily before design begins, while design strategies and evaluation tools are used interactively during design.

Analysis Tools

Designing successfully for natural ventilation requires knowing wind speed and direction, temperature, and relative humidity on an hourly basis for the time period the building will be ventilated. It is important to analyze wind for specific time periods since wind patterns often vary considerably across seasons and across the day. Wind roses are a commonly used tool for understanding wind patterns. Several references to sources of wind roses and climate data are included at the end of this Tip.

Data from the Seattle-Tacoma International Airport indicates that during the daytime of the 120 hottest days of the year the wind blows from the north and south-westerly directions. At these times there are very few calm periods. This suggests that cross ventilation is feasible for designs that incorporate day ventilation. At night the wind blows less frequently from the westerly directions and more from the north and south, with some easterly flows. For about 10% of the time at night the wind is too calm for cross ventilation. Stack ventilation can be used to cool the building during these hours. This is important if night ventilation of mass is being considered as a cooling strategy.

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There are two issues that are important to consider for adjusting wind data to a particular site. First, there are usually differences between the data collection site and the building site in altitude and roughness of the terrain, which will affect wind speed and direction. Second, there are local effects, such as those caused by topography, buildings, albedo, and vegetation that can create micro-climates different from the airport climate.

Evaluation Tools

The purpose of evaluation tools is to enable the designer to understand how well a proposed building ventilation system design will work. Tools and methods can be physical or mathematical models. Some tools combine thermal and ventilation models. When selecting a tool, the designer must consider its form (non-computerized or computerized), the costs to purchase and use the tool (time, expertise), which effects need to be accounted for (i.e. single versus multizone, heat sources, pollutant transport, mechanical systems, and others), and what data is available.

What Kind of Incentives and Technical Assistance Is Available for Natural Ventilation?

There are a number of programs in the Northwest that are designed to reduce the first cost of constructing energy-efficient buildings. In Washington, Oregon, and Montana, design assistance and/or incentives are available from the Northwest Energy Efficiency Alliance's BetterBrick's program. Design assistance is also available from Washington's State Department of General Administration and some utilities.

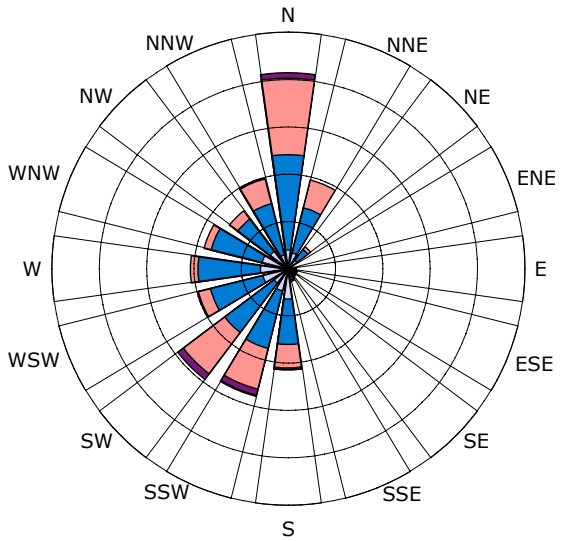
Specifically in Seattle, Seattle City Light offers technical assistance services for both renovations and new construction through its Energy Smart Services program. Under this program, developers building new commercial spaces or planning major renovations can receive technical advice, energy analyses, and grants for energy efficient construction. Seattle City Light provides calculations of funding and energy savings for some types of measures. For other measures, the utility offers funding for energy analyses by a consultant selected and hired by the customer.

Existing commercial and industrial buildings are also eligible for Seattle City Light grants and free energy audits for projects that save electrical energy without fuel switching. Reimbursements of up to 70% of the cost of qualifying energy-efficiency improvements are available.

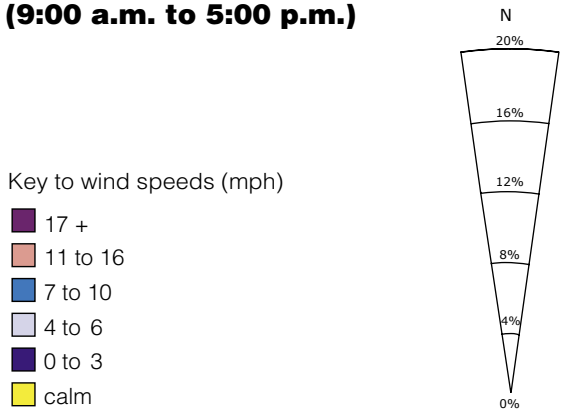
What Is a Wind Rose?

A wind rose gives detailed information about wind direction and frequency for a year or portion of a year. The radial bars show the percentage of the time that the wind blows from each direction for various ranges of speeds.

Wind direction varies with the time of the year and day. It is important that the wind be evaluated for the periods that natural ventilation is planned.



Seattle - 120 Hottest Days (9:00 a.m. to 5:00 p.m.)



Each segment of a wind rose is divided radially into percentages

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Cost/Benefit Analysis and Comparison to Conventional Mechanical Systems

The larger the share of ventilation and cooling load that can be handled by natural ventilation, the greater the potential for reducing operating energy and costs. Substituting natural ventilation for mechanically supplied outside air and cooled air reduces the number of hours per year the mechanical system must operate and therefore reduces the utility costs. While the potential for savings is significant, if the natural ventilation system is not designed to mesh with the mechanical system, the actual cost of operating the building may increase (for example, if windows are left open when the mechanical cooling system is operating).

The median first cost of heating, ventilating, and air-conditioning systems in the Northwest varies from $7.70/sf in factories to $18.60/sf in restaurants. In Seattle, the cost for offices is $10.25/sf, and is $14.35/sf for schools, which is approximately 12% of the construction budget (R.S. Means, 2009). A reduction in first cost is possible either by downsizing or by eliminating the mechanical ventilation and cooling systems. For example, if the outside air requirements for occupants can be met all year using natural ventilation, this frees the mechanical system from having to supply air, which requires ducts. Water in smaller pipes can then be used as the heat transfer medium, reducing the size and cost of the distribution system. Downsizing the cooling system requires that the peak load be reduced.

The cost of making the changes necessary to downsize the cooling system depends on what is already included in the design. For example, if the building or space design permits cross ventilation, there are already operable windows in the design, the construction is thermally massive, and users will open and close windows when appropriate, then night ventilation of mass is a low-cost cooling strategy. On the other hand, if none of these elements were included in the design, the increase in cost to include them would probably exceed the savings from downsizing the system.

This Tip is based on Natural Ventilation in Northwest Buildings by G.Z. (Charlie) Brown, Dale Northcutt, Jeff Kline, Gina Livingston, and Emily Wright, which is available from the Energy Studies in Buildings Laboratory at the University of Oregon. Contact information is included to the right.

Additional Resources

- *Natural Ventilation in Northwest Buildings*, Energy Studies in Buildings Laboratory, University of Oregon and Better Bricks, June 2004.
- National Climatic Data Center, U.S. Department of Commerce. This site provides access to summary climate data including temperature and wind: **www.ncdc.noaa.gov/oa/ncdc.html**.
- National Renewable Energy Laboratory. This site provides climate data files for typical meteorological years. This data is useful for analyzing temperature and relative humidity but not appropriate for understanding wind patterns: **http://rredc.nrel.gov/solar/old_data/srdb/1991-2005/tmy3/**.
- National Water and Climate Center, U.S. Department of Agriculture. This site provides wind data and wind roses: **www.wcc.nrcs.usda.gov/climate/windrose.html**
- *Sun, Wind, and Light: Architectural Design Strategies*, by G.Z. Brown and Mark DeKay. New York: Wiley, 2000.

Helpful Contacts

- BetterBricks Program of the Northwest Energy Efficiency Alliance. A network of information, tools and resources, including temperature and wind: (800) 411-0834 or (503) 827-8416; **www.ncdc.noaa.gov/oa/ncdc.html**.
- Energy Studies in Buildings Laboratory, University of Oregon. Provides design assistance, research and education on natural ventilation, daylighting, and sustainability. (541) 346-5647; **http://aaa.uoregon.edu/esbl/**.
- Integrated Design Lab, Puget Sound,operated by the University of Washington. Provides project-based technical and educational services to building design professionals. (206) 616-6566 or toll free (877) 604-6592; **www.integrateddesignlab.com/Seattle/**.
- Seattle City Light Energy Smart Services. Offers financial incentives and technical assistance for both existing facilities and new construction. (206) 684-3254; **www.seattle.gov/light/**.

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Access to Information

Links to electronic versions of Seattle DCI **Tips, codes** and **forms** are available on the "Tools & Resources" page of our website at **www.seattle.gov/sdci**. Paper copies of these documents are available from our Public Resource Center, located on the 20th floor of Seattle Municipal Tower at 700 Fifth Ave. in downtown Seattle, (206) 684-8467.

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