Ventilative Cooling: Can Businesses Live Without Mechanical Cooling?

Rod Olsen and Reid Hart, Eugene Water and Electric Board
Michael Hatten and Galen Ohmart, SOLARC, Architecture & Engineering, Inc.
G. Z. Brown, University of Oregon Energy Studies in Buildings Laboratories

ABSTRACT

The application of ventilative cooling in the commercial sector has been promoted as a sustainable building practice. Four buildings with ventilative cooling have been completed recently in Eugene, Oregon. They include a bicycle manufacturing facility, a food bank, a childcare center, and a business school building. Two of them were occupied during one of the warmer summers on record. In a time when there is an increasing expectation of full air-conditioning, what is the reaction of occupants and business owners to ventilative cooling?

The general design approach, predicted savings, actual energy use, and occupant reactions are all reviewed. Authors found that the design effort went beyond attention to daylighting, equipment loads, thermal mass, and effective ventilation methods. It was important for the design team to carefully verify and document owner expectations and communicate how the performance of the building may be different than mainstream expectations and professional standards. The studies found that businesses can live without mechanical cooling, but ventilative cooling requires occupants to operate the building in harmony with the diurnal cycle and to schedule work and building occupancy to avoid summer weather extremes.

Introduction

Ventilative cooling[1] is increasingly being evaluated as an energy efficiency strategy to achieve high-performance buildings. When the right combination of climate, building function, and occupant activity is present, ventilative cooling can maintain comfort conditions with reduced energy requirements. Comfort standards have begun to evolve in response to interest in buildings without mechanical cooling. Two approaches to defining comfort in naturally ventilated buildings seem to be dominant among emerging concepts—adaptive comfort standards and percentage thresholds for occupied hours above a particular interior design temperature. Each approach recognizes the inherent flexibility in satisfactorily defining occupant comfort in buildings with ventilative cooling.

Comfort is not the only design and operational consideration in determining the applicability of ventilative cooling to a particular project. Climate suitability is a particularly important initial consideration. The climate of the Pacific Northwest—especially that of the coastal regions, the Willamette Valley, and the Puget Sound—is well suited to ventilative cooling of non-residential buildings. In an average climate year in Portland or Eugene, Oregon, dry-bulb temperature exceeds 82^{o}F for only about 3% of the total annual hours (Brown 2004). In addition, diurnal temperature swings on peak cooling days exceed 30^{o}F resulting in typical low dry-bulb temperatures less than 60^{o}F. These climate conditions allow knowledgeable building

[1] The term "ventilative cooling" is used rather than "natural cooling" because some of the buildings studied have active ventilation elements such as exhaust fans or convective fans.

designers to engage more passive building cooling systems and concepts. The four buildings discussed here all considered use of ventilative cooling during both occupied and unoccupied periods, allowing natural cooling of spaces by occupants during mild climate conditions and ventilative cooling of thermal mass during cool early morning hours when the building was unoccupied.

As a practical consideration to a building owner or developer, the potential for construction cost savings due to simplification or elimination of mechanical cooling systems proved to be important considerations for two of the four projects. In all projects the potential operating cost savings, in the form of energy and maintenance cost reductions, were important decision criteria.

This paper focuses on the anecdotal response of Pacific Northwest building occupants and business owners rather than attempting to repeat the many other time-series studies of occupant thermal sensation relative to actual space temperature (Oseland 1998).

Building Descriptions

Four buildings[2] located in Eugene, Oregon, are evaluated here as case studies for buildings with ventilative cooling. The key building characteristics are shown in Table 1.

Table 1. Key Building Characteristics

	Lillis Business Complex; University of Oregon	**East Campus Childcare Center; University of Oregon**	**Food for Lane County Distribution Center**	**Co-Motion Cycles Production Facility**
Floor area, sq.ft.	137,400	11,900	33,000	15,000
Completed	2004	2004	1998	1999
Predominant function	Academic higher education	Pre-school	Food bank storage and distribution	Manufacturing
Secondary function	Office	Office	Office	Office
Mechanical cooling	Partial[1]	Partial Radiant[2]	None	None
Operable windows	Yes	Yes	Yes	Yes[5]
Automatic controls	Yes	Partial[3]	Partial[4]	No
Night ventilation of mass	Yes	No	Yes	No
Ventilative cooling system qualities	Hybrid; Exhaust fan assist	Convective Fans; Passive Wind	Passive Stack & Wind Ventilation	Exhaust fan assist.

[1]North-facing faculty offices have no mechanical cooling. Other spaces prioritize ventilative cooling.
[2]Spaces have partial cooling via radiant cooling slab floors coupled to ground-source, water-to-water heat pumps.
[3]Building has direct digital controls; however, ventilative cooling system components are occupant controlled.
[4]Warehouse system is equipped with automatic temperature controls. Office system is controlled by occupants.
[5]Operable windows in office only.

[2] Several authors had involvement with project design: Galen Ohmart was Design Architect for Food for Lane County and CoMotion; Mike Hatten was Energy Analyst/Design Assistance Provider for Food for Lane County, Child Care and Lillis, and also provided commissioning for Lillis; G.Z. Brown provided Daylighting analysis and design assistance for Food for Lane County and CoMotion, and provided Energy Sustainability Analysis and design assistance for Lillis and Childcare.

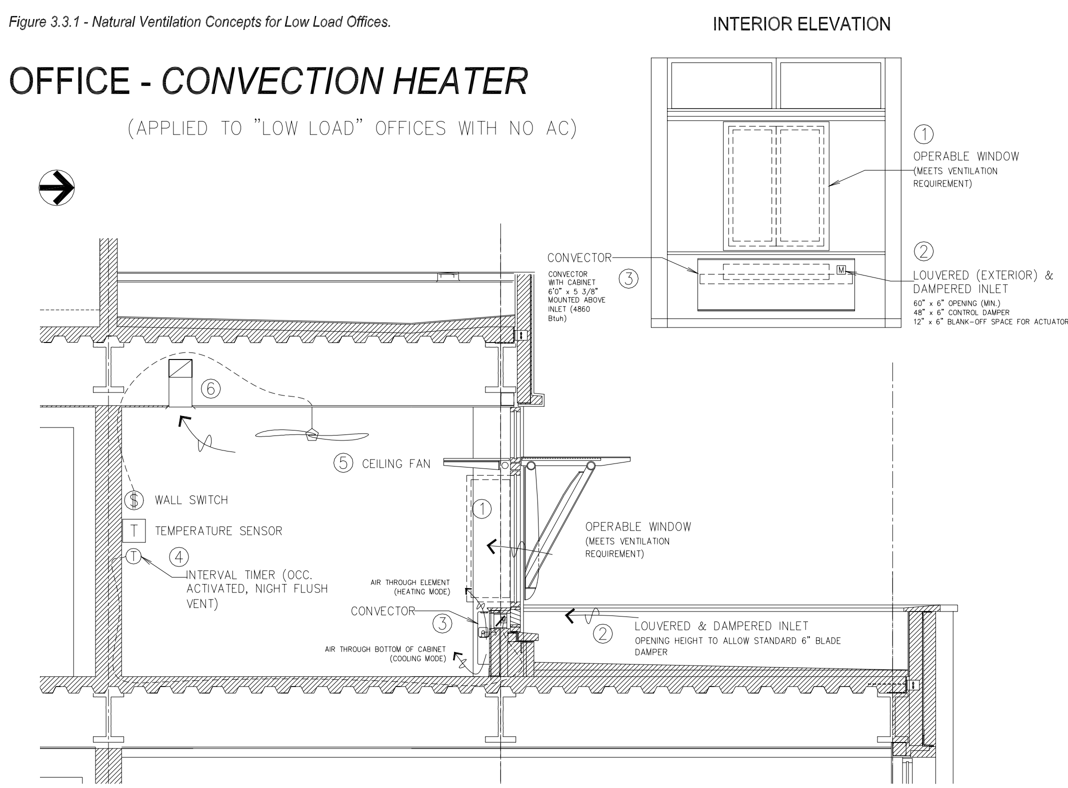
Lillis Business Complex

A mixed-mode ventilation system is designed at Lillis Business Complex, using a central four-story high atrium as a stack-effect driver for the system. Double-loaded corridors limit cross ventilation potential. Not all occupied spaces are designed with ventilative cooling systems. Ventilative cooling is included in exterior small classrooms, north-facing faculty offices, the lecture hall, and the auditorium. Spaces with ventilative cooling cover about 20% of total building area.

In the small classrooms dedicated louver/damper air inlets integral to the window systems introduce fresh air into a floor plenum where air tempering can occur, if needed, via radiant heating in the concrete plenum floor. Air is drawn through the room and exits through outlets located high in the interior walls. Exhaust air is ducted to variable speed transfer fans that discharge into the atrium. Ceiling fans increase air velocity in the rooms and operate automatically when rooms are functioning in ventilative cooling mode.

In the north faculty offices, dedicated and dampered air inlets are also integrated into the windows (Figure1). Air outlets are tied into exhaust ducts and transfer fans discharging air into the central atrium. Each office has an operable window and ceiling fan that can be adjusted by the occupant to supplement the ventilative cooling system.

Figure 1. Lillis "Passive" Office



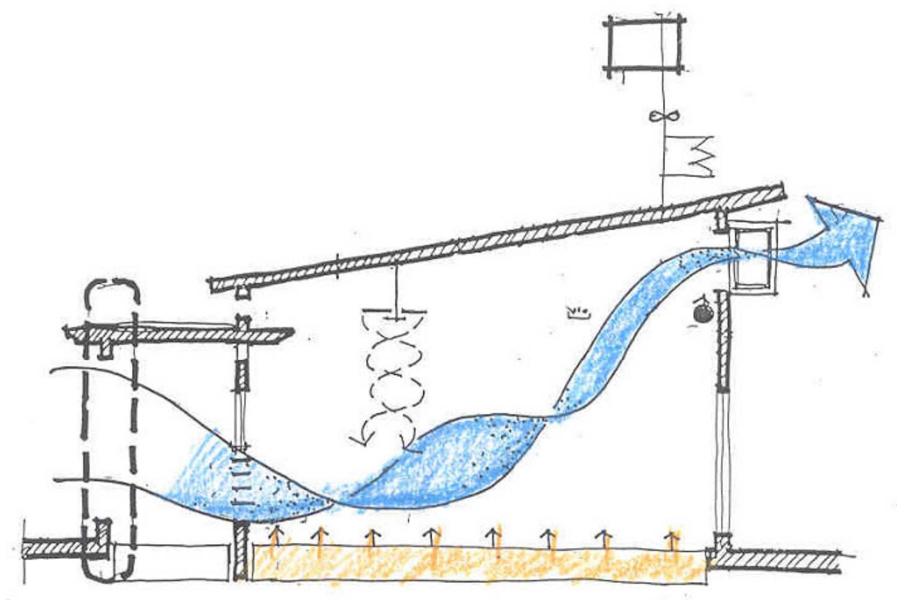
The atrium is equipped with gravity air vents as well as fan-assisted exhaust air vents. Gravity vents are used as the priority ventilation system. When passive ventilation via air buoyancy is not sufficient to meet the exhaust air needs of the building, exhaust fans are enabled and passive vent dampers closed. The ventilative cooling system in the building functions in two modes: space ventilation cooling and night ventilation of mass.

The auditorium and lecture hall are both equipped with stack-effect-driven ventilative cooling systems. Inlets are louvered and dampered openings in the north wall. Air is exhausted through exhaust shafts with louvered and dampered outlets at the top of the shafts.

East Campus Childcare Center

The passive ventilative cooling system in the University of Oregon's East Campus Childcare Center uses cross ventilation via wind pressurization (Figure 2). The classrooms and offices are arranged along a single-loaded corridor/enclosed breezeway. Operable windows in the exterior wall can be opened in combination with opening windows and doors into and out of the breezeway on the opposite side of the classroom. Wind-driven fresh air can then pass through the room. The ventilation system is manually controlled and can be augmented by ceiling fans installed in each classroom. A ground-coupled, water-to-water heat pump provides partial peak-shaving cooling capability in the occupied spaces via a radiant cooling floor.

Figure 2. Wind Powered Ventilation at East Campus Childcare Center



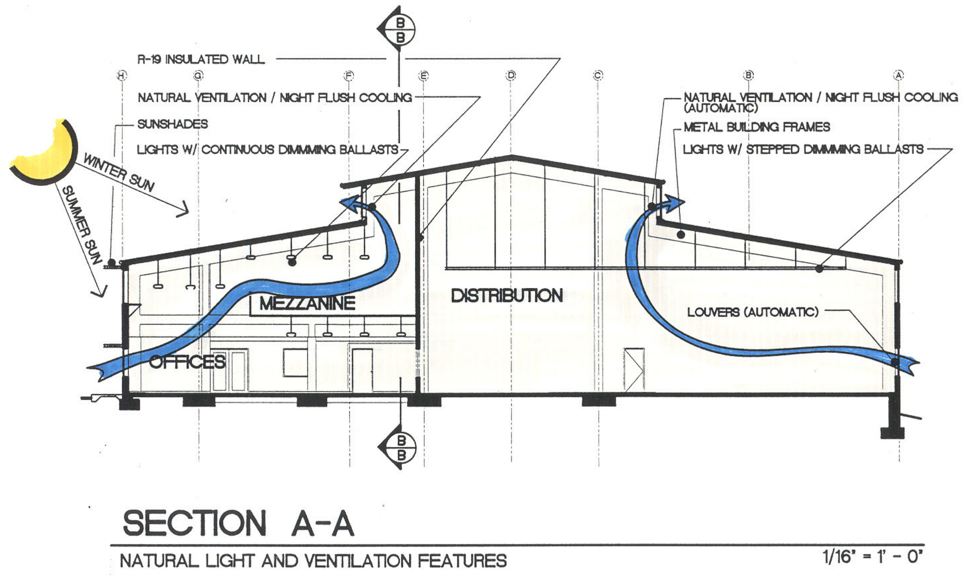
Food for Lane County Distribution Center

The passive ventilative cooling system at the Food for Lane County Distribution Center is a combination of cross ventilation and a stack- effect-driven system. Two systems are implemented—one serving the distribution center warehouse and one serving office spaces (Figure 3).

The distribution warehouse system uses dampered low inlets, located in the north wall, to introduce ventilation air. Air is exhausted through motorized clearstory windows. Automatic temperature-based controls implement occupied period ventilation of the space and unoccupied period night ventilation of mass. Integral thermal mass in the distribution warehouse is provided by the concrete floor and the tilt-up concrete north wall. There is no mechanical cooling in the warehouse, which has a maximum space temperature limitation of 75°F.

The south-facing office area system relies on manually operated windows to introduce and exhaust air. There is no mechanical cooling.

Figure 3. Separate Office and Warehouse Ventilation at Food for Lane County



Co-Motion Cycles Manufacturing Center

The system in the Co-Motion Cycles facility is a mixed-mode ventilation system with air inlets located low in the south wall in the form of dedicated intake louvers and the overhead door that is often open during occupied periods. Air outlets are exhaust fan-assisted, located high in the north wall, and are designed to provide night flush cooling by drawing cool air through the space at night. There is no mechanical cooling in the facility.

Reaction of Occupants and Owners to Ventilative Cooling

Of the four case studies evaluated within this paper, two facilities were occupied through several cooling seasons. Written occupant surveys were conducted with 21 respondents at Food for Lane County and 6 respondents at Co-Motion Cycles. The survey was used to evaluate long-term occupant perception of comfort in the buildings for the entire time they have occupied the new buildings.[3] It was based on a questionnaire previously conducted at PLC Hall at the University of Oregon (Brown 2001).

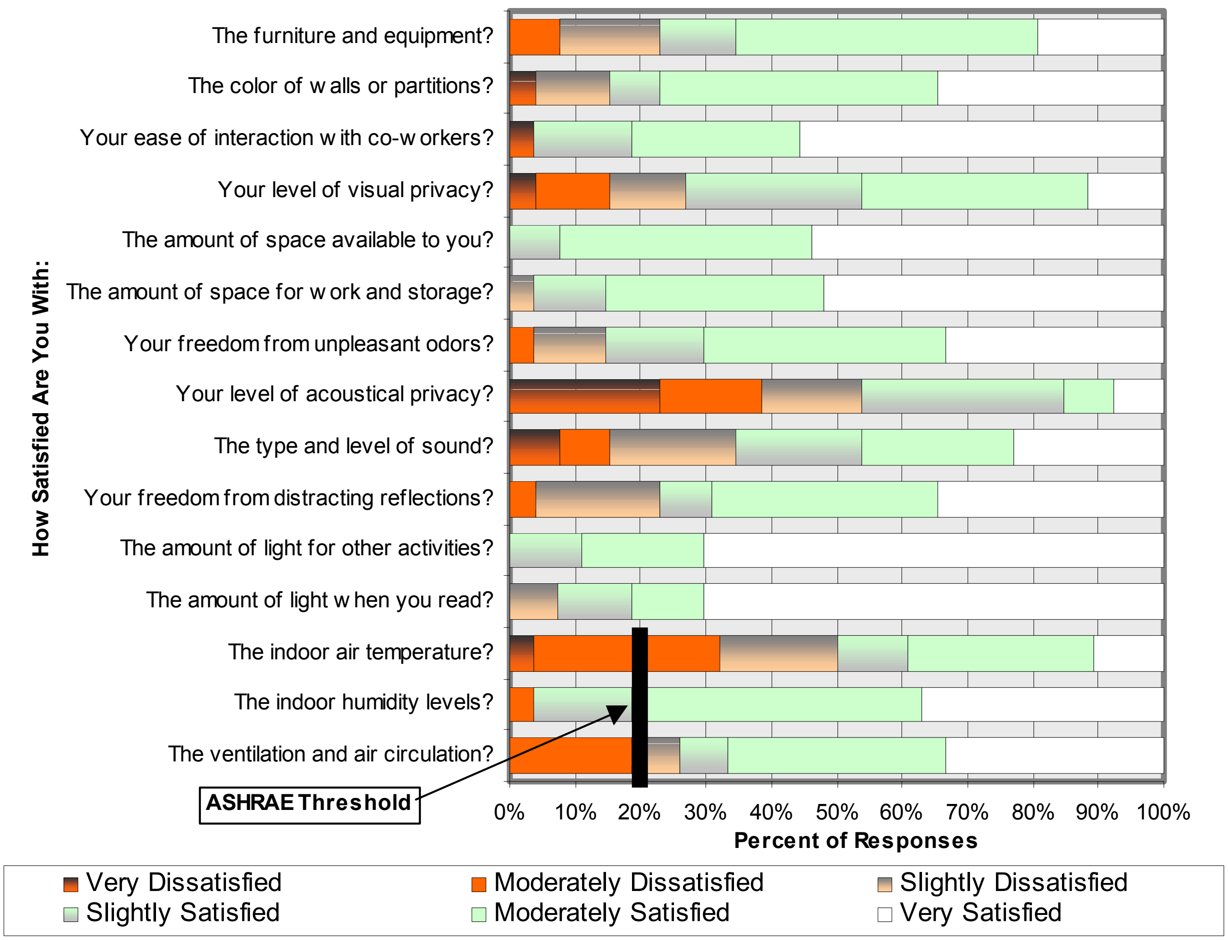
[3] The survey was not intended to get immediate occupant feedback to transient temperature or humidity conditions. There was no monitoring of space conditions.

Occupant Survey

Results of the comfort survey for occupants of Food for Lane County and Co-Motion Cycles are summarized in Figure 4. Results of surveys for each occupant group were evaluated and were similar enough in results that the results for both facilities were combined into a single results summary graph. The survey asked occupants to rate each of 15 space attributes from *highly satisfied* to *highly dissatisfied* on a six-point scale. The percentage of respondents selecting each option is indicated as a section of the bar.

In general, occupant satisfaction with the thermal comfort is somewhat below the recognized threshold of 80% satisfaction. Almost half of the respondents are dissatisfied with the space temperature conditions. Interestingly, only about 25% of respondents indicate dissatisfaction with air ventilation and circulation. Space humidity levels are satisfactory.[4]

Figure 4. Occupant Comfort Survey Results



In addition to humidity, respondents are very satisfied with lighting levels and quality. Both facilities are designed for natural lighting and are equipped with integrated systems that provide natural lighting and ventilative cooling. The buildings were designed to meet the

[4] Some of the occupants in both spaces with long tenure indicated that while thermal conditions were not necessarily satisfactory, they were better than the previous building that was of standard construction without air-conditioning. There was no survey question related to this issue.

integrated goals of the natural lighting and ventilative cooling. High levels of occupant satisfaction with the lighting conditions have some relevance in the perception of the overall performance of the ventilative cooling systems.

Thermal Adaptive Behavior

Occupants typically respond to changing thermal comfort conditions with adaptive behavior. Access to adaptive opportunities, such as operable windows, has been shown to be important in occupant ratings of thermal and perceived comfort (Nicol & Kessler 1998). Survey respondents ranked their adaptations to hot or cold space conditions according to actions taken on a scale of "always," "sometimes," or "never." The preferred actions—as defined by "always" or "sometimes" responses—are summarized in Table 2.

Table 2. Occupant Reported Thermal Adaptations

When Occupants Are Too Hot:		When Occupants Are Too Cold:	
Adaptation	Occupants Selecting	Adaptation	Occupants Selecting
Remove clothing	23	Add clothing	23
Eat/drink cold food	20	Eat/drink hot food	23
Use electric fan	17	Close window	11
Arrive earlier	13	Turn on overhead lights	9
Open window	10	Move to different space	9
Eat/drink hot food	10	Use space heater	8
Turn off overhead lights	9	Adjust thermostat	7
Move outside	8	Eat/drink cold food	7
Move to different space	7	Arrive earlier	6
Close window	6	Call manager	6
Adjust blinds	6	Turn off overhead lights	4
Call manager	6	Move outside	4
Turn on overhead lights	5	Adjust blinds	3
Adjust thermostat	4	Turn on task lights	3
Turn off task lights	3	Arrive later	3
Arrive later	3	Adjust radiator	1
Adjust radiator	2	Remove clothing	1
Turn on task lights	2	Nap	1
Add clothing	2	Open window	0
Nap	1	Use electric fan	0
Use air conditioning	0	Use AC	0
Use space heater	0	Turn off task lights	0

Review of Table 2 indicates a common set of preferred adaptation responses on the part of occupants to comfort conditions that are either too hot or too cold. It is interesting to note that the preferred responses in both conditions involved adjustment to clothing and/or consumption of cold (or hot) food or drink.

Reaction of Business Owners

In the Food for Lane County and Co-Motion buildings the owners desired a building with low initial costs and low operation costs. The ventilative cooling system allowed for the owners to install furnaces in lieu of a full air-conditioning system, dramatically reducing first cost of construction. Because mechanical cooling was not installed, energy and maintenance costs for cooling are zero. At the outset this was very attractive to the owners. The fact that owners of Food for Lane County and Co-Motion Cycles accepted a building without cooling is very unique. In both cases, the owners came from previous buildings that had no cooling and inadequate ventilation. The previous building in each case became, in effect, the baseline for consideration of a building type that relied on ventilative cooling to provide fresh air and cooling for the building. In general the owners are satisfied with their buildings. This satisfaction comes from the daylight the windows provide, the connection to the outdoors, and the personal control over their ventilation needs. In addition to general satisfaction, the owner of Co-Motion stated that his building's daylighting characteristics make it unique in an otherwise industrial area. The unique quality has positively influenced customers of his high-end cycling product.

In the fall of 2002, after a hot summer, owners of Food for Lane County had concerns when high summer daytime temperatures cause the office area occupants to experience summer afternoon space temperatures that often exceeded comfort thresholds. They seriously considered retrofitting the building with an air-conditioning system. After once again considering the first cost and the operation cost of mechanical cooling, they opted to install motorized operators on the office windows and changed the summer workday schedule to 7:00 A.M. to 3:30 P.M. rather than 9:00 A.M. to 5:30 P.M.. The motorized operators allowed occupants to open exhaust windows more easily, thus improving ventilative cooling in the office area. The schedule change avoided times when heat built up in the building and let staff enjoy summer afternoons.

The green elements of the Lillis Business Complex helped recruit a new Business School Dean. The complex already has helped the UO attract new staff in the highly competitive field of faculty recruiting and it won't hurt when it comes to attracting top-quality students (Baker 2004).

Energy Performance

Energy performance of Food for Lane County for Lane County and Co-Motion Cycles reflects the design decision to incorporate ventilative cooling systems. Table 4 shows the past 12 months energy use for those two facilities. Energy performance for the Lillis Business Complex and the East Campus Childcare Center is predicted by energy modeling performed during the design phase.

Table 4. Energy Use Comparison

Building	Overall Energy Use Index, Btu/square foot/year	Projected Ventilative Cooling Annual Savings			Estimated First Cost Savings[2]
		Btu/sq ft	Btu %	Energy $	
Food for Lane County[1]	83,230	6,453	7.7%	$3,744	$103,000
Co-Motion Cycles	59,041	4,778	8.1%	$1,260	$13,500
Lillis Business Complex[3]	52,661	12,406	23.5%	$21,421	($184,000)
East Campus Childcare Center[3]	49,928	3,659	7.3%	$702	($5,000)

[1]Food for Lane County baseline use includes food storage refrigeration energy use.
[2]First cost savings or increase due to ventilative cooling features. Negative savings represents cost increase.
[3]Based on design-phase energy analysis and modeling.

Ventilative cooling reduced operating costs at both Food for Lane County and Co-Motion Cycles. The operating cost savings for both facilities are modest compared to the first cost savings from eliminating mechanical cooling from the building design.

Ventilative cooling systems conceived and implemented at the Lillis Business Complex and the East Campus Childcare Center were mixed-mode systems. First costs increased in both projects as a result of the integration of ventilative cooling systems into the overall ventilation system for the facilities. In the case of the Lillis Business Complex, the system included an extensive quantity of dedicated louvered and dampered inlets that were integral to the window systems. These proved expensive and resulted in a significant cost increase. In the case of the East Campus Childcare Center, the additional cost was from addition of ceiling fans in classrooms. In both projects, expected payback period is less than 10 years. Electric utility incentives further reduced payback by about 25%.

While passive ventilative cooling will reduce cooling loads and associated energy use, field case studies have shown that overall energy use can be lower in a building that uses active mass storage due to better control of heating loads (Braham 2001). The Lillis Business Complex and the East Campus Childcare Center incorporate some mass storage in the form of the concrete floor slab and intermediate floor slabs. Food for Lane County includes floor mass as well as a massive concrete north-facing wall to provide passive thermal storage for the warehouse side of the facility.

Design Considerations

Natural cooling calls for a higher degree of interaction between the architect and environmental engineer (Jones 2001). In many cases implementation of ventilative cooling into the design also requires use of new design tools such as thermal and airflow modeling tools. These tools proved helpful for the Lillis Business Complex project that employed a mixed-mode system. When a mixed-mode building is designed, integration of the passive elements with the traditional mechanical elements requires an iterative design approach and increased communication between mechanical engineer, structural engineer, and architect (Arnold 2000).

Comfort Standard Application

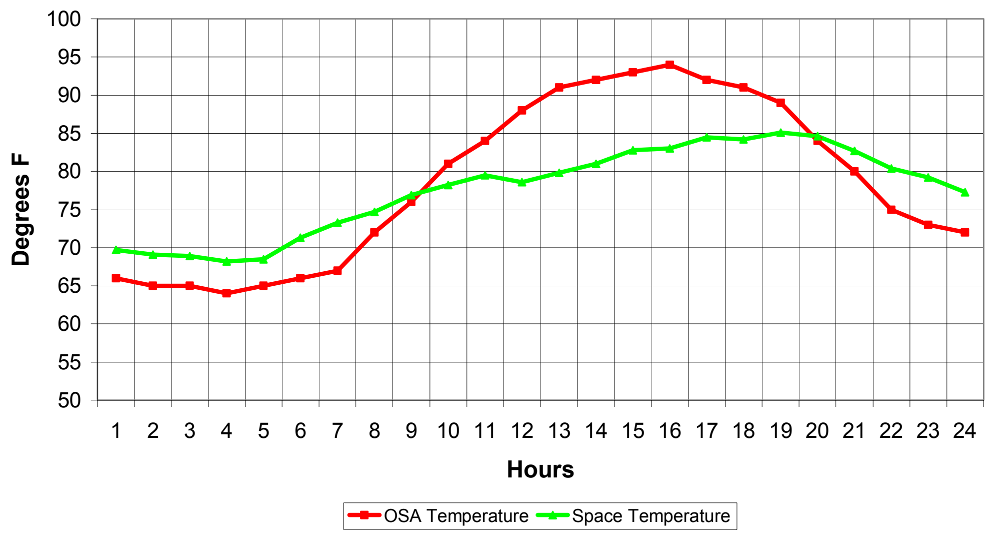
There are currently several proposed European and United States standards for comfort in buildings without mechanical cooling. While full comments on these standards is beyond the scope of this paper, it is interesting to note that for the Lillis building, where the most in-depth analysis was undertaken, naturally ventilated portions of the building do not meet the proposed ASHRAE adaptive comfort standard (Brager & de Dear 2000).

Lillis Business complex. The user group specifically requested the design team to identify the thermal performance associated with the proposed ventilative cooling system. Figure 5 shows the thermal performance predictions for the offices and case study rooms developed with a combination of hourly thermal modeling and airflow modeling.

In addition to documenting maximum space temperatures, a percentage threshold analysis of potential ventilative cooling systems was conducted during the design phase. When ventilative cooling was applied to parts of the Lillis Building, analysis determined that there were several hours a year when comfort conditions of ASHRAE Standard 55-1992 would not be met. The analysis gave stakeholders a clear picture of how often and when the extreme conditions would occur. With this information, a conscious decision was made to forgo mechanical cooling in parts of the building, even though several hours would exist outside the comfort range. One example is the north classrooms, where temperatures would be above 83°F for 46 hours a year. The analysis predicted that all these hours occurred after 3:00 P.M. and most occurred after 5:00 P.M. That information allowed decision makers to accept these conditions, even if they did not meet adaptive comfort standards.

To meet diverse user demands, half of the faculty offices were designed with mechanical cooling and no operable windows. The other half was located on the north side with ventilative cooling, operable windows, and no air conditioning. This unique approach worked out with faculty members selecting an office that met their needs.

Figure 5. Lillis Thermal Performance Predictions



In some cases mechanical engineers have vetoed ventilative cooling because they cannot assure the building will meet professional cooling standards and are concerned about their reputation and errors and omission liability. The Lillis mechanical engineer, Mark Penrod, indicated that several meetings were held with business school stakeholders and University planning staff to carefully explain what the design criteria meant (Penrod 2004). While only a few hours were expected with indoor temperatures in the 80s, Mr. Penrod had a stronger concern about having frequent interior morning temperature of 65°F during the cooling season. The low temperature would be a daily occurrence in many spaces for the night flush to work and impacts a larger number of hours than the afternoon high temperature. These meetings were documented for the benefit of the other design team members and the stakeholders. Since the comfort range would be outside professional association standards, the mechanical engineering firm requested and received a memorandum from the University documenting the design conditions.

East Campus Childcare Center. Consideration of passive ventilative cooling strategies for this project began at the very beginning of the schematic design phase. As a consequence, the building massing and space adjacencies were adjusted in response to anticipated seasonal use patterns and summertime comfort requirements. Information received from the user group indicated that summertime occupancy and use was about half that experienced during the rest of the school year. This led to the suggestion of a "passive" wing that could be relatively unoccupied during the summer session and would thus require little if any mechanical cooling from the mixed-mode cooling system. With design team and owner cooperation, space adjacencies were modified to accommodate this concept into the design.

Early involvement in a project has been identified as critical to cost-effective implementation of energy efficiency features such as ventilative cooling where the ultimate success of the concepts rely upon seamless integration into the overall building fabric. The revised space adjacencies of the East Campus Childcare Center illustrate this point. Early design phase consideration of occupancy patterns throughout the annual cycle of seasons led to the development of a seasonal sequence of operations where passive ventilative cooling was accepted as the primary comfort system during mild spring and autumn climate conditions. This early discussion engaged not only the design team but also the university users' group who was able to accept ownership of the system concepts from the outset.

Lessons Learned

After discussions with the owners who have lived with their buildings, the architects and engineers realize that for these specific projects, greater attention could have been given to providing a night flush cooling system and optimizing thermal mass. A night flush cooling system allows for nighttime ventilation to cool internal thermal mass and maintain adequate comfort during the following day.

Conclusions

Ventilative cooling is an emerging practice that is applicable to relatively cool climates like the Pacific Northwest. While occupant surveys do not find full thermal satisfaction with ventilative cooled spaces, they are more comfortable and inviting than standard construction without air-conditioning. Living in a building without mechanical cooling requires flexible scheduling in summer months, and may be appropriate for non-profit, educational, and green-oriented businesses that feel the schedule adjustments are a good trade-off for a greener building.

While natural cooling was the only option a century ago, higher building mass and lower internal gains along with relaxed expectations made it workable. In today's real estate market, ventilative cooling requires good documentation and a clear understanding between the design team and stakeholders. Buildings designed for occupants with higher expectations may require partial mechanical cooling, evaporative cooling, or more sophisticated active ventilation and mass storage systems.

Application of currently proposed comfort standards remains unclear, and it does not appear that simple passive ventilative cooling systems will meet currently proposed adaptive standards. Even if a clear standard is adopted, application of ventilative cooling in the commercial sector will require care. In a sector where occupant expectations have been shaped by air conditioning, eliminating mechanical cooling will require communication to determine stakeholder needs and areas of flexibility. Analysis will be needed to predict the thermal performance of a specific design and verify that it will work for the stakeholders. Overall, ventilative cooling is a workable strategy, but it requires some flexibility on the part of the building occupant and care on the part of the design team.

References

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). 1992. *ASHRAE Standard 55-1992: Thermal Environmental Conditions for Human Occupancy*. Atlanta, Ga.: ASHRAE.

Arnold, David. 2000. "Thermal Storage Case Study: Combined Building Mass and Cooling Pond." *ASHRAE Transactions.* 106 (Part 1): 819-827. Atlanta, Ga.: ASHRAE.

Baker, Mark. 2004. "University of Michigan professor to lead UO College of Business." *The Register-Guard*. March 2, 2004. Eugene, Oreg.

Brager, Gail S. and Richard de Dear. 2000. "A Standard for Natural Ventilation." *AHSRAE Journal*. 42 (10): 21-28.

Braham, George D. 2000. "Comparative Performance of U.K. Fabric Energy Storage Systems." *ASHRAE Transactions.* 106 (Part 1): 811-818. Atlanta, Ga.: ASHRAE.

Brown, G. Z., Laura W. Jensen, Jeff Kline, Dale Northcutt, and Nicholas Rajkovich. 2001. "Comfort Study Phase II, Prince Lucien Campbell Hall." Energy Studies in Buildings Laboratory, University of Oregon. Eugene Oreg.

Brown, G. Z., Jeff Kline, Gina Livingston, Dale Northcutt, and Emily Wright. 2004. "Natural Ventilation in Northwest Buildings." *Northwest Energy Efficiency Alliance Betterbricks White Paper.* Portland, Oreg.

Jones, Jim and Aaron W. West. 2001. "Natural Ventilation and Collaborative Design." *ASHRAE Journal.* 43 (11): 46-50.

Nicol, J. Fergus and Maria R.B. Kessler. 1998. "Perception of Comfort in Relation to Weather and Indoor Adaptive Opportunities." *ASHRAE Transactions.* 104 (Part 1B): 1005-1017. Atlanta, Ga.: ASHRAE.

Oseland, Nigel A. 1998. "Acceptable Temperature Ranges in Naturally Ventilated and Air-Conditioned Offices." *ASHRAE Transactions*. 104 (Part 1B): 1018-1030. Atlanta, Ga.: ASHRAE.

Penrod, Mark (Balzhiser & Hubbard Engineers). 2004. Telephone Interview with Reid Hart on the Lillis Business Complex. February 23, 2004.