Eugene Water & Electric Board

Energy Management Services
500 East 4th Avenue / Post Office Box 10148
Eugene, Oregon 97440-2148
541-484-1125 Fax 541-334-4614

July 13, 2007

Ms. Terry Regan
Bonneville Power Administration KLK-1
P.O. Box 3621
Portland, OR 97208

Dear Terry,

In the engineering review comments for the new construction Slocum Health Center project, BPA staff questioned including productivity benefits in the TRC cost analysis:

> We are not aware of any study regarding productivity and building controls (measure 2) or insulation (measure 3). There have been studies regarding lighting and productivity (not readily available to us) but we are not aware of any policy that includes commercial building staff productivity with O&M. If there isn't any policy specifically including this, then our suggestion is to develop a policy that excludes it.

The issue of productivity savings is important to new construction in the region. As building codes have incorporated most cost-effective stand-alone measures, an integrated design approach is the only way to develop significant additional savings in the new-construction sector. Integrated design has been promoted nationally and regionally by NEEA, NBI, USGBC, ESBL, and AIA. At this point, the BIDS project at Carnegie-Mellon School of Architecture has identified 130 case studies or evaluations showing significant productivity or other cost savings with a relevant subset in the noted areas:

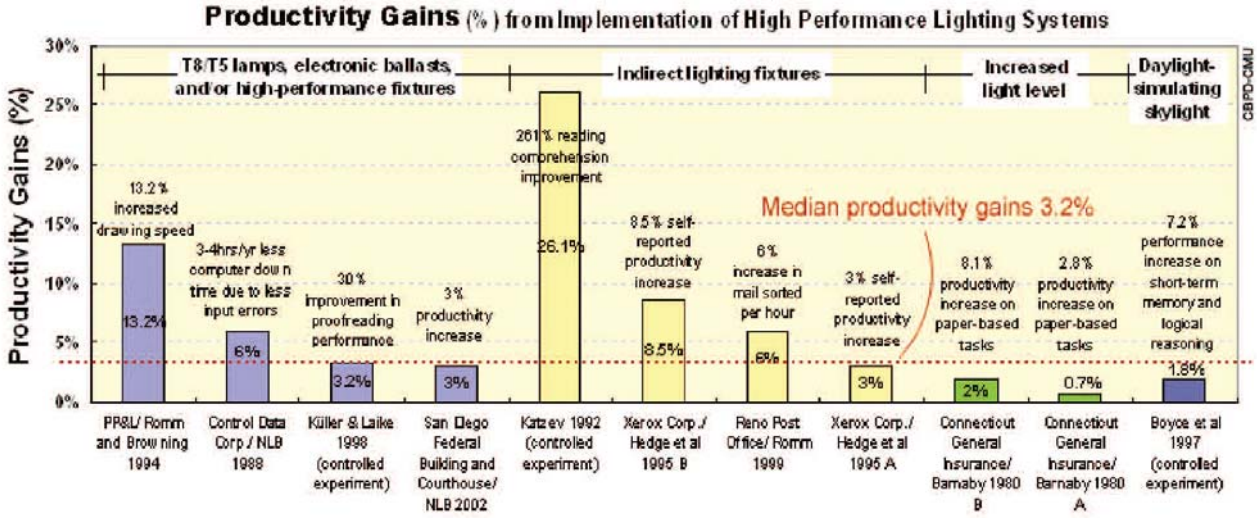
- 52 ventilation studies
- 24 temperature control studies
- 39 lighting control studies
- 79 whole building studies

BPA staff may access these studies by contacting John Jennings at NEEA. BetterBricks has highlighted some of these studies in a Seattle City Light link. The range of reported staff cost savings is from 3% to 16%. There are additional risk reduction benefits reported for these strategies too.

While it is difficult at this time to project specific productivity savings for a particular building and set of measures, the building owners' willingness to pay significant added design and incremental measure costs for an integrated design with improved comfort and lighting indicates that building investors do see a benefit; hence, consideration of significant "other benefits" is legitimate to arrive at a true TRC.

While comprehensive studies indicating benefits in the range of 3% to 16% of staff costs exist, an industry standard method of projecting savings to a particular building and set of measures is not fully developed. EWEB's approach for this project has been to state a **very conservative** productivity savings of 1% of permanent staff costs. No claim is made for patient risk reduction or revenue enhancement. This obviously simplified analysis is intended to represent a minimum benefit that should be reliably achieved, since it is well below the range of actual results shown in the literature. More detailed analysis increases productivity savings to 1.68% and maintains conservative reductions from published results.

An important productivity element is the median productivity gain from 11 actual lighting case or research studies shown in the graph below.



source: www.aia.org/SiteObjects/files/BIDS_color.pdf

As a broader regional issue, the proposal to exclude productivity savings from TRC analysis would derail a longstanding effort to promote integrated design in the Pacific Northwest. It is very important that productivity benefits be considered. Given the subjective nature of these savings, we would not object to a 1% limit on assumed productivity improvement when the analysis is simplified, as in our original approach. This would apply when a good share of space quality improvement measures have been included. For there to be a robust new construction participation of larger buildings and meet regional DSM acquisition targets, productivity gains must be considered an allowable savings component in the TRC.

We are happy to participate in further regional dialogue on this issue.

Respectfully Submitted,
Eugene Water & Electric Board

Reid Hart, PE
Engineering Supervisor, Energy Management

Encl: Selected Comfort Case Studies from BIDS
cc (via email):

Todd Amundson, BPA (KLJD-1)
Tim Steele, BPA (KLJD-1)
Mira Vowles, BPA (KLI-1)
Tim Scanlon, BPA (KLJC-SEATTLE)
Margaret Lewis, BPA (KLJB-1)
Jack Callahan, BPA (KLJD-1)
John Jennings, NEEA
Mark Frankel, NBI
Dave Hewitt, NBI
Charlie Grist, NWPPC
G. Z. Brown, ESBL
Mike Hatten, SOLARC
Greg Stiles, ETO
Javad Maadanian, SCL
Steve Ottenbreit, Snohomish PUD
Jason McLennan, USGBC
Rod Olsen, EWEB
Bob Lorenzen, EWEB

Calculator Last Revised 2/07/06	Today's Date =>	07/13/2007
Line No.	***INPUTS***	
1	**Select Sector =>**	Commercial
2	**Select measure or load profile description that best matches the proposed project or measure**	New Construction and Major Renovations
3	**Select Industrial Reimbursement Option 1 or 2**	◉ Industrial Option 1 ○ Industrial Option 2
4	**Potential Reimbursement ($/kWh)**	**$ 0.20**
5	**Suggested Measure Life**	**15 years**
6	**Enter Measure Life**	**22 years**
7	**Enter Annual Site Energy Savings (kWh/yr)**	**537,392**
8	**Enter Annual Site Energy Use Post-Efficiency Project Implementation (kWh/yr)**	**987,943**
9	**Enter Project Cost**	**$ 778,260**
10	**Enter Change in Project/Measure O&M Cost (Savings -$ or Increases +$)**	**$ (127,014)**
11	**Enter Customer Retail Rate (cents/kWh)**	**4.02 cents**
	RESULTS	
12	**Annual Energy Savings @ Busbar**	**578,368 kWh**
13	**Annual Energy Cost Savings**	**$ 21,603**
14	**Simple Payback**	**36.0 years**
15	**Present Value of Change in Operation and Maintenance Cost**	**$ (1,835,500)**
16	**Project Life Cycle Cost**	**$ (361,472)**
17	**Present Value of Energy Savings**	**$ 407,322**
18	**Project Benefit/Cost Ratio**	**2.88**
19	**BPA Project Reimbursement**	**$ 115,674**
20	**Display Credit/Reimbursement for Measure if Benefit/Cost Ratio < 1.0 when Project Benefit/Cost Ratio is 1.0 or greater** ☑	**$ -**

Operation and Maintenance Benefit Annual Impact

Natural Gas Reduction

4369	Therms Saved
$1.37653	Gas Rate, Northwest Nat
$6,014	Annual Gas Savings

Productivity

45000	Average Salary
160	# staff
1.68%	Productivity Improvement
8.1	min per staff day
$121,000	
$127,014	Annual O&M Savings

Measure Life by ECM Component

	kWh Saved	Life,years	
Shade/Envelope	60218	30	11.2%
Lighting/Load	186087	20	34.6%
HVAC Hardware	237240	23	44.1%
Controls/commisioning	53848	15	10.0%
	537393	21.9439	
Composite measure life in years		**22**	

Note, this is single tenant new building with initial 15-year lease
Not speculation commercial or renovation

Number Service / Hannula et al 2000 - Improving Temperature Control

	Basis: 25% of 2.8% measured productivity impact		
2.80%	Study productivity improvement	25%	0.7%

BIDS Summary of 11 lighting studies: www.aia.org/SiteObjects/files/BIDS_color.pdf

3.20% Median productivity improvement for 11 lighting studies

Area served by Daylight Dimming

Daylight Dimming in	12262	sf
sf/workstation	150	sf/workstation
Staff affected	81.7	people
Percent staff affected	51.1%	

ECM's provide the following elements that improve productivity due to better lighting, comfort, and ventilation

	Productivity Improvement	Affected Staff	Productivity Factor
South and west shading reduces window glare			
Carefully designed lighting in workspaces reduces contrast issues			
-Moderate improvement in lighting Quality 25% of 3.2%	0.80%	48.9%	0.39%
Daylight dimming control in 2nd floor offices affect 81 staff	3.20%	51.1%	1.63%
Improved LEED ventilation (30% > ASHRAE + DCV)	0.63%	100%	0.63%
Improved comfort with improved envelope and			
advanced VAV with hydronic vs dX/Elec RH	0.70%	100%	0.70%
Total Productivity Improvements			**3.36%**
Further reduction for overlapping productivity improvement effects	*50.00%*		**1.68%**

Ventilation Improvement Productivity Analysis

0.4719474 Note - Drinka & Polaroid savings is only directly reduced absence

l/s/p	cfm/person	productivity improvement				
2.4	5.1	0.00%	Base		save	base
10	21.2	0.51%		Drinka et al 1996	$230	$45,000
	20	0.61%		Polaroid / Milton et al 2000	1.2-1.9	256 days
15	31.8	3.70%		Bourbeau et al 1997 / Wargocki et al 2000		
	50	6.00%		Wargaki: Call center productivity		

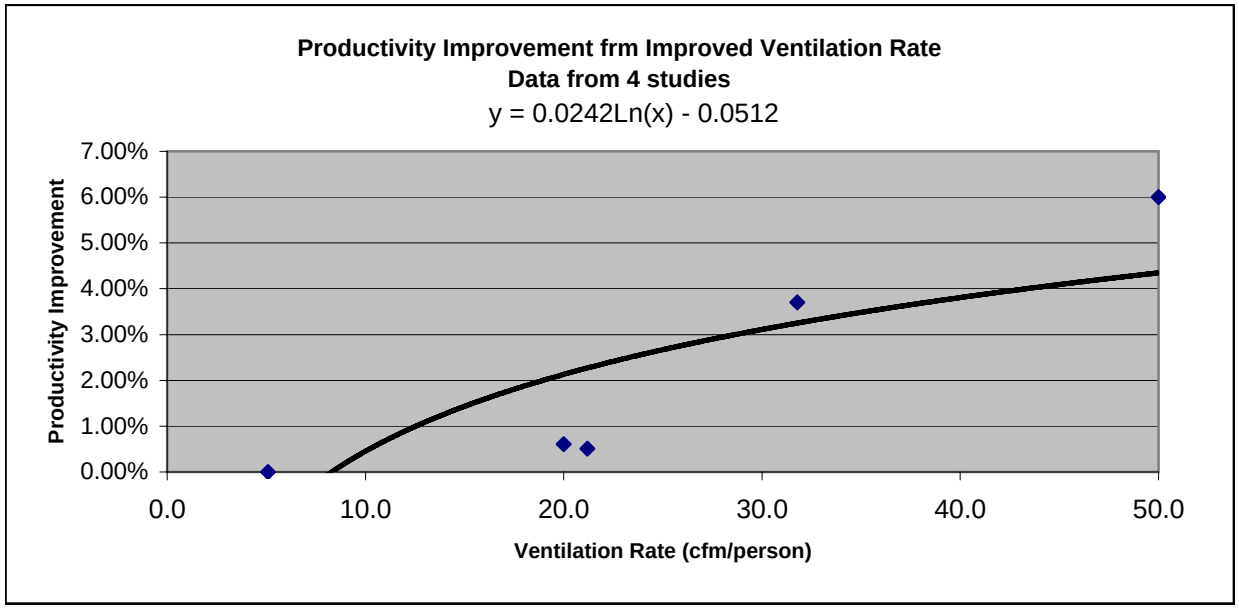
Studies provide logarithmic curve fit

Curve fit parameters a 0.0242 b 0.0513

Subject Building 30% LEED ventilation improvement

20	2.12%	Code Baseline
26	2.75%	LEED ventilation + 30%
	0.63%	Logarithmic difference

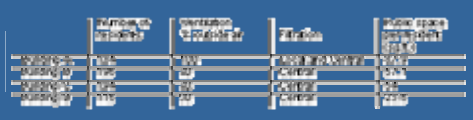
Logarithmic trend fit to find productivity improvement from 20 to 26 cfm/person
(using this method, the slope of the curve is more important than absolute position)



Increased outside air + Filtration = Individual Productivity

Drinka et al 1996

In a 1996 multiple building study at a nursing home facility in Wisconsin, Drinka et al identify an 87.3% reduction in the incidence of influenza in a building with 100% outside air ventilation and local filtration for each room, as compared to three facilities with 30% - 70% recirculated air and central filtration only.



First cost increase:	$26,175	
Annual savings:	IndividualProductivity:	$832,218
	OMEnergy:	$-25,527
ROI:	**405 %**	

more information

Reference:
Drinka, P, P. Krause, M. Schilling, B. Miller, P. Shult, S. Gravenstein (1996) Report of an Outbreak: Nursing Home Architecture and Influenza-A Attack Rates. Journal of the American Geriatrics Society, v. 44, pp. 910-913.

National Center for Health Statistics (1999) Current estimates from the National Health Interview Survey,1996. (DHS 99-1528) Hyattsville, MD: U.S. Department of Health and Human Services, pp. 54.

Indoor Environments Division, U.S. Environmental Protection Agency (2000) Energy Cost and IAQ Performance of Ventilation Systems and Controls. EPA-402-S-01-001 http://www.epa.gov/iaq/largebldgs/eiaq_page.htm

Eto, J. and Meyer, C. (1988) The HVAC Costs of Increased Fresh Air Ventilation Rates in Office Buildings. ASHRAE Transactions, 94(2), pp. 53-58.

R.S. Means Facilities Construction Cost Data, 19th Annual Edition. (2004) Kingston, MA: R.S. Means Company, Inc. Construction Publishers & Consultants.

Drinka et al 1996 - *Increased outside air*

Detailed Information:

• Overview

In a 1996 multiple building study at a nursing home campus in Wisconsin, Drinka et al investigated the relationship of nursing home architecture and attack rates during an influenza epidemic. The study took place at the Wisconsin Veterans Home, a skilled nursing facility for wartime veterans and their spouses, during the 1993-1994 flu season. The Veteran's Home campus consists of four residential buildings (A – D) and a separate activity building. All buildings have patients living on four floors, except building D, with two floors. All four buildings include both single- and double-occupancy rooms, with an equal proportion of single rooms (76-77%). The ventilation system in Building A provides 100% outside air, and the supply duct for each room has an 8 micron filter, as well as central filtration. Buildings B - D have ventilation systems that supply less than 100% outside air, and only central filtration. In addition, Building A has more public space per resident than the other buildings. During the 1993-1994 flu season, the vaccination rate of Building A residents was 89%, and was equal to the combined rate in Buildings B – D.

Table 1, Characteristics of Buildings A – D

	Number of residents	Ventilation % outside air	Filtration	Public space per resident (sq.ft.)
Building A	154	100	Local and Central	87.9
Building B	108	70	Central	67.1
Building C	104	70	Central	64
Building D	110	30	Central	23.9

• Study Methods and Results

The Veterans Home maintains a prospective influenza surveillance program as part of an NIH-sponsored study to optimize the use of antiviral agents in nursing homes. Participation in the NIH study is voluntary for all residents. Surveillance consists of twice-weekly visits by a skilled nurse to determine new respiratory symptoms among participants and to review daily reports prepared by the nursing staff of the Veterans Home documenting respiratory symptoms for all residents (study participants and non-participants). When respiratory complaints are documented, nasopharyngeal and throat swabs are taken and cultured for various respiratory illnesses at the Wisconsin State Laboratory for Hygiene within 24 hours. Only individuals from whom influenza was cultured were considered "positive" for this study; these residents were voluntarily quarantined for the duration of their illness.

A total of 65 positive influenza cultures were taken in Buildings B – D, while only 3 positive cultures were taken in Building A. This represents an 87.3% reduction in influenza attack rate for Building A.

• BIDS life cycle assumptions

Eto and Meyer (1988) conservatively estimate a first cost of $0.32/sf to increase the outside air ventilation rate from 2.5 to 10 L/s/person, and RS Means (2004) identifies a first cost of $0.05/cfm for a medium efficiency (8 micron) filter ($1.25 per employee for a ventilation rate of 25 cfm/person). In a 1999 simulation study, the U.S. EPA identifies an average 4.6% increase in HVAC energy consumption due to increasing the outside air ventilation rate from 2.5 to 10 L/s/person. Keech (1998) reports the average indirect cost of influenza to be 1.55 days per employee per year, including both absence from work and reduced effectiveness at work .

Offices

The 2005 BIDS baseline assumes a 100,000 sf building, 500 employees with an average salary of $45,000 and 256 workdays per year, and 11.4 kWh/sf HVAC energy consumption at a cost of $0.08/kWh annually. In a baseline organization, the value of an 87.3% reduction in the incidence of influenza (minus additional energy costs) is $230 per employee, resulting in an ROI of 120%.

Hospitals

The 2005 BIDS baseline assumes a 100,000 sf building with 500 beds, 20.9 kWh/sf annual HVAC energy consumption, and an energy cost of $0.08/kWh.

References:

Drinka, P, P. Krause, M. Schilling, B. Miller, P. Shult, S. Gravenstein (1996) Report of an Outbreak: Nursing Home Architecture and Influenza-A Attack Rates. Journal of the American Geriatrics Society, v. 44, pp. 910-913.

National Center for Health Statistics (1999) Current estimates from the National Health Interview Survey,1996. (DHS 99-1528) Hyattsville, MD: U.S. Department of Health and Human Services, pp. 54.

Indoor Environments Division, U.S. Environmental Protection Agency (2000) Energy Cost and IAQ Performance of Ventilation Systems and Controls. EPA-402-S-01-001 http://www.epa.gov/iaq/largebldgs/eiaq_page.htm

Eto, J. and Meyer, C. (1988) The HVAC Costs of Increased Fresh Air Ventilation Rates in Office Buildings. ASHRAE Transactions, 94(2), pp. 53-58.

R.S. Means Facilities Construction Cost Data, 19th Annual Edition. (2004) Kingston, MA: R.S. Means Company, Inc. Construction Publishers & Consultants.

Increased Ventilation Rate = Individual Productivity

Polaroid / Milton et al 2000

In a 2000 multiple building study of Polaroid Corporation workers in 40 buildings, Milton et al identify a 35% reduction in short-term sick leave for employees in work areas with a 50 cfm/person outdoor air supply rate, as compared to employees in work areas with a 25 cfm/person outdoor air supply rate, resulting in 1.2 to 1.9 days of decreased sick leave per person per year.

First cost increase:	$25,600
Annual savings:	IndividualProductivity: $936,803 Annual cost: $-281,653
ROI:	**336 %**

more information

Reference:
Milton, D.K., Glencross, P.M., and Walters, M.D. (2000) Risk of sick leave associated with outdoor air supply rate, humidification and occupant complaints. In Proceedings of Indoor Air 2000, Vol. 10, pp.212-221.

Polaroid / Milton et al 2000 - *Increase Outdoor Air Supply*

Detailed Information:

• Overview
In a 2000 multiple building study of 40 Polaroid Corporation buildings, Milton et al analyze sick leave reported on 1994 timecards for 3720 employees with 115 independently ventilated work areas, to investigate the relationship between sick leave and ventilation rate. All employees were hourly, and were classified as manufacturing, trades and technical, or clerical office workers. Ventilation of each work area was rated with a moderate (25 cfm or 12 L/s per person) or high (50 cfm or 24 L/s per person) outdoor air supply rate, based on knowledge of the ventilation systems and CO2 measurements. Results of Poisson regression indicated a consistent association between lower air supply levels and increased sick leave. 35% of short-term sick leave was attributed to low ventilation rates among exposed workers, amounting to 1.2 to 1.9 days per person per year.

• BIDS life cycle assumptions
The 2005 BIDS baseline assumes a 100,000sf building, 500 employees with an average salary of $45,000 and 1.7% average absenteeism. Eto and Meyer (1988) give a high estimate of $0.32/sf for the first cost premium to increase the rate of outdoor airflow from 5 to 20 cfm per person, which may be comparable to an increase from 25 to 50 cfm per person). Based upon the average cost in the study buildings, the authors estimate the annual cost of increasing the outdoor air supply by 25 cfm per person to be $3.22/cfm per person. In a baseline organization, a 35% reduction in sick leave minus additional operating costs yields net annual savings of $187 per employee, resulting in an ROI of 292%.

References:

Milton, D.K., Glencross, P.M., and Walters, M.D. (2000) Risk of sick leave associated with outdoor air supply rate, humidification and occupant complaints. In Proceedings of Indoor Air 2000, Vol. 10, pp.212-221.

Increased outside air = Health + Individual productivity

Bourbeau et al 1997 / Wargocki et al 2000

In a 1997 before and after building study in Quebec City, Bourbeau et al identify an average 33.6% reduction in SBS symptoms for office workers who moved from five buildings with an outside air ventilation rate less than 2.4 liter per second per person to a single building with an outside air ventilation rate of at least 15 liters per second per person. In a 2000 metanalysis, Wargocki et al identify a 1.1% improvement in productivity for every 10% reduction in SBS symptoms, indicating a net 3.7% improvement in productivity due to an increased outside air ventilation rate.

First cost increase:	$25,600
Annual savings:	Health: $143,769 IndividualProductivity: $5,819,198 OMEnergy: $-25,527
ROI:	**3,049 %**

more information

Reference:
Bourbeau, J., C. Brisson, S. Allaire (1997) Prevalence of the sick building syndrome symptoms in office workers before and six months and three years after being exposed to a building with an improved ventilation system. Occupational and Environmental Medicine, v. 54, pp.49-53.

Wargocki, P, Wyon, D, and Fanger, P.O. (2000) Pollution Source Control and Ventilation Improve Health, Comfort and Productivity. In Proceedings of Cold Climate HVAC 2000, Sapporo, Japan, November 1-3, 2000, pp. 445-450.

Indoor Environments Division, U.S. Environmental Protection Agency (2000) Energy Cost and IAQ Performance of Ventilation Systems and Controls. EPA-402-S-01-001 http://www.epa.gov/iaq/largebldgs/eiaq_page.htm

Office of Pollution Prevention and Toxics, U.S. Environmental Protection Agency. Cost of Illness Handbook. http://www.epa.gov/oppt/coi

Eto, J. and Meyer, C. (1988) The HVAC Costs of Increased Fresh Air Ventilation Rates in Office Buildings. ASHRAE Transactions, 94(2), pp. 53-58.

Bourbeau et al 1997 / Wargocki et al 2000 - *Increased outside air*

Detailed Information:

• Overview

In 1991, all workers at a large public organization in Quebec City moved from five buildings into a single building with an improved ventilation system. All five old buildings and the new building had HVAC systems with humidification and sealed windows. The five original buildings were built in the 1960s and had between two and eleven floors. The new building, building in 1991, consists of three towers with four to six floors each. Each of the five original buildings had one or two CV or VAV ventilation systems with an outdoor air intake of less than 2.4 L/s per person, an adjustment threshold of humidification at 20%, and air conditioning in operation at minimum temperatures of 13°C or 16°C. The new building has nine CV systems with 30 distribution units, an outdoor air intake of at least 15 L/s per person, an adjustment threshold of humidification at 35%, and air conditioning in operation year-round. The smoking policy and maintenance schedules were the same in all buildings.

• Method

Workers completed a self-administered questionnaire during working hours in February 1991 (before moving), in February 1992 (six months after moving), and February 1995 (three years after moving). The study population consisted of 1390 workers in 1991, 1371 workers in 1992, and 1359 workers in 1995. The questionnaire encompassed seven types of symptoms: eye, nose and throat, respiratory, skin, fatigue, headache, and difficulty concentrating. The questionnaire also measured a worker's history of respiratory disease, number of hours working at a computer, proximity to a photocopier, smoking status, psychological job demands (job strain) and social support at work. In addition, a five-point Likert scale was used to assess workers' perceptions of the physical work environment, including noise, intensity of lighting, comfort, and workplace intimacy. In each building, carbon dioxide, temperature, and relative humidity were measured in at least five locations, and total VOCs, formaldehyde, and other airborne particulates were measured in one location, on the same days that surveys were administered.

Only symptoms that were identified as occurring two or more times per week and only at work were included in the analysis. Symptom prevalences for each year were calculated, and prevalence ratios were determined using 1991 prevalences as reference. To control confounding effects of personal, psychosocial, and work-related factors, adjusted prevalence ratios were obtained using logistic regression.

• Results

The prevalence of most symptoms decreased by 30-50% from 1991 to 1992, and the reductions were maintained at an average level of 33.6% in 1995. The prevalences and prevalence ratios for all symptoms are detailed in Table 1. The prevalence of difficulty concentrating did not decrease in 1992 or 1995. The adjusted prevalence odds ratios showed that when adjusted for personal, psychosocial, and workstation factors, the measured reductions remained similar for all symptoms except respiratory.

Table 1: Prevalence of symptoms in 1991, 1992 and 1995

	Percentage of workers reporting symptoms			% Improvement,	Prevalence ratio,
Symptom	1991	1992	1995	1991 to 1995	1991 to 1995
Nose and throat	23.0	12.4	15.2	33.9	0.54
Eyes	17.1	13.5	13.7	19.9	0.77
Respiratory	3.1	1.3	1.5	-	0.49
Skin	6.9	3.2	3.0	56.5	0.46
Headache	7.3	4.5	4.8	34.2	0.53
Difficulty concentrating	16.4	16.8	16.7	-	0.91
Fatigue	15.0	9.4	9.3	38.0	0.66
Average	13.9	8.4	9.2	33.6	

T

The reported prevalences of job strain and social support at work did not differ between 1991, 1992 and 1995. However, the perception of certain aspects of the workplace changed after moving into the new building, as indicated by a slight deterioration in ambient noise and improvements in lighting and workspace cleaning. Environmental measurements showed a decrease in mean daily CO2 concentration in the new building (from 810 to 601 ppm), a slight increase in humidity (from 22% to 28%), and no change in mean temperature, tVOCs, formaldehyde, or airborne particles.

A 2000 meta-analysis by Wargocki et al indicates a 1.1% productivity increase for every 10% reduction in SBS complaints. A 33.6% reduction in SBS symptoms due to an increased outdoor air ventilation rate would then produce an estimated 3.7% improvement in productivity.

• BIDS life cycle assumptions

The 2005 BIDS baseline assumes 500 employees with an average salary of $45,000, and 11.4 kWh/sf annual HVAC energy consumption at an electricity rate of $0.08/kWh. Eto and Meyer (1988) give a high estimate of $0.32/sf for the first cost premium to increase the rate of outdoor airflow from 2.5 to 10 L/s per person. In a 1999 simulation study, the U.S. EPA identifies an average 4.6% increase in HVAC energy consumption due to increasing the outside air ventilation rate from 2.5 to 10 L/s/person. The Office of Pollution Prevention and Toxics at the U.S. EPA reports annual per capita direct costs of $73 for headaches, $18 for eye irritation, and $37 for sinus and throat irritation (EPA). In a baseline organization, a 3.7% productivity increase combined with a reduction in the direct cost of SBS symptoms, minus additional energy use, amounts to a net savings of $1,697 per employee, resulting in an ROI of 2,652%.

References:

Bourbeau, J., C. Brisson, S. Allaire (1997) Prevalence of the sick building syndrome symptoms in office workers before and six months and three years after being exposed to a building with an improved ventilation system. Occupational and Environmental Medicine, v. 54, pp.49-53.

Wargocki, P, Wyon, D, and Fanger, P.O. (2000) Pollution Source Control and Ventilation Improve Health, Comfort and Productivity. In Proceedings of Cold Climate HVAC 2000, Sapporo, Japan, November 1-3, 2000, pp. 445-450.

Indoor Environments Division, U.S. Environmental Protection Agency (2000) Energy Cost and IAQ Performance of Ventilation Systems and Controls. EPA-402-S-01-001 http://www.epa.gov/iaq/largebldgs/eiaq_page.htm

Office of Pollution Prevention and Toxics, U.S. Environmental Protection Agency. Cost of Illness Handbook. http://www.epa.gov/oppt/coi

Eto, J. and Meyer, C. (1988) The HVAC Costs of Increased Fresh Air Ventilation Rates in Office Buildings. ASHRAE Transactions, 94(2), pp. 53-58.

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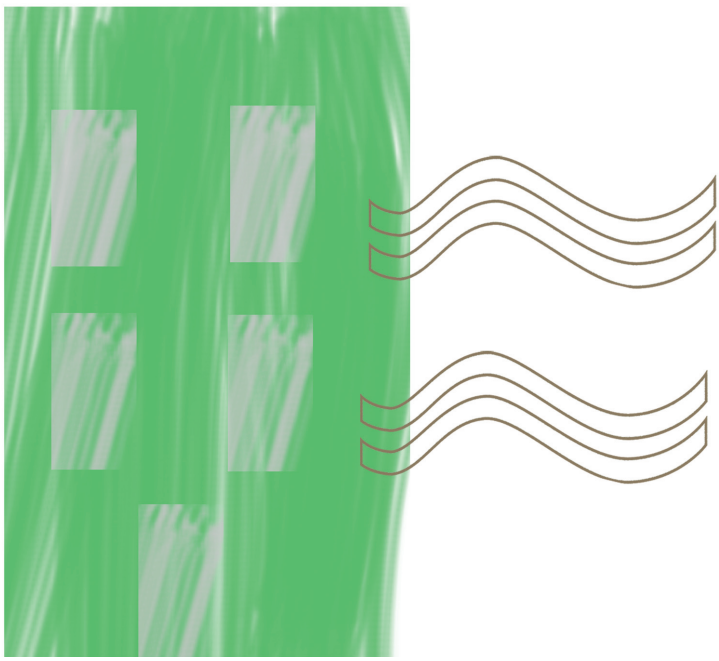

LEED® and Standard 62.1

By Steven T. Taylor, P.E., Fellow ASHRAE

Version 2.2 of the United States Green Building Council's popular Leadership in Energy and Environmental Design Green Building Rating System for New Construction & Major Renovations (LEED®-NC)[1] is scheduled to be released in November 2005. The rating system includes prerequisites and credits for six major design categories, summarized in *Table 1*. Points are awarded for the credits, and projects can achieve various levels of certification (shown at the bottom of *Table 1*) based on the number of awarded points.

LEED-NC Section	Points
Sustainable Sites	14
Water Efficiency	5
Energy & Atmosphere	17
Materials & Resources	13
Indoor Environmental Quality	15
Innovation & Design Process	5
Total	**69**
Certified 26–32 points	**Silver** 33–38 points
Gold 39–51 points	**Platinum** 52–69 points

Table 1: LEED-NC sections and point totals.

The changes made in the proposed LEED-NC Version 2.2 were intended to fix implementation problems and clarify language while keeping the same basic structure and focus of each of the sections and credits. This article discusses the changes made to the Indoor Environmental Quality (abbreviated EQ) section related to ventilation. *Table 2* summarizes these changes.

EQ Prerequisite 1: Minimum IAQ Performance

EQ Prerequisite 1, which is intended to establish minimum indoor air quality performance for the building, requires compliance with ANSI/ASHRAE 62.1-2004 *Ventilation for Acceptable Indoor Air Quality*. Version 2.1 referenced the 2001 version of Standard 62. The 2004 version includes significant revisions, including adoption of Addendum 62*n* that completely revised the Ventilation Rate Procedure (VRP).

As with prior versions of LEED-NC, this prerequisite requires that outdoor air

About the Author
Steven T. Taylor, P.E., is a principal at Taylor Engineering in Alameda, Calif., and a former chair of ASHRAE Standard 62. He is a member of the LEED IEQ Technical Advisory Group.

rates be calculated using the VRP; use of the IAQ Procedure (IAQP) is not allowed. The VRP is a prescriptive approach where rates are determined using per-person and per-unit-area rates prescribed in a table based on occupancy category. The IAQP is a performance approach that requires data that are seldom fully available to designers, such as concentration limits of pollutants of concern and their source strengths from materials and activities in the space. Disallowing the use of the IAQP was due to concerns about the availability of these data and with the level of expertise and judgment required by the designer and by the enforcement authority.

One other change to EQ Prerequisite 1 is that compliance is explicitly required for Sections 4, 5, 6, and 7 of Standard 62.1. Many designers feel that simply providing the outdoor air rates prescribed by the standard in Section 6 constitutes complete compliance. In fact, the standard includes significant requirements other than outdoor air rates, such as requirements for equipment to reduce the potential for microbial growth, air cleaning requirements, and start-up and commissioning requirements. All of these requirements must be met to comply with this prerequisite.

EQ Credit 1: Outdoor Air Delivery Monitoring

EQ Credit 1 requires that ventilation system monitoring be provided to ensure that ventilation systems continue to work long into the life of the building. The original credit used carbon dioxide (CO_2) concentration as an indicator of acceptable ventilation (and, indirectly, of acceptable indoor air quality) for all buildings. But, several problems exist with this approach both conceptually and in practice:

- CO_2 concentration can be a reasonable indicator of the concentration of pollutants generated by people and their activities (e.g., bioeffluents), but it is not an indicator of pollutants generated by other sources such as off-gassing of volatile organic compounds from building materials and furnishings. These building-related sources can be the predominant source of indoor pollution in spaces that are not densely occupied. For instance, Standard 62.1-2004 requires about 0.025 cfm/ft^2 [0.125 L/s/m^2] of outdoor air for occupants in office spaces (based on an occupant density of five people per 1,000 ft^2) and 0.06 cfm/ft^2 [0.3 L/s/m^2] for building related sources. The building ventilation rate component is almost 2.5 times larger than the occupant component. Thus, in spaces that are not densely occupied, CO_2 may not be a good indicator of air quality.
- CO_2 concentration also cannot be used to accurately determine outdoor air rates, particularly overall rates (cfm or L/s) as opposed to per-person rates. This has been demonstrated theoretically[2] and also through detailed study of real buildings.[3] This weakness is particularly relevant now that Standard 62.1 no longer specifies rates solely on a per-person basis.
- No guidance was provided in the LEED rating system language or in the LEED Reference Guide[4] regarding placement of CO_2 sensors. In practice, it is not uncommon for sensors to be placed in the return airstream of air-handling units serving multiple spaces. This is a not a good location for several reasons. First, it indicates only the average CO_2 concentration from several spaces. It is possible that the average concentration may be acceptable while some spaces are under-ventilated and others are overventilated.

  Second, the concentration of CO_2 in the return air may not be indicative of space CO_2 concentration due to short-circuiting of supply air to return air (low air-change effectiveness) or due to infiltration of outdoor air into negatively pressurized return air ducts and plenums.

To address these issues, the requirements for this credit in proposed Version 2.2 for mechanically ventilated spaces were revised to:

- For densely occupied spaces (those with a design occupant density greater than or equal to 25 people per 1,000 ft^2), carbon dioxide concentration must be monitored within the space between 3 ft and 6 ft (0.9 m and 1.8 m) above the floor.
- For non-densely occupied spaces, an outdoor airflow measurement device must be installed in the ventilation system capable of measuring the outdoor airflow rate at all expected system operating conditions within 15% of the design minimum outdoor air rate.

Requirements to achieve this credit for naturally ventilated spaces also were addressed. Since outdoor airflow to these spaces cannot easily be measured directly, CO_2 concentration is once again used as an indicator of acceptable ventilation and air quality, despite its shortcomings noted previously. As with densely occupied mechanically ventilated systems, CO_2 concentration in naturally ventilated spaces must be monitored within the occupied space.

EQ Credit 2: Increased Ventilation

EQ Credit 2 was originally titled "Ventilation Effectiveness" and required that the ventilation system be designed to maintain an air change effectiveness (ACE) greater than or equal to 0.9 as determined by ANSI/ASHRAE Standard 129-1997, *Measuring Air-Change Effectiveness*.

Problems quickly arose as designers attempted to achieve this credit. First, ASHRAE Standard 129 is a laboratory method of test and not easily applied in the field. Full-scale mockups of each air-distribution design must be built and tested to achieve the credit using this standard. To avoid this expense, LEED 2.1 allowed compliance to be achieved by showing that the air-distribution system complied with the recommended design approaches in *2001 ASHRAE Handbook—Fundamentals* Chapter 32, Space Air Diffusion. This was interpreted to mean that for each space type and application, the designer had to show that diffusers were selected to maintain an Air Diffusion Performance Index (ADPI) of at least 0.8. In addition to calculations, plans and sections had to be submitted for each space and air-distribution application type, so this credit was expensive to document.

But the credit also had more fundamental problems:

- High ACE does not improve indoor air quality because Standard 62 requires that ventilation rates be adjusted upwards when effectiveness is less than one. The ventilation rate to the breathing level is the same. Thus, high ACE if anything is an energy conservation measure and does not qualify as an EQ credit.
- Virtually every laboratory and field study[5,6,7,8] has shown that ACE is always greater than 0.9 when supply air is cooler than room temperature regardless of diffuser location or design. The default table of zone ventilation effectiveness in Standard 62.1-2004 also reflects this fact. So virtually any cooling-only system earns this credit inherently, regardless of the details of the air-distribution system design.
- Low ACE can occur with heating systems, whether the air is supplied from the ceiling or from the floor. People have mistakenly assumed that underfloor supply systems and displacement ventilation systems have inherently high ACE, but that is only true when cooling. These systems have low ACE when heating, often lower than conventional overhead systems.
- The LEED credit equated high ACE with high ADPI. They are not the same, although high ADPI usually results in high ACE. But, ADPI only applies to cooling systems that inherently have high ACE. ADPI does not apply to heating systems where low ACE can occur. Thus, ADPI is not a good surrogate for ACE.

It was clear to the LEED EQ Technical Advisory Group (TAG) responsible for maintaining EQ credits that Credit 2 needed to be significantly revised. The TAG decided to replace the credit entirely with a new one that requires increasing outdoor air ventilation rates to the breathing zone of all occupied spaces by at least 30% above the minimum rates required by Standard 62.1-2004. The rationale for this change was the following:

- The majority of existing literature indicates that increasing ventilation rates will decrease respiratory illness and associated sick leave, reduce sick building syndrome (SBS) symptoms, and improve productivity. While the original credit had little or no effect on indoor air quality, increasing ventilation rates will have a positive impact. The following research supports this conclusion:
  - Wargocki et al.[9] concluded that outdoor air rates below 50 cfm per person in offices increase the risk of SBS symptoms, increase short-term sick leave, and decrease productivity.
  - Seppanen et al.[10] found that increases in ventilation rates above 20 cfm per person up to approximately 40 cfm per person, are associated with a statistically significant decrease in the prevalence of SBS symptoms.
  - Wargocki et al.[11] found that for outdoor airflow of 6, 20, and 60 cfm per person, for each twofold increase in ventilation rate, performance improved on average by 1.9%.
  - Milton et al.[12] determined that lower ventilation rates of 25 cfm per person were associated with a 50% increase in short-term absence (considered a surrogate for sick leave), relative to ventilation rates of 50 cfm per person.
  - Wargocki et al.[13] found that call center productivity increased 6% at 50 cfm/person vs. 5–10 cfm/person.
- Giving credit for increased rates also is justified by the fact that the revised Standard 62.1-2004 rates (now referenced in EQ Prerequisite 1) are lower than the previous standard for most occupancy types. The standard is considered a "code-minimum" document. It is consistent with LEED philosophy to encourage designers to go beyond code minimum. *Figure 1* shows the reduction in breathing zone ventilation rates for sample occupancies. The 30% increase above Standard 62.1-2004 rates was selected to increase breathing zone office outdoor air rates from the 15 cfm/person to 20 cfm/person range that results from the Standard 62.1-2004 formula (based on four to six people per 1,000 ft^2 occupant density) up to a range of 20 to 25 cfm/person. Even higher rates could be justified by the studies referenced earlier.
- It is acknowledged that increasing ventilation rates will, in most applications and climates, increase energy use. However, the impact is relatively small[14] and it can be mitigated using heat recovery and other technologies that can be modeled and taken credit for in Environment and Atmosphere (EA) Credit 1 (Optimize Energy Performance). Note that other EQ credits, Credit 7 (Thermal Comfort) and Credit 8 (Daylight and Views) also increase energy use, Credit 7 because it takes considerable energy to maintain temperature and humidity within acceptable ranges, and Credit 8 because windows result in a net increase in HVAC loads even if lighting is controlled to take advantage of daylight. The benefits of these credits

	LEED NC Version 2.1 Title	LEED NC Version 2.2 Title	Summary of Changes
EQ Prerequisite 1	Minimum IAQ Performance	Minimum IAQ Performance	Updates reference to ASHRAE Standard 62.1-2004. Emphasizes that all sections of the standard must be complied with, not just rate section.
EQ Credit 1	Carbon Dioxide (CO_2)	Outdoor Air Delivery Monitoring	CO_2 used to monitor ventilation only for densely occupied spaces. Other spaces must have outdoor airflow measuring devices.
EQ Credit 2	Ventilation Effectiveness	Increased Ventilation	Credit replaced with new credit for increasing ventilation rates to 30% more than those required by Standard 62.1-2004.

Table 2: LEED-NC Indoor Environmental Quality (EQ) prerequisites and credits related to ventilation.

are deemed to outweigh the energy impacts. Similarly, it is argued that the energy impact of increased ventilation is more than offset by the health and productivity benefits.[15,16]

- Complying with this increased ventilation credit will not jeopardize compliance with EA Prerequisite 2 (Minimum Energy Performance) nor will it likely reduce the number of credits achieved in EA Credit 1. The reason is that ASHRAE Standard 90.1 modeling rules require that the same ventilation rate be modeled for the proposed and baseline building. Thus, if the minimum outdoor air rate in the proposed building is increased 30%, so is the outdoor air rate in the baseline building to which the proposed building is compared. In fact, since most LEED buildings have heating and cooling plants that exceed Standard 90.1 minimum efficiency levels, the increase in ventilation rate will most likely increase the number of credits achieved in EA Credit 1. This is because the outdoor air rate will increase heating and cooling loads that the proposed design will be able to handle more efficiently than the baseline building.

EQ Credit 2 requirements for natural ventilation systems have also been refined, although they are still very general. The design must meet the recommendations set forth in the Carbon Trust "Good Practice Guide 237"[17] and the CIBSE "Applications Manual 10: 2005, Natural ventilation in Non-Domestic Buildings."[18]

Conclusions

The LEED Green Building Rating Program for New Construction & Major Renovations has been updated to proposed Version 2.2. The revisions are intended primarily to fix implementation problems, but changes to the Indoor Environmental Quality credits relating to ventilation are significant. EQ Prerequisite 1 now references Standard 62.1-2004 and emphasizes that compliance is required for all relevant sections of Standard 62.1, not just the ventilation rate section. EQ Credit 1 has been revised to require CO_2 sensing to monitor ventilation system performance in densely occupied spaces while direct outdoor airflow measurement is required for mechanical ventilation systems serving other spaces. EQ Credit 2 has been completely revised to require an increase in ventilation rates of 30% above Standard 62.1-2004 rates. The increase (and even higher rates) can be justified by recent research showing higher outdoor air rates improve occupant productivity and reduce sick building syndrome symptoms.

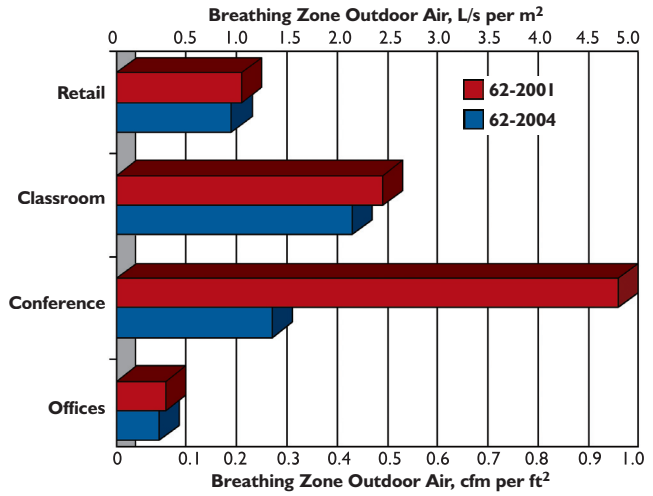

Figure 1: Breathing zone ventilation rate comparison for four common occupancy types.

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