Productivity and Energy Conservation are NOT Mutually Exclusive Objectives

Leonard A. Damiano, *EBTRON,* Inc. April 2011

INTRODUCTION

About 15 years ago, ASHRAE Standard 62 – 1989 was adopted ("Ventilation for Acceptable Indoor Air Quality" by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.). Just before its approval by ASHRAE and later by ANSI, the construction industry was myopically focused on the energy implications of tripling the ventilation rates from 5 cfm/person to 15 cfm/person. A lot of money was spent, much at the request of Congress or Building Owners, for research into the economic implications of the change.

Fortunately for our collective indoor health, sufficient benefit and insufficient negative economic impact was found by the studies. Standard 62-1989 was adopted and included requirements for effectively increasing the dilution ventilation rate required previously in the 1981 version by 3 times.

Based on subsequently published research, we now know that 1989 rates may not be sufficient for acceptable indoor air quality under all situations. Even greater ventilation rates may be required under many conditions.[3] Similar economic projections on the energy implications of increasing the rates are again being thrown around, without consideration for the reasons the increases are being proposed in the first place or the expected benefits. Namely, most of us are living and working in unhealthy environments during our daily activities.

Instead of concentrating on the energy cost alone, we should be looking at the greater positive impacts that are expected (by orders of magnitude larger). We should be finding design methods and technologies that could minimize or eliminate any financially negative impacts.

This paper explores some of the many technical justifications published for providing optimal amounts of dilution ventilation. We will also offer some potential methods of minimizing the costs for providing the needed outdoor air, while simultaneously providing the flexibility in control for changes in space usage and dynamic environmental effects.

THE BIG CARROTS - PRODUCTIVITY AND HEALTH

Everyone believes that they will never be the one on the receiving-end of poor IAQ's big legal "stick". It will always be the other guy. Conversely, few have spent time considering the huge potential IAQ "carrot" that would provide more than sufficient motivation for most building owners to insist on exceptional indoor environments – PRODUCTIVITY and HEALTH.

Indoor Air Quality (IAQ) is significant to achieving overall improvements in Indoor Environmental Quality (IEQ), which includes several comfort-related factors. It has been indicated in numerous studies that improving a building's indoor environment will also improve occupant productivity.

Because aspects of IEQ and IAQ are normally addressed simultaneously and because IAQ is typically not addressed in isolation in new building design, we will for practical purposes equate the research references for IEQ to IAQ, using them almost interchangeably for the purposes of this discussion. In doing so, we identify the need for future IAQ and ventilation-specific research related to their impact on productivity and health.

An early study in Europe by Professor Fanger showed that indoor air quality has an impact on human comfort and health, and documents for the first time that it also has a significant impact on human productivity in offices.[1] This will have far-reaching economic consequences for the design of indoor environments in the future and can mean billions of dollars in savings and/or increased capacity for U.S. companies and public sector organizations. The U.S. Navy's *Whole Building Design Guide* confirms:

> *"…there is mounting evidence of a strong positive correlation between environmental satisfaction and increased productivity."* [2]

While few people doubt a connection between productivity and IAQ, there have been few quality studies showing a definite effect. Several such studies are currently under way. Still, some analysts have shown that ignoring the IAQ impact of building management policies can have a negative financial effect that far outweighs minor savings from operational cost-cutting policies.

Very often, building managers propose cost-cutting moves that negatively influence the indoor environment without considering the added expense from lowered productivity. An example of this can be illustrated using the Building Owners and Managers Association's (BOMA) own data, as published with pride to members after successfully beating back two proposed requirements in ASHRAE's Standard 62-2001. [3a]

Titled "ASHRAE 62: The Check's in the Mail," the article appeared in BOMA's member newsletter *SkyLines*. The two provisions of the ASHRAE Standard in question would have required major construction areas to be isolated from the rest of the building by negative pressure and it mandated a 48-hour period for purging contaminants from those areas following construction.[4]

BOMA claims that these provisions were onerous and would have cost building owners about \$0.10 per square foot (ft^2) for the first provision and \$0.01 per ft^2 for the second. According to the BOMA analysis, defeating those provisions would save a building owner about \$11,096 for a 100,000 ft^2 building. Even a small negative impact on productivity in the same 100,000 ft^2 building could more than offset the \$11,096 saving.

Consider the example of a building with a default occupant density for offices specified by ASHRAE 62.1[3b] table 6-1 (5 persons per 1,000 ft^2 or about 1 per 200 ft^2) for a total of 500 people in the building. Then, assume an average annual salary of \$35,000. This would be a total weekly salary of \$336,538 for the building. If construction activities cause IAQ degradation and a conservative 1% drop in productivity, this would equal a loss of \$3,365 for each week that the situation existed. It's easy to see that it would take about 30 days to eat up the calculated $11,096 in "savings" if the degraded IAQ was more severe or lasted more than a few weeks throughout one year. If we take 5% as a more realistic average productivity loss, as reflected in most current literature on the subject, the resulting loss of $16,825 would financially justify the BOMA-preempted measures in only a few days.

This example does not take into account possible long-term health effects, potentially disastrous lawsuits, lost time, health insurance premiums and such intangibles as employee dissatisfaction and poor morale. These would necessarily be factored into any thorough analysis.

VENTILATION RATE MINIMUMS AND PRESSURIZATION REQUIREMENTS

The provision of good air quality indoors need not necessarily cost more or require more energy, if the building envelope and the HVAC system are designed intelligently, and building and furnishing materials are carefully selected. Reducing contaminant sources indoors are always a prudent way of minimizing the total amount of dilution air needed for acceptable air quality. But, it cannot be addressed in isolation, without also considering controls and system performance to insure that reduced minimums are maintained “under all operating conditions”.[3]

We should be wary of methods that allow the drastic reduction of outdoor air intake rates, below the minimums required by our national ventilation standard or local codes. Intake rates should not be reduced below the point required to maintain adequate and consistent space pressurization. More precise controls are needed to effectively maintain smaller minimum rates. Precision control would all but eliminate the very large risks created of negatively pressurizing the space. It would also allow effective and dynamic control of both pressurization and outdoor air intake, regardless of the rate selected.

Negative pressurization could pull untreated humid air through open doors, cracks and gaps in the building envelope into walls where it can cool and condense to liquid form. This increases the risk of unhealthy mold infestation by providing the ingredients for a more-than-adequate growth medium. Negatively pressurizing a space would also increase operating costs for energy usage immediately and decrease the systems ability to control comfort. Consistent positive pressurization flow would provide a barrier to infiltration; effectively seal the envelope from infiltration and provide a proactive solution to one of the causes of mold infestation in exterior building walls.

The potential negative health impacts from “toxic” mold have been hyped by the media to the point of consumer and insurance carrier panic. It is an area of IAQ that is fairly obvious. The impact of dilution ventilation, however, is not as apparent and therefore does not get the same visibility. It is only when linked to “sick building syndrome” and the damage awards for occupants generated that we tend to hear about it.

As we will see in subsequent examples, dilution ventilation rates have also demonstrated a profound impact on the measured productivity of building occupants. You will see significant authorities referencing that occupant salaries in offices often exceed one hundred times the building energy and maintenance costs. That equals nearly as much as the annual amortized cost of construction or rental.

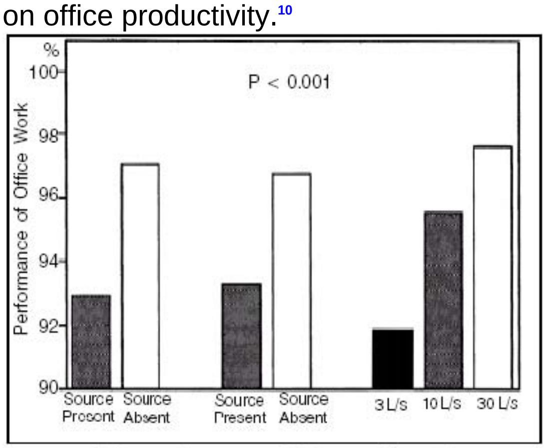
A realized increase of **only one or two percent** in office productivity **is sufficient to justify the increased energy, maintenance, and any additional equipment or construction costs** in an owner-occupied setting. But, what evidence is there that the performance of office workers can be positively impacted by ventilation rates supplied to the space? Are there any other costs that can be offset by increasing mechanical ventilation rates? Do these conclusions apply to structures and situations other than commercial offices?

OFFICE WORK EFFECTS

In one study, Productivity, IAQ and SBS (Sick Building Syndrome) symptoms were evaluated by the Technical University of Denmark's International Centre for Indoor Environment and Energy. Their study determined that removing a pollution source from a space or increasing the outdoor air supply rate improved the perceived air quality, reduced the intensity of general SBS symptoms such as headaches, and improved the performance of office work (Figure 1). Similar effects were observed in the recently completed study in which the main pollution source was personal computers after three months of normal office operation.

> *"Based on the results obtained, quantitative relationships were established showing that the performance of office work can be increased by 1.1% for every 10% reduction in the proportion of persons dissatisfied with the air quality,* ***by 1.6% for every twofold decrease of pollution load****, and by* ***1.8% for every twofold increase of the ventilation rate*** *(outdoor air supply rate)."* [9]

These relationships can be used to roughly estimate the effects of improved air quality on office productivity.[10]



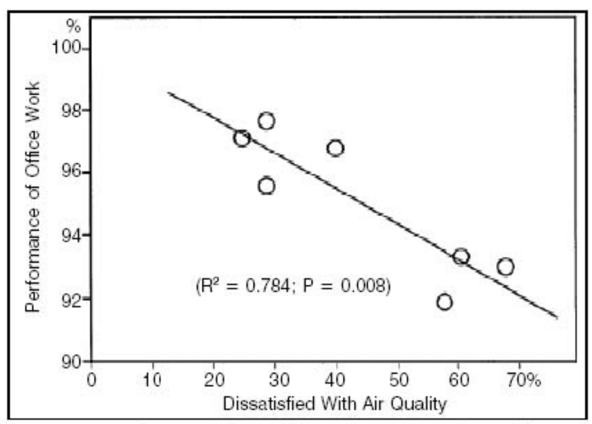


Figure 1 (left): Performance of office work as a function of the presence or absence of the pollution source, or the outdoor air supply rate. Figure 2 (right): Performance of office work as a function of the perceived air quality.

COST TO TENANTS - OFFICE WORKER DISCOMFORT

As it relates to the office building environment, some health professionals feel that discomfort is an aesthetics issue (odors, temperature) and others feel that it is a minor or first stage health problem (irritancy, nausea). As this debate continues, a recent study conducted by BOMA revealed that more than half of all the office building tenants in America are "uncomfortable".

Currently, the driving force behind addressing indoor air quality problems can be seen as the building owners' and the employers' concern with the "cost of discomfort".

The energy cost for operating an office building is widely cited as approximately $1 to $2/ft²/yr. The energy cost for an office worker with a $30,000 a year salary who occupies 150 ft² is between 0.5% and 1% of the employee cost. Even if the energy expenses were doubled it would be cost effective by providing a 1% improvement in productivity. Reducing outdoor air rates to save energy can raise indoor contaminant levels, thereby increasing employee discomfort and lowering worker productivity.

Furthermore, with building costs totaling approximately $20/ft²/yr, the previously mentioned office worker's space costs $3,000 per year. Therefore, a 1% improvement in this worker's productivity would justify a 10% investment in improving the ventilation system and hence the indoor air quality.

The bottom line is that a properly designed, functioning and maintained ventilation system will provide employees with an acceptable thermal and indoor air environment. In turn, absenteeism will be reduced, and morale, well-being and productivity will be increased.

COSTS TO STUDENTS

The U.S. Environmental Protection Agency's (EPA), Indoor Environments Division, Office of Radiation and Indoor Air published *Indoor Air Quality and Student Performance*, in document #EPA 402-F-00-009, in August of 2000. Among the conclusions they presented were good indoor air quality contributes to a favorable learning and a sense of comfort, health, and wellbeing for school occupants. These factors combine to assist a school in its core mission - educating children.[12]

It only makes sense that children can not perform as well when they are sick or absent from school. Indoor air quality problems can result in absences because of respiratory infections, allergic diseases from biological contaminants, or irritant reactions to chemicals used in virtually every part of the school. Other sources support this.

Some conditions in the school environment are closely associated with the incidence of sick building syndrome and asthma symptoms,[13,14] *and asthma-related illness is one of the leading causes of school absenteeism, accounting for over 10 million missed school days per year.*[15] *In addition, persons with asthma or other sensitivities may have reduced performance in the presence of environmental factors that trigger their asthma.*

Motivation can often overcome small burdens of environmental stress so that children's performance may not decline. However, continued environmental stress can drain children's physical and mental resources and ultimately affect their performance. Evidence from office workers suggests that when individuals experience just two symptoms of discomfort, they begin to perceive a reduction in their own performance. That perception increases as the number of symptoms increases, averaging a 3% loss with 3 symptoms, and an 8% loss with 5 symptoms.[16] *It follows that when large numbers of students and staff experience signs of discomfort related to the air inside their* *school, teaching and learning performance will likely degrade over time.*[12]

All of these "building-related illnesses" (BRI's) result from the lack of effective indoor environmental quality management. In extreme cases, schools sometimes have to be closed until problems are investigated and solved.

There is widespread concern that indoor environments can affect occupants' health, comfort and performance. Indoor environments in schools are of particular concern because:

1) *Schools are seen as particularly likely to have environmental deficiencies that could lead to poor indoor environmental quality (IEQ). In particular, chronic shortages of funding in schools contribute to inadequate operation and maintenance of facilities.*

2) *Children breathe higher volumes of air relative to their body weights and are actively growing. Thus, they have greater susceptibility to environmental pollutants than adults do. Children also spend more time in school than in any other indoor environment outside the home. Adverse environmental impacts on the learning and performance of students in schools could have important immediate and lifelong effects* (GAO, 1995).[11]

The available evidence indicates that **lower outdoor air ventilation rates**, known to cause generally higher concentrations of the pollutants produced indoors, **were related to reduced performance among occupants** (Wargocki, 2000; Smedje, 1996).[17]

The most persuasive available evidence suggests that some aspects of IEQ, including low ventilation rate and less daylight, may reduce the performance of occupants, including students in schools. Sufficient evidence is available to justify actions to safeguard IEQ in schools.[19,20]

Overall, the leading IAQ concerns for educational facilities include outdoor-air control. While school control systems traditionally are as simple as possible, outdoor-air control can be helpful, and the cost of digital control systems—which provide more precise and reliable control—has dropped to the point that they can be considered for educational facilities. Digital control, in conjunction with airflow measuring devices, can also offer precise control as well as real-time verification of intake rate performance.[18]

In exploring system options for schools that would overcome the IAQ deficiencies recorded in traditional systems, Charles A. McCoy and Scott C. Bernth wrote about their experience with VAV (Variable Air Volume) systems in Indiana.[19]

Equipment for VAV systems is more complex and more expensive than other ventilation alternatives. However, cost savings from the system's energy-efficiency and load-balancing capabilities usually result in a relatively short payback time, allowing the school district to enjoy a net gain in long-term energy savings. The use of VAV designs in modern schools has increased dramatically in recent years and means are required to insure that the needed ventilation rates are maintained under all operating conditions.[3]

The authors noted that many technology innovations have emerged to offset the drawbacks of VAV, specifically for our discussion:

“Highly accurate airflow measuring stations on the AHUs automatically fine-tune the outside airflow, and compensate as needed…” [19]

PRODUCTIVITY “GAINS”

If we assume that current IAQ levels in many buildings are below an acceptable level, then continuous productivity gains should be available from the improvement of those levels. The easiest, simplest and most cost-effective method of improving the relative level of a building’s IAQ is through increased dilution ventilation. However, without active control of intake rates, you never really know if you are bringing in enough outdoor air or too much.

Either situation has its own resulting costs. Some of those costs are: direct energy consumption, the risk of legal liability for individuals that the deficiency injures, incremental time losses due to increases in and lengthened sick leave due to poor ventilation, and lastly in the opportunity losses associated with relative IAQ levels and its effect on productivity.

Multiple government and private studies have shown that improvements in productivity, ranging from 3% - 20%, can be expected due to improvements in a worker's indoor environment (National Contractors Study, et. al. 1990, 1993, 1995, LBNL-1997). This is the magnitude of the benefit that might be captured with improved intake control through HVAC instrumentation and ventilation design.

Nunes et al. (1993) demonstrated that simulated work performance is worse when SBS symptoms are greater. Wargocki et al. (1998) showed that simulated office work performance was negatively affected by an indoor pollution source.

UC-Berkeley is investigating whether or not the ventilation rate is correlated with work performance while controlling for other variables such as temperature by analyzing existing data, and by conducting a controlled “field intervention”. They are changing the ventilation rate and will be checking for an effect on work performance, energy use, and indoor air quality. This two-part study will be collaboration with William Fisk and David Faulkner of the Indoor Environment Department at Lawrence Berkeley National Laboratory.

“While more research is clearly needed, the ***message to architects and engineers is to pay attention to IEQ, in particular to ensuring minimum ventilation rates****, because many studies have found that ventilation rates influence health, satisfaction with indoor air quality or absences.”* [20]

HIGH PERFORMANCE BUILDINGS – THE MN INITIATIVE

A movement toward “high performance buildings” may provide much of the desired benefits, without excessive costs. In a high performance building, all of the issues that impact the resulting IAQ are addressed. Material selection is carefully reviewed, the HVAC system is designed to allow for proper amounts of outdoor air and purging, the HVAC systems are commissioned and provided with dynamic controls, so that they perform in accordance with the specifications regardless of changes in the environment. MN High Performance Building Goals for State-funded projects were developed collaboratively by six state agencies as part of the Smart Building Partnership and are now part of the Minnesota Department of Finance's 2002-2007 Capital Budget Instructions.[21]

Among those outcomes desired by MN are prioritized objectives, including:

*1. **Minimize the lifetime costs** of state-owned, leased and financed buildings. Relevant costs include…impacts on human health, productivity and well-being.*
*2. **Create healthier indoor environments** that enhance employee productivity and wellness.*
*3. Ensure that facility managers and users can **optimize the building's systems by commissioning** the building and developing and following an operations and maintenance plan. Plans should include strategies for **documenting the building's performance and operations** and maintenance costs as compared to the average for that building type.* [21]

If we look at the range of possible improvements to productivity from technical journals, what are the likely labor cost impacts for a range of salaried employees? The table below illustrates the simple calculation for productivity changes from 3% to 20%, as related to labor costs.

PRODUCTIVITY LOSSES / GAINS

Annual Salary	Value / Person / Yr.			Value / Sq.Ft. / Yr.		
	3%	10%	20%	3%	10%	20%
$30,000	$900	$3,000	$6,000	$6	$20	$40
$40,000	$1,200	$4,000	$8,000	$8	$27	$53
$50,000	$1,500	$5,000	$10,000	$10	$33	$67
$60,000	$1,800	$6,000	$12,000	$12	$40	$80
$100,000	$3,000	$10,000	$20,000	$20	$67	$133

Note: Cost per sq. ft. based on ~150 sq.ft per person.

PRODUCTIVITY VS. ENERGY COST COMPARISONS

Several significant organizations have already concluded that building management policies that ignore the IAQ impact can have a negative financial effect that far outweighs the minor savings projected from those policies. For example, NIBS and the Naval Facilities Engineering Command, as early as 1997, stated in their *Whole Building Design Guide*:

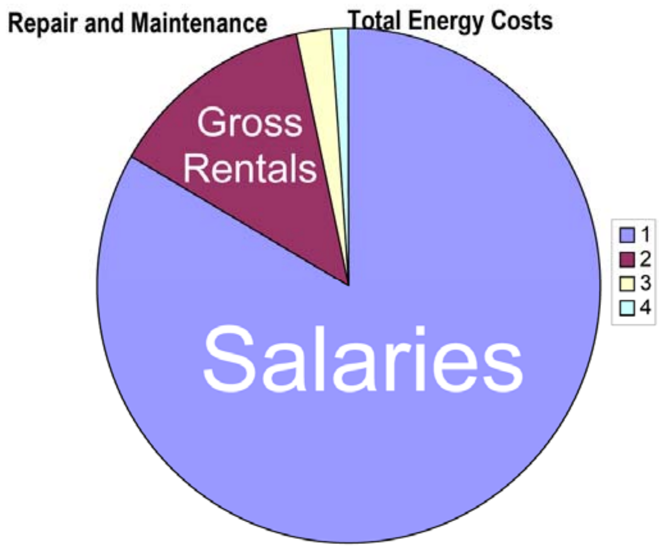
> *"Because worker salaries exceed building energy, maintenance and annualized construction costs by a large factor, the cost-effectiveness of improvements in indoor environments will be high even when the percentage improvements in health and productivity are small…**The resulting benefit-to-cost ratios were very high, approximately 50 to 1...for increased ventilation…"*** [1]

They go on to propose:

> ***"…a 'productivity' increase of 1% will completely offset the building's entire energy bill.** This implies that it is crucial that interventions made in the name of energy efficiency do not negatively impact occupant satisfaction and productivity."* [1]

In many non-industrial workplaces, the cost of workers' salaries and **benefits exceeds energy costs by approximately a factor of 100**. Consequently, businesses should be strongly motivated to change building designs or methods of operation if these changes improve worker performance by even a significant fraction of a single percent of their salaries, or reduced sick leave by one day or more per year.

With this magnitude of benefits-to-cost ratio, there should be little hesitation from building owners and operators to comply with our national standards for ventilation and IAQ. While some employers may be tempted to neglect energy efficiency when seeking to improve health and productivity, the most desirable measures (or packages of measures) are those that improve IEQ/IAQ and simultaneously save energy.[8] The smart building operator will provide his system with a control system and input devices sufficiently accurate and reliable to allow optimizing adjustments for changing conditions. This would enable the system to be controlled at the most cost-effective points of operation without sacrificing the benefits of providing improved IAQ.



83.3%	$ 130.00	Salaries
13.5%	$ 21.00	Gross Office Rent
2.1%	$ 3.20	Repair and Maintenance
1.2%	$ 1.80	Total Energy Costs
100.0%	$ 156.00	Typ. Office Bldg. Operating Costs/SF/Yr. Source: BOMA, 1999

The National Energy Management Institute (NEMI) reports that approximately 80% of commercial buildings do not comply with engineering standards to provide the best indoor air quality for building occupants. In general, building maintenance personnel will take action only when the HVAC system is very old and, therefore, not able to function properly or when tenants complain about the air quality.

If building owners make it a priority to improve the IAQ/IEQ proactively, then their annual return on investment (ROI) can increase by 283% in less than six months, provided that they invest $100,000 in IEQ improvements. It will be cheaper for the building in the long run because the energy savings will be higher. According to the City of New York Department of Design and Construction, by improving the IEQ, occupants will also benefit by an increase in employee attendance, productivity, and moral. Added benefits can include a decrease in workers compensation claims, medical expenses, union grievances, and legal expenses.

Nonetheless, an increasing number of studies are beginning to suggest that worker well being and satisfaction with the physical environment - even if not yet accurately quantifiable - are fundamental aspects of productivity. The GSA agrees and concedes in *The Integrated Workplace* that:

"…since people are the most important resource and greatest expense of any organization, the long-term cost benefits of a properly designed, user-friendly work environment should be factored into any initial cost considerations." [22]

While literature on high performance buildings emphasizes the energy and resource savings possible with off-the shelf technologies and design solutions, it also suggests that the real savings may come in the form of increased occupant productivity.

PRODUCTIVITY IMPROVEMENT WITHOUT ENERGY PENALTIES

In four schools studied by SAIC for the New York State Energy Research and Development Authority (NYSERDA),[23] the energy penalty did not preclude increasing outdoor air ventilation rates to meet ASHRAE Standard 62-2001[3a] requirements of 15 cfm per occupant in classrooms. Their summary also illustrates that implementing energy conservation measures (ECMs) could offset any increase in energy consumption resulting from higher ventilation rates. In fact, energy cost savings are possible through implementing ECMs and increasing ventilation. Depending on baseline ventilation rates and the type of ventilation measures, the NYSERDA studies illustrate the following:

In one case, the ECMs planned by the school could easily offset the rise in energy consumption caused by increased ventilation rates. "In fact, **net future facility cost energy savings of 9.1% (15.1% - 24.2%)** are possible with the ECMs and increased ventilation."[23] This equates to a savings of $6.48 per occupant per year.

Technical publications have provided us with many references that conclude increased ventilation rates do not necessarily need to result in increased energy costs. In new designs, with the proper attention and intelligent selections of control components and building materials, a balance can be struck between the seemingly conflicting objectives.

"Energy Cost and IAQ Performance of Ventilation Systems and Controls" was published by the EPA in 1999. Although this study was primarily concerned with the increases in ventilation required by ASHRAE Standard 62-1989 vs. the 1981 version (20 vs., 5 cfm/person), the analysis is still applicable, as are their general conclusions. Current comparisons can be made to systems that propose decreasing intake rates to the range allowed under ASHRAE 62-1981, against the current level of dilution ventilation rate requirements in ASHRAE 62-2001. Some of their key findings included the following:[24]

* ***VAV Systems Save Energy:*** *Variable air volume systems provided $0.10 - $0.20 energy savings per square foot over constant volume systems.*
**** VAV with Fixed Outdoor Air Fractions Caused Outdoor Airflow Problems****: VAV systems may require a different outdoor air control strategy at the air handler to maintain adequate outdoor air for indoor air quality than the constant volume predecessor.*
* ***Core Zones in VAV Systems with a Fixed Outdoor Air Fraction Received Very Little Outdoor Air****: The VAV system with fixed outdoor air fraction diminished the outdoor air delivery to the core zone to only about one third of the design level. With a design level of 20 cfm of outdoor air per occupant, the core zone received only 6-8 cfm per occupant, and only 2-3 cfm per occupant with a design level of 5 cfm per occupant. Along with higher temperatures in the core zone, this shortfall could contribute to higher indoor air quality complaint rates in the core relative to the perimeter zones.*

* ***VAV with Constant Outdoor Air Control Displayed Improved Indoor Air Performance without any Meaningful Energy Penalty.*** *A VAV system with an outdoor air control strategy that maintains the design outdoor air flow at the air handler all year round had slightly lower energy cost in the cold climate, and slightly more energy cost in the hot and humid climate. It is therefore comparable in energy cost, but preferred for indoor air quality.*
* ***Economizers on VAV Systems May Be Advantageous for Both Indoor Air Quality and Energy in Cold and Temperate Climates.*** *By increasing the outdoor air flow when the outside air temperature (or enthalpy) is less than the return air temperature (or enthalpy), economizers can reduce cooling energy costs. For office buildings, economizers may operate to provide free cooling even at winter temperatures (e.g. at zero degrees Fahrenheit), provided that coils are sufficiently protected from freezing. For the office building, energy savings of about $0.05 per square foot were experienced by the VAV system economizer over the non-economizer VAV system in cold and temperate climates. The economizer on the CV system was much less advantageous due to increases in heating energy costs for this system, and was actually more expensive under some utility rate structures.*
* ***VAV with Constant Outdoor Air Control and an Economizer Offers Significant Advantages, while VAV with Fixed Outdoor Air Fraction and No Economizer offers Significant Disadvantages:*** *Of all the ventilation systems and controls studied, the VAV system with constant outdoor air flow, provided the good overall performance considering outdoor air flow, thermal comfort and energy efficiency.*
* ***Raising Outdoor Air to Meet ASHRAE Standard 62-1989 in Office Buildings Resulted in Very Modest Increases in Energy Costs.*** Raising outdoor air flow from 520 cfm per occupant in office buildings typically raised HVAC energy costs by only $0.02 - $0.08 per square foot (2% - 10%) depending on the type of system and climate. Considering the total energy bill, this increase amounted to approximately 1% - 4%. This is much less than is commonly perceived by practitioners. The cooling cost increases in the summer months were counterbalanced by cooling cost savings during cooler weather. The most significant factor affecting this increase was occupant density.
**** Contrary to Conventional Wisdom, the Impact of Raising Outdoor Air Flow Rates in High Occupant Density Buildings may be Least in Hot Humid Climates****. While raising outdoor air flow rates in the education and auditorium buildings raised cooling costs in Miami more than it did in Minneapolis and Washington, D.C., this was more than offset by the high increase in heating and fan energy in these climates which were not experienced in Miami. The net result was much less relative impact in Miami.*
**** Energy Recovery Technologies May Potentially Reduce or Eliminate the Humidity Control, Energy Cost and Sizing Problems Associated with ASHRAE Standard 62-1989 in Education Buildings, Auditoriums, and Other Buildings with Very High Occupant Density****.*
**** Protecting or Improving Indoor Environmental Quality During Energy Efficiency Projects May Not Hamper Energy Reduction Goals.*** *Many energy efficiency measures with the potential to degrade indoor environmental quality, appear to require only minor adjustments to protect the indoor environment. When energy efficiency retrofit measures (including lighting upgrades), which were adjusted to either enhance or not degrade indoor environmental quality, were combined with measures to meet the outdoor air requirements of ASHRAE Standard 62-1989, total energy costs were cut by 35%-45%. Operational measures compatible with indoor environmental quality cut total energy costs by 10%-20%. Avoiding operational measures that degrade indoor*

environmental quality meant that total energy reductions of only 3%-5% in the office building, and 7%-10% in the education building were foregone. ***There appears to be demonstrable compatibility between indoor environmental goals and energy efficiency goals, when energy saving measures and retrofits are applied wisely***. [24]

DYNAMICALLY OPTIMIZED DILUTION VENTILATION (DODV)

DODV is a combination of system design, controls strategy, instrumentation, equipment and the operational imperatives employed that allow a building's HVAC system to continuously compensate for the dynamic changes in internal building system or thermal pressures, as well as external wind pressures. It simultaneously minimizes the volumetric intake of outdoor dilution air to a predetermined amount, sufficient to maintain desired IAQ levels or ventilation rates -- and no more – without going below that minimum amount required for pressurization.

Many building designers and operators tend not to consider airflow measurement a significant factor in the system's ability to provide consistently comfortable working environments. Without reliable pressurization control, temperature and humidity fluctuations due to infiltration can be hourly occurrences. The cost to compensate for inadequate control systems is counted in energy dollars that are otherwise squeezed by budget-minded operations people.

All of the objectives for High Performance Building design and IAQ are provided with more than a good chance of success when **Dynamically Optimized Dilution Ventilation (DODV)** is employed. Electronic instrumentation, for the direct control of ventilation rates, is the heart-and-soul of DODV. When this can be accomplished in reference to national performance standards, we are presented with an unparalleled level of authority in the resulting measurements and the conclusions that are derived from them. Its use also provides us with a much more stable method of space pressurization through the use of differential volumetric airflow control. Improved IEQ through DODV can provide measurable increases in worker productivity.

You wouldn't attempt to control temperature without permanently mounted thermostats… so, why would you try to control ventilation rates without permanently mounted airflow measuring devices?

Reliable and continuous measurement of key airside components for direct feedback control is essential for accomplishing our objectives reliably and in the most cost-effective manner. More precise and consistent control inputs would therefore make spaces more comfortable for the occupants and more energy efficient for the building manager.

CONCLUSIONS

Those focused solely on energy should be silenced with common sense and the thoughtful pursuit of improvements in broader objectives: PRODUCTIVITY & HEALTH.

We have the research and supporting documentation to show that these objectives support "sustainability". They do not need to add to the operating costs of a building.

We have the methodology. We have the needed hardware and technology to implement the method. So, what's stopping us?

REFERENCES

[1] Fanger, P. Ole, "Poor indoor air quality decreases human productivity", 19

[2] U.S. Navy Facilities Engineering Command / NIBS, 2003, Whole Building Design Guide, http://www.wbdg.org/design/resource.php?cn=2.8.5&cx=0&rp=19 and http://www.wbdg.org/design/index.php?cn=2.6&cx=0 Abstract: Federal Mandates, Legislation, etc: OMB Circular A-131 Public Law 104-106, Section 4306, Value Engineering for Federal Agencies Federal Acquisition Regulations, Parts 48, Value Engineering Federal Acquisition Regulations, Parts 52, Solicitation Provisions and Contract Clauses Executive Order 13123 Greening the Government through Energy Efficient Management Executive Order 13148 Greening the Government through Leadership in Environmental Management

[3a] American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE), Standard 62-2001: Ventilation for Acceptable Indoor Air Quality, Atlanta, GA, July 2002.

[3b] American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE), Standard 62.1-2010: Ventilation for Acceptable Indoor Air Quality, Atlanta, GA, January 2011.

[4] Building Owners and Managers Association (BOMA), SkyLines, "ASHRAE 62: The Check's in the Mail," 1999.

[5] Wargocki, P., D.P. Wyon, Y.K. Baik, G. Clausen, and P.O. Fanger, "Perceived air quality, sick building syndrome (SBS) symptoms and productivity in an office with two different pollution loads." Indoor Air 9:165–179, 1999.

[6] Wargocki, P., D.P. Wyon, J. Sundell, G. Clausen, and P.O. Fanger, "The effects of outdoor air supply rate in an office on perceived air quality, sick building syndrome (SBS) symptoms and productivity." Indoor Air 10:222–236, 2000.

[7] Wargocki, P., L. Lagercrantz, T. Witterseh, J. Sundell, D.P. Wyon, and P.O. Fanger, "Subjective perceptions, symptom intensity and performance: a comparison of two independent studies, both changing similarly the pollution load in an office." Indoor Air 12: 74–80, 2002.

[8] Wargocki, P., D.P. Wyon, and P.O. Fange, "Pollution source control and ventilation improve health, comfort and productivity." Proceedings of Cold Climate HVAC. Sapporo. Pgs. 445–450, 2000.

[9] Djukanovic, R., P. Wargocki, and P.O. Fanger, "Cost-benefit analysis of improved air quality in an office building." Proceedings of Indoor Air 2002, The 9th International Conference on Indoor Air Quality and Climate. Monterey, Calif. Vol. 1. Pgs. 808–813, 2002.

[10] Wargocki, Pawel, "Making the Case For IAQ", ASHRAE IAQ Applications, Fall 2002.

[11] U.S. General Accounting Office (GAO). School facilities: Condition of America's schools. Washington, DC. U.S. GAO. 1995. http://www.access.gpo.gov/su_docs/aces/aces160.shtml (search for report GAO/HEHS-95-61).

[12] U.S. Environmental Protection Agency, Indoor Environments Division. 2001. IAQ Tools for Schools: Indoor Air Quality and Student Performance. http://www.epa.gov/iaq/schools/perform.html, accessed February 20,2003.

[13] Smedje, G., and D. Norback. 1999. The School Environment – Is It Related to the Incidence of Asthma in the Pupils? In Indoor Air '99. The Eighth International Conference on Indoor Air Quality and Climate. Vol 5, pp. 445-450.

[14] Daisey, Joan M., and William J. Angell. 1999. Indoor Air Quality, Ventilation and Health Symptoms in Schools: An Analysis of Existing Information. In Indoor Air 99. The Eighth International Conference on Indoor Air Quality and Climate. Vol 2, pp. 1-6.
[15] Asthma and the Environment: A Strategy to Protect Children. President's Task Force on Environmental Health Risks and Safety Risks to Children. January 28, 1999.
[16] Raw, G.J., M.S. Roy, and A. Leaman. 1990. Further Findings from the Office Environment Survey: Productivity. In Indoor Air '90. The Fifth International Conference on Indoor Air Quality and Climate. Vol 1, pp. 231-236.
[17] Heath,G.A., and M.J. Mendell, "Do Indoor Environments In Schools Influence Student Performance? A Review Of The Literature". Indoor Environment Dept., Lawrence Berkeley National Laboratory, Berkeley, CA, and Dept. of Civil and Environmental Engineering, University of California, Berkeley, CA, USA
[18] Wilson, Scott, P.E. "Graduating to Better IAQ", http://www.buildingteam.com/applic/articles/c01f024.asp, accessed 7/13/01.
[19] McCoy, Charles A. and Scott C. Bernth, "Invisible Touch". Engineered Systems, February, 2002.
[20] Kumar, Satish and William J. Fisk, IEQ and the Impact on Building Occupants, ASHRAE Journal, April, 2002.
[21] Nordstrom, Rolf, Return On Investment - High Performance Buildings, MN State Planning Agency, 2002, http://www.mnplan.state.mn.us/.
[22] U.S. General Services Administration, Office of Real Property in the Office of Government-wide Policy, "The Integrated Workplace: A comprehensive Approach to Developing Workspace" , May 1999. http://policyworks.gov/org/main/mp/library/policydocs/Completeiwrpt.pdf.
[23] U.S. Environmental Protection Agency, Indoor Environments Division, "Energy Cost and IAQ Performance of Ventilation Systems and Controls", 1999.