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Don't Manage Energy At the Expense of Comfort

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Managing Energy And Comfort

Don't Sacrifice Comfort When Managing Energy

By Steve Tom, Ph.D., P.E., Member ASHRAE

In Lewis Carroll's classic *Through the Looking Glass,* the White Knight shows Alice his own invention—a lunch basket mounted upside down. "I carry it upside down so the rain can't get in" he says with pride. "But the things can get *out*," Alice replies. "Do you know the lid's open?"

The White Knight made the classic engineering mistake of focusing on a secondary objective to the point where he totally overlooks the primary goal. Many engineers and managers make a similar mistake with their HVAC energy programs. They focus on a secondary objective—minimizing energy use—while ignoring the primary goal of controlling the indoor environment. This misdirection is encouraged by common accounting practices. If you look at typical building costs through the eyes of a facility manager, the picture might look like *Figure 1.*

These costs are for a single-story, light industrial building in the Southeast. It's an occupant-owned building, and the original land purchase and construction costs were amortized over a 30-year life. The specific costs may not be typical of other buildings, as costs often vary widely depending on the type, location, energy sources, etc. What is of interest is the relative magnitudes and the control that a facility manager has over these costs. The

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facility manager has little or no control over the original construction costs (or rent, if it's a leased facility) or the taxes. Maintenance is an obvious target for cost reductions, but in some facilities it's been cut to the point where its primary function is responding to breakdowns. Energy, however, stands out as the largest single cost that a facility manager can control, and one that is increasing every year. Add in the environmental concerns over sustainability, and it's easy to see why there is so much focus today on reducing energy costs.

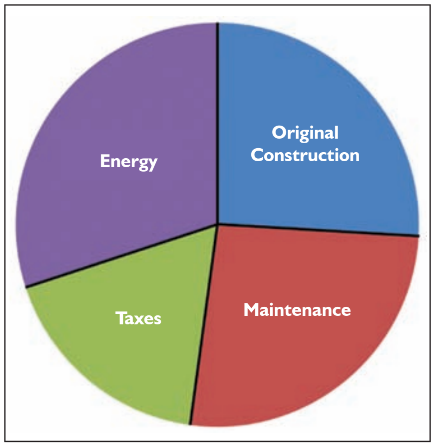

***Figure 1:** Life-cycle building costs breakdown.*

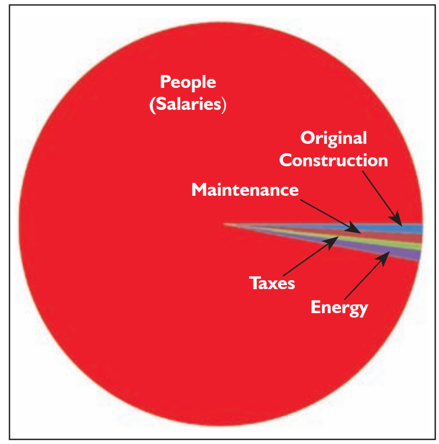

***Figure 2:** Life-cycle building costs breakdown with people (salaries).*

If the facility manager stops with the preceding analysis, he's running the risk of making the same mistake as the White Knight. He's become so focused on the goal of saving energy, worthy though that goal may be, that he may be forgetting the primary reason why the energy consuming systems were installed in the first place. The purpose of these systems, indeed the sole reason the building was constructed, was to provide a comfortable and healthy place for people to work. If we include the cost (salaries) of these people with the other facility costs, the picture looks a little different (*Figure 2*).

Looking at *Figure 2*, it's obvious that the salaries of the people who work in the building dwarf any other building cost. Indeed, it is not unusual for salaries to be more than 100 times larger than any other facility cost. Even if energy costs doubled they would still amount to only a tiny fraction of the total cost. Does this mean that energy costs are unimportant? Not at all, and any facility manager who adopts that attitude is liable to soon be looking for another job! Energy costs still constitute the largest single cost that the facility manager can control. What this analysis indicates is that the facility manager should not become so focused on energy costs that he adversely affects people costs.

How could an energy program affect people costs? In the short term it's not likely to have any influence on the number of people in the facility or on the salaries those people are paid, but energy programs can affect comfort and many studies have shown that comfort affects productivity. Researchers from the University of Helsinki and Lawrence Berkeley National Laboratory reviewed several such studies on the productivity of office workers and summarized the results in *Figure 3*.[1]

Although individual studies do not show identical results, perhaps in part because many factors beside temperature affect human comfort, the trend is that a range of temperatures exists between roughly 72°F and 77°F (22°C and 25°C) at which people are most productive. Their productivity decreases rapidly (the performance decrement increases in *Figure 3*) when the temperatures are above or below this range. This study estimated that a typical office could save $330 per employee per year by maintaining office temperatures within this range.

Case studies from actual workplaces confirm the link between comfort and productivity. When an insurance company in Florida raised the temperature of the room used by their data entry personnel from 68°F to 77°F (20°C to 25°C) their keystroke productivity increased by 150% while the error rate dropped 44%. In financial terms, this amounted to an increase of $2/hour per worker.[2] The Rocky Mountain Institute studied green building projects completed in the 1990s and found that in addition to saving energy, these projects improved comfort within the buildings. They documented retrofit projects that showed productivity increases of up to 13%, together with decreases in absenteeism of up to 25%. New construction projects showed similar improvements. As would be expected from the typical building costs presented previously, they also found that in many buildings the cost savings from a 1% increase in productivity exceeded the total annual energy bill for that facility.[3]

Studies on school classrooms show similar links between comfort and student learning, although perhaps at temperatures somewhat lower than those that are optimal for office workers. (Different activities require different temperatures.) The University of Denmark found that when classroom temperatures were dropped from 76°F to 67°F (24°C to 19°C), math performance improved by 28% and reading performance improved by 24%. Additionally, when they increased the ventilation rate from 10 cfm to 20 cfm (4.7 L/s to 9.4 L/s) per person they measured a 14% improvement in math performance.[4] In a less formally documented research project, students from the Westview High School in Portland, Ore., won an EPA special achievement award for their experiment that showed when students were randomly assigned to rooms at 61°F, 72°F, and 81°F (16°C, 22°C, and 27°C) and then given a short test, students in the 72°F (22°C) room scored 14% better than students in the cold room and 18% better than students in the warm room.[5] Although the 61°F and 81°F (16°C and 27°C) temperatures may seem a bit extreme, the students were asked to stay in the room only long enough to take a 10 minute test. They were not asked to spend hours in the room, trying to keep their minds focused on a lecture or a textbook. With numbers like these, it's not surprising a 2002 UCLA School Facility Report concluded the building condition with the most influence on student learning was air conditioning.[6]

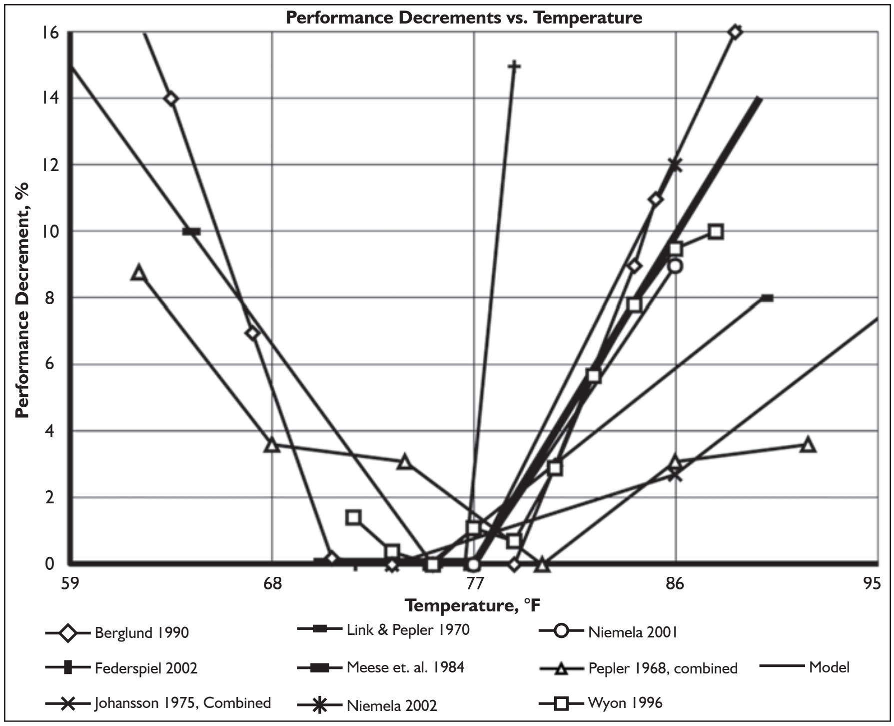

Figure 3: Productivity of office workers according to nine individual studies.[1]

With all the research that's been done on the effects of the indoor environment upon productivity, it's surprising that little research has been done into the follow-on effects of productivity upon the outdoor environment. Basic economic theory would indicate that, assuming the work people are doing is work that needs to be done, if people are less productive, more hours are needed to accomplish the work. This can be achieved by working overtime, hiring more workers, or having the work done at another location (which involves outsourcing or yielding market share to a competitor). None of these options benefits the environment. Working overtime extends the operating hours of HVAC systems, lights, and other energy-consuming systems. Hiring more workers increases the load on the transportation system and eventually requires additional space, which increases energy consumption. Transferring work to another location incurs all the environmental costs of hiring additional workers, and carries the risk that the other location may be less environmentally aware than the current location. Whether an organization is focused on profits, environmental stewardship, or carbon footprints, productivity is important.

An oil embargo caused facility managers in the United States to take drastic steps to cut energy consumption in the 1970s. Air-handling units were placed on duty-cycle schedules where they were turned off for, say, 10 minutes out of every hour regardless of the effect this had upon ventilation and comfort. Heating and cooling setpoints were arbitrarily set at 68°F and 78°F (20°C and 26°C). Phantom-Tubes, essentially capacitors shaped like a fluorescent tube, were used to replace, say, one out of every four lights in an open office environment. They gave off no light, but they didn't use energy either. Some facility managers dubbed this cutback approach to energy conservation "Let 'em sweat in the dark." Ultimately, most of these piecemeal strategies were abandoned. Some proved to be ineffective, some violated environmental health standards, some adversely affected HVAC equipment, and almost all were unpopular. Given what we now know about the effects of comfort on productivity, they were also much more expensive than anyone suspected at the time.

It would be nice to believe that today's energy managers have learned from mistakes made in the 1970s, but sadly that is not always so. A quick review of recent press releases and reports on energy conservation revealed these statements:

- AHUs in buildings with constant volume systems are cycled off for 20 minutes per hour on a rotational basis throughout the building;
- Results of computer simulations show that the 78°F (26°C) thermostat setpoint used for air conditioning is too conservative and wastes energy;
- Even though raising setpoints from 79°F to 82°F (26°C to 28°C) is uncomfortable, and in some cases unhealthy, there is growing social pressure in Japan not to complain;
- In response to the current energy crisis, 68°F (20°C) heating and 78°F (26°C) cooling setpoints have again been imposed on federal buildings; and
- The control strategy aims for 30% to 50% reduction of connected load through duty cycling.

Why are facility managers once again focusing on energy cutbacks that have been proven to make occupants uncomfortable? Perhaps part of the problem is that energy costs are visible and easy to measure, while comfort is difficult to measure. There is an old management adage: "What gets measured gets done." The corollary is equally true: "What doesn't get measured gets ignored." Many facility managers measure energy use but few measure comfort. Like the White Knight, they focus on a secondary goal while ignoring the primary objective.

This does not mean that energy and comfort are mutually exclusive. Many actions can be taken to cut back on *wasted* energy, to make systems more efficient and to turn them off when they're not being used. These measures don't make people uncomfortable and in fact, as the Rocky Mountain Institute study showed, green buildings often provide a *more* comfortable environment and make people *more* productive. Unfortunately, there are also some cutback schemes that do make people uncomfortable, and if comfort is not being measured a facility manager may not be aware that he's making people uncomfortable. Uncomfortable people are less productive, and in addition to being expensive this may ultimately result in more energy use and more environmental degradation.

One of the reasons why comfort is seldom measured is that it's difficult to measure. Comfort is, to some extent, subjective, and there are many factors which influence an individual's perception of comfort. The *ASHRAE Handbook—Fundamentals* devotes an entire chapter to thermal comfort, taking into account factors such as temperature, humidity, air movements, activity, clothing, etc. (Interestingly, the *Handbook* also shows that perceptions of comfort do not depend upon the native climate, culture, or population of the groups being studied. As a group, all human beings essentially find the same conditions to be comfortable or uncomfortable.) With so many factors affecting comfort, many of which are outside a facility manager's control, it's tempting to abandon the idea of measuring comfort. Fortunately, it is possible to measure factors that have a significant impact on comfort and come up with an index which, if not perfect, is certainly much better than no measurement at all.

Not surprisingly, the factor that is most influential in determining thermal comfort is temperature. Building automation systems have been measuring temperature for years and using it to control HVAC equipment, but they haven't processed these temperature measurements into anything that gave a quantitative indication of comfort. Some systems compare the temperature to the setpoint and provide color-coded floor plans that indicate how close to setpoint the temperatures are in various parts of the building. In essence, these colors provide an instant visual summary of comfort conditions within the building. These aren't quantitative, though, and don't provide a measurement that can be compared to the energy used over a billing period, so a facility manager can't point to them and say "this is what we got in return for the energy we used."

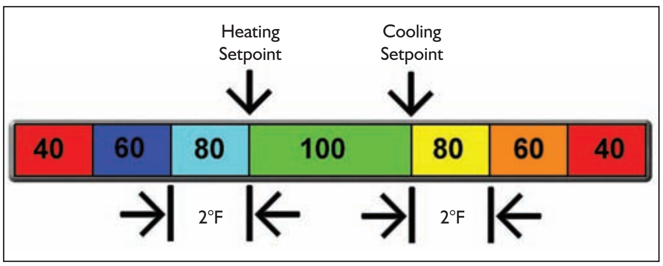

Figure 4: United Environmental Services' environmental index.

United Environmental Services (UES) in Texas recognized the need for a quantitative measurement of comfort. They installed building automation systems that included color coded floorplans, and they realized that all that was needed was to assign a point value to the colors. If the temperature was between the heating and cooling setpoints, the system was providing optimal comfort so they assigned a point value of 100 to this band. Temperatures outside of this band were divided into user adjustable color bands, typically spanning a 2°F range, and assigned lower comfort values (*Figure 4*).

By assigning numbers to the color bands, UES created a simple, elegant way to quantify comfort. Every room in a facility had a comfort number that could be averaged over a day, a week, or any other time period, and the numbers could be "rolled up" to provide comfort indices for floors, wings, or entire buildings. The fact that the numbers were arbitrary didn't matter, because their purpose was to provide a basis of comparison: one building compared to another, last month compared to this month, before and after renovation work was done, etc. Basing the numbers upon deviation from setpoint worked as long as the setpoints were selected to provide comfortable conditions in the rooms. This actually provided a means to compensate for some of the factors that weren't being measured, such as radiation gains or losses through windows, activity within the room, clothing worn by the occupants of the room, etc. If the setpoints were selected to take these factors into account, or if the occupants were allowed to adjust the setpoints themselves, the color bands gave a reasonable indication of the comfort conditions. (The index would obviously not be as accurate if the setpoints were dictated by an arbitrary policy.) When they presented this concept to facility managers, the primary concern was that it was called a comfort index, and some managers didn't want to publicly admit that they were controlling for comfort. UES changed the name to "environmental index" and it was warmly received.

The simple temperature-based index shown in *Figure 4* works quite well in rooms where only temperature is being measured, but it can be improved upon if humidity or CO_2 sensors are present. An exact calculation of comfort requires measurement of many more factors than just temperature and humidity, but ANSI/ASHRAE Standard 55-2004, *Thermal Environmental Conditions for Human Occupancy*, provides equations and graphs that can be used as a starting point. The ASHRAE standard does not, however, provide equations for assigning a numerical index, only indications of what conditions people tend to regard as being comfortable. This could be a fertile area for future research. In the absence of this research numerical values assigned to comfort are somewhat arbitrary, but they can still be useful for comparing one facility to another or for looking at the performance of a building before and after changes have been made to the HVAC systems. A reasonable indication of comfort, even if it's not perfect, is better than having no indicator at all. *Figure 5* shows how humidity can be added to the temperature-only comfort scale shown in *Figure 4.* A similar table can be constructed for CO_2, with the difference that the comfort index would only degrade at high levels of CO_2, not at low levels. (CO_2 does not directly affect comfort, but it's an indication of how well ventilated a room is and ventilation does affect comfort.) Similarly, for zones that have both humidity and CO_2 sensors, a combined temperature + humidity + CO_2 comfort index would be applicable.

Whatever combination of temperature, humidity, and CO_2 you use to determine comfort, it's important to express it as a single index that can be tracked, averaged, and analyzed as easily as energy consumption. Although the individual readings are important for troubleshooting and correcting problems, a single index is needed to give it visibility comparable to energy consumption in building summary reports and. The building dashboard graphic in *Figure 6* is one example where this has been done.

One of the advantages of the indices described previously is that they make it simple to combine the readings of multiple zones into a building index. Ideally, every room in a building would have a temperature sensor, a humidity sensor, a CO_2 sensor, and sensors for every other factor that can affect occupant comfort. That is not the case in most buildings. If a room has only a temperature sensor, temperatures between the heating and cooling setpoints would be assigned a value of 100. If the room also had a humidity sensor, the environmental index would be 100 if the temperature was between the setpoints and the humidity was between 40% and 60%. These rooms could be averaged together as part of a building environmental index because they are both being measured on a 100 point scale. The index may not be perfect, but it's useful and in many facilities it can be implemented now, using an existing building automation system, without requiring major expenditures.

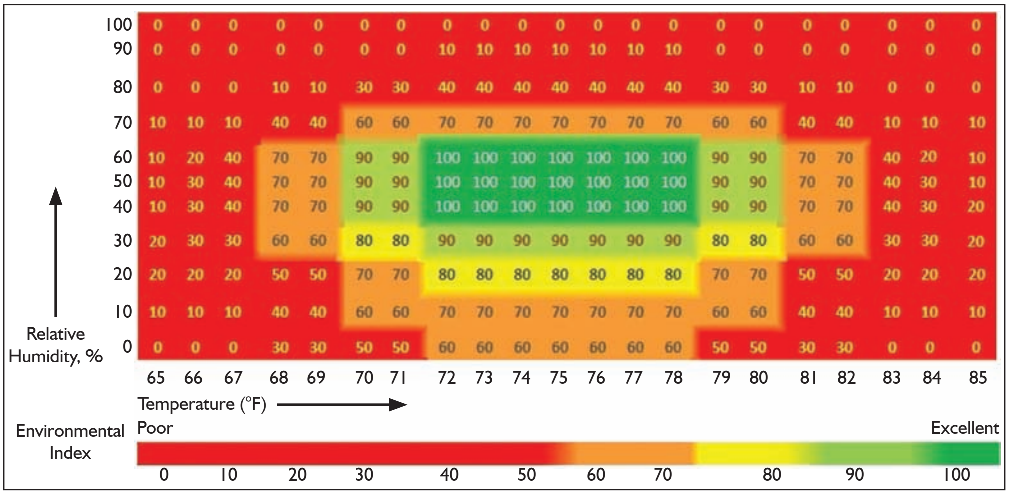

Figure 5: Environmental (comfort) index for temperature and humidity.

How can an environmental index help a facility manager? It can help identify buildings or sections of a building where the HVAC system is not performing correctly, and it can also be used as a benchmark to make certain performance does not degrade when a system is being modified. A good example of the first situation is provided by the Crosby Integrated School District (ISD) near Houston, Texas. This district consists of six schools serving about 4,500 students. In May 2006 UES installed an energy reporting system which included environmental indices in the Crosby ISD. Energy figures were normalized on a kWh/ft^2 (kWh/m^2) occupied hour basis to make it easier to compare schools with many after-hours programs to those with a shorter school day. The energy figures were then compared to the school with the lowest energy use and expressed as a consumption index:

$$\text{Consumption Index} = \frac{\left[\text{Most Efficient School}\ \frac{\text{kWh}}{\text{ft}^2\cdot\text{h}}\right]}{\left[\text{This School}\ \frac{\text{kWh}}{\text{ft}^2\cdot\text{h}}\right]} \times 100 \qquad (1)$$

This made it easy to compare schools, and also made it easy to compare the energy performance to the environmental index since both were on a 100 point scale with 100 indicating the best performance (*Table 1*).

Table 1 makes it easy to see at a glance which schools are doing best from an energy consumption index and which are doing best at providing comfortable environmental conditions. Although Crosby would implement a comprehensive energy improvement program at all schools, an obvious priority from *Table 1* was the Crosby Middle School. This school had the second poorest energy consumption index and the poorest environmental index. Further investigation showed problems with the air distribution. Rebalancing the system fixed these problems, reducing energy costs by $2,500/month while bringing the environmental index up to 95.8. The school district took a similar approach to other schools, using the energy index and the environmental index to help find low or no-cost, tune-up type improvements. In the six-month period from May to October 2006 they cut their energy use by 1.6 million kWh, saving $131,000 (which gave a four-month payback period) while improving the overall environmental index by 11 points.[7]

Figure 6: Building dashboard graphic showing energy and comfort.

The experience of the Boeing Bay Area Boulevard building in Houston, Texas, shows how this approach can work on a larger scale. This 400,000 ft^2 (37 161 m^2) facility was built in 1985 and provides the work environment for more than 1,400 employees. In 2006 the building underwent a major control retrofit that included replacing pneumatic controls with DDC controllers, installing enthalpy wheel energy recovery units, implementing demand controlled ventilation, incorporating VAV static pressure reset, and making many other system improvements. In the first three quarters of 2007 (January through August), it saved 1.4 million kWh compared to the same period in 2006, which reduced its electric bill by $253,521. This amounts to a greenhouse gas reduction of 915 metric tons of carbon dioxide equivalent.* Boeing is pursuing ENERGY STAR® certification for this building, and preliminary data indicates the ENERGY STAR rating rose from 46 to 76 as a result of this work. Boeing also installed an environmental index monitoring system as part of the DDC upgrade, and although they had no comparable data from the pneumatic system they were able to monitor the environmental index from December 2006 on. This data showed the environmental index improved as they completed the controls retrofit and continued to make other changes to the building. Their environmental index for December 2007 was 97.6 compared to 93.6 in December 2006.

A detailed analysis of the energy calculations, weather compensations, and other accounting procedures is outside the scope of this article. Many well-documented reports show how actions such as improving the efficiency of HVAC equipment, getting systems to run the way they were designed to run, implementing optimal start routines, and turning off equipment when it's not needed can reduce energy use without cutting back on comfort. Sometimes, as in the examples given earlier, they can even improve comfort. On the other hand, actions such as reducing outside air ventilation, changing setpoints, and raising supply air setpoints potentially can affect comfort. This doesn't mean they should never be implemented, but it does mean you should keep a close watch on the comfort conditions inside the building when you make these changes. If you're not measuring comfort, you're not managing it and you could end up with a system that saves a few energy pennies while hemorrhaging productivity dollars. Like Alice's White Knight, you could make a lunchbox that's very effective at keeping the rain *out* but not very good at keeping the lunch *in*.

Facility	Consumption Index	Environmental Index
Barrett Primary	95.1	87.3
Crosby High	100.0	88.2
Crosby Kindergarten	81.1	94.8
Crosby Middle	76.5	87.2
Drew Intermediate	74.9	91.2
Newport Elementary	99.2	92.8
Operations Center	100.0	94.0

Table 1: Crosby ISD energy and comfort indices.

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*CO_2 equivalent was calculated using the Power Profiler at www.epa.gov/cleanenergy/energy-and-you/how-clean.html.

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