Cost Effective HVAC
Managing Energy <u>and</u> Performance

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ABSTRACT

"What gets measured gets done" is a well-known management axiom. When it comes to commercial HVAC systems, countless studies have shown that employees are happier and more productive in a comfortable working environment. A quick look at the budget of almost any commercial building will also show that employee salaries far exceed energy costs. Nevertheless, when it comes to managing HVAC, the vast majority of organizations focus on energy costs and pay only minimal attention to the indoor environment. Why? Because there are no qualitative measurements or performance indices for the indoor environment. Educational institutions can be similarly myopic. Although students are not being paid a salary, educating students is the sole reason a school exists. In effect, the entire school budget can be considered the "cost" of these students. Numerous studies have shown a direct relationship between learning and environmental conditions, yet many schools focus on energy costs while making no attempt to measure the performance of their HVAC systems.

This paper will summarize some of the research which has documented the effects of the indoor environment upon performance. It will then show how a simple temperature vs setpoint index can provide an effective measure of performance in existing facilities, without requiring any additional instrumentation. The presentation will also include case study results that show how HVAC management programs can benefit from utilizing this performance metric as well as traditional energy measurements.

INTRODUCTION

There are many ways to analyze energy programs, but one key question to keep in mind is "Is the energy being used in a cost effective manner?" Another way to phrase this is "Are we getting the best possible return for our energy investment?" Reducing energy use is a very worthwhile goal, but if you're not accomplishing your mission then all the energy you do use is essentially wasted.

When it comes to analyzing energy use in a building, it's easy to see why there's so much interest in energy conservation. Energy is a big portion of any facility manager's budget. How big depends very much on the type of facility you're looking at, but Figure 1 shows typical numbers for a small office building near Atlanta Georgia:

Typical Life Cycle Building Costs

Category	($/SF/Yr)
Original Construction	$2.22
Maintenance	$2.24
Taxes	$1.52
Energy	$2.57

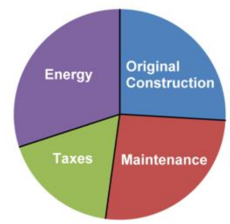

Figure 1: Life Cycle Costs

From Figure 1 it's easy to see that the energy cost is the largest single item in the annual facility budget, and if you amortize the original building construction over a 30 year life the cost of the energy used within the building easily exceeds the cost to put up the building in the first place. In fact, energy is the largest single factor in this "traditional" way of looking at building costs. Is the energy being used in a cost effective manner? That depends on whether or not it's contributing to the mission of the building. For an office building, the mission is to provide a place for people to work, and if you include the salaries of the people who work in a building the picture looks a little different: (Figure 2)

Typical Life Cycle Building Costs

Category	($/SF/Yr)
Original Construction	$2.22
Maintenance	$2.24
Taxes	$1.52
Energy	$2.57
People (salaries)	$284.11

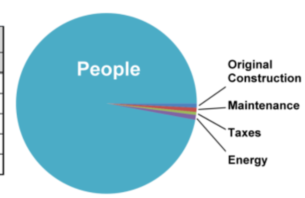

Figure 2: Life Cycle Cost Including People

Figure 2 makes it clear that what we traditionally consider to be building costs are dwarfed by the salaries of the people who work inside the building. Thus, when evaluating potential energy programs it is important not to implement any change that makes the people who work in the building less productive, as the cost in lost productivity could easily outweigh the energy savings.

PRODUCTIVITY IMPACT

Can energy programs affect productivity? If they affect the room temperature or other aspects of the indoor air quality, they can have considerable impact on productivity. This is borne out by multiple studies. In 2004 Cornell University did a study of the effects of indoor air temperature on keyboard data entry for a large insurance company. [1] For one test, they raised the indoor air temperature from 68 °F to 77 °F and found the data entry rate went up by 150% while the errors dropped 44%. This amounted to a productivity increase of $2.00/hr per worker. A graph of their findings is shown in Figure 3.

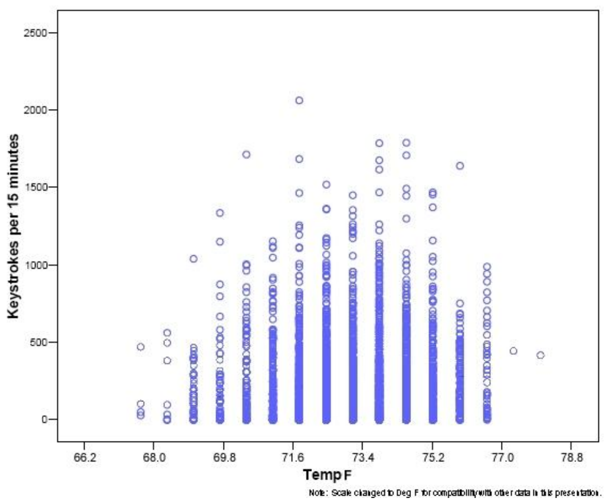

Figure 3: Cornell Keyboard Entry Results

Figure 3 shows that the productivity actually peaked at a temperature lower than 77 °F, and the best productivity was achieved around 74 and 75 °F. This is consistent with other research. In 2004 the Helsinki University of Technology summarized the results of multiple studies into the effect of temperature on the productivity of office workers. [2] They found productivity peaked and complaints minimized if the temperature was kept between 72 and 77 °F. (Figure 4)

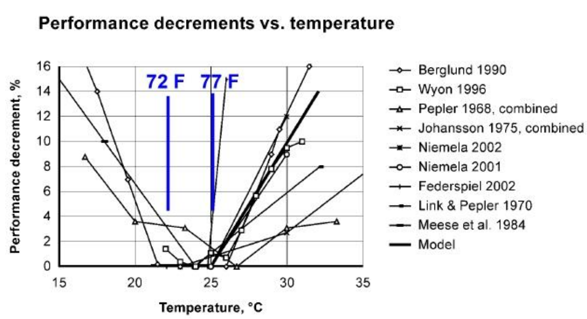

Figure 4: Helsinki University Summary

Similar studies have been done on classroom performance with similar results, although the optimum classroom temperatures may be a little cooler than the optimum office temperatures. A 2005 study at the University of Denmark showed that when classroom temperatures were lowered from 76 °F to 68 °F, math performance increased 28% while reading speed increased 24%. [3] When the ventilation was increased enough to drop the CO_2 concentration from 1175 ppm to 840 ppm math performance increased by 14%. A 2002 UCLA School Facility Report came to the conclusion that the building condition with the most influence on student learning was air conditioning. [4] And in 2005 the students of Portland High School conducted their own experiment to determine the effects of room temperature on student performance by randomly assigning students to rooms at 61 °F, 72 °F, and 81 °F. [5] While these temperatures may seem extreme, the students were only asked to stay in these rooms long enough to take a 10 minute test. They found that even with such a short exposure, the students in the 72 °F room scored 14% higher than the students in the cold room and 18% higher than the students in the warm room. (Fig 5)

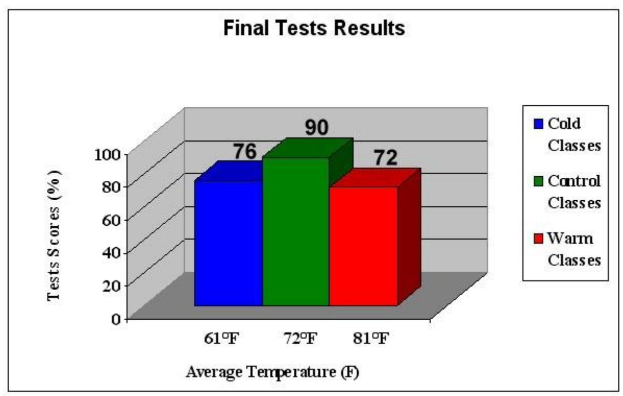

Figure 5: Portland High School Experiment

MEASURING COMFORT

Since thermal comfort has such a strong impact on productivity and the cost of employee salaries far outweighs other building costs, you would think that facility managers would make comfort a top priority. Surprisingly, this is often not the case. Thermal comfort may be given lip service in mission statements and other documents prepared for public consumption, but it's conspicuously absent from goals, priorities, and performance indices. Comfort issues are handled on a case by case basis when occupants complain, and even then they may be ignored if correcting them would require a change to the organization's energy policy. In part this reflects accounting practices. Employee salaries are usually in an entirely separate accounting code from facility costs, and except for the salaries of the facility staff the facility manager isn't even aware of them. In essence he's focused on the costs shown in Figure 1, not Figure 2.

Another reason for this disconnect is cultural. Thermal comfort, particularly air conditioning, is often viewed as a luxury, and a frivolous luxury at that. Many senior managers grew up in homes, schools, and workplaces that didn't have air conditioning and their attitude is that workers can "suck it up" and learn to live with warmer setpoints in the summer and cooler setpoints in the winter. Unfortunately, the research on productivity indicates that while they may learn to "suck it up" and not complain, their productivity will suffer. As the Cornell research showed, when an office worker's fingers get cold their work output drops and their errors increase.

There is also a technological reason why comfort is often ignored and that's because it's difficult to measure. Common sense tells us that thermal comfort is a subjective concept, and this is supported by research. The ASHRAE Fundamentals handbook devotes an entire chapter to thermal comfort, taking into account factors such as temperature, humidity, air movements, activity, clothing, etc. (Interestingly, they found that perceptions of comfort did 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 it would seem to be impossible to develop a "comfort sensor" that would give a facility manager a simple measurement of comfort that could be compared to the energy consumption measurements he gets from utility meters. Thus it's no surprise that the manager follows the axiom that "what gets measured gets done" and its unspoken corollary "what doesn't get measured gets ignored."

Fortunately, there are ways to get a reasonable indication of comfort without measuring the dozens of factors ASHRAE considers. The studies on productivity would seem to indicate temperature is the single most important factor in determining thermal comfort, with humidity and ventilation (as indicated by CO2 levels) playing a secondary role. Within a building, people in any single zone are often performing the same activity, wearing comparable clothing, and experiencing similar air movements, which minimizes the impact of these factors. Furthermore, as Figure 4 shows (and as other studies on comfort confirm) there is a range of temperature values within which people will be most productive and most comfortable. The challenge therefore is not to develop an exact method of measuring thermal comfort so that the building may be maintained at an optimal level, but rather to establish the boundaries of the comfort zone and keep the building within those boundaries. Furthermore, if the activity, clothing, etc. is relatively constant within each building zone, then the comfort boundaries are primarily determined by temperature, with humidity and CO2 levels playing a subsidiary role. This simplifies the problem to something that can easily be handled by building automation systems: monitor the temperature, humidity, and CO2 levels within the building and provide an index to show how well the system is performing in terms of staying within the comfort boundaries. If the building does not already have humidity and CO2 sensors, then a simple temperature measurement will still provide a reasonably accurate comfort index.

Pioneering work on the idea of developing a comfort index has been done by Bill Gnerre and Kevin Fuller of Interval Data Systems. [6] They sifted through ASHRAE research relating comfort to humidity and condensed it into temperature vs humidity tables for different work activities, clothing levels, etc. An example is shown in Figure 6:

RH	Temperature									
0%	65.00	69.40	73.80	76.00	78.00	80.00	82.00	83.60	86.80	90.00
10%	64.50	69.10	73.70	76.00	78.00	80.00	82.00	83.50	86.50	89.50
20%	64.00	68.80	73.60	76.00	78.00	80.00	82.00	83.40	86.20	89.00
30%	63.50	68.50	73.50	**76.00**	78.00	80.00	**82.00**	83.30	85.90	88.50
40%	63.00	67.93	72.87	75.33	77.33	79.33	81.33	82.67	85.33	88.00
50%	62.50	67.37	72.23	74.67	76.67	78.67	80.67	82.03	84.77	87.50
60%	62.00	66.80	71.60	**74.00**	75.33	76.67	**78.00**	79.80	83.40	87.00
70%	61.50	66.50	71.50	74.00	75.33	76.67	78.00	79.70	83.10	86.50
80%	61.00	66.20	71.40	74.00	75.33	76.67	78.00	79.60	82.80	86.00
90%	60.50	65.90	71.30	74.00	75.33	76.67	78.00	79.50	82.50	85.50
100%	60.00	65.60	71.20	74.00	75.33	76.67	78.00	79.40	82.20	85.00

Figure 6: Gnerre & Fuller Temperature vs Humidity

The blue square in the center of this table represents conditions that meet the ASHRAE criteria for thermal comfort.

To make this table easier to use as a management tool, they then converted the ASHRAE numbers to a thermal comfort index.

RH	Temperature									
0%	3	5	6	6	6	5	5	5	4	3
10%	3	5	6	6	6	6	6	5	4	3
20%	3	6	8	6	7	7	7	7	4	2
30%	3	6	9	**10**	**9**	**8**	**8**	7	2	1
40%	3	6	9	**10**	**9**	**9**	**8**	7	2	1
50%	3	6	9	**10**	**9**	**9**	**8**	7	2	1
60%	3	6	9	**10**	**9**	**8**	**8**	7	2	1
70%	2	5	5	5	4	4	4	3	2	1
80%	2	3	4	4	4	2	2	2	2	1
90%	1	2	1	1	1	1	1	1	1	1
100%	1	1	1	1	1	1	1	1	1	1

Figure 7: Gnerre & Fuller Comfort Index

By programming Tables 7 into a Building Automation System, a facility manager can easily generate a comfort index that will provide a numeric "score" of how well an HVAC system is performing. This number can then be given the same visibility as traditional energy indices (Btu/hr-ft^2, \$/ ft^2, etc.) so the manager can make certain he is meeting the needs of the building occupants while using the least amount of energy possible.

The single Gnerre & Fuller table shown here works well for many traditional office buildings, but it there is no "one size fits all" comfort index for all situations. The data given earlier in this paper shows that the optimum temperature for classrooms may be lower than that for offices, and physical activities in manufacturing areas, gymnasiums, and other special purpose areas may also require different temperature ranges. The table in Figure 7 can easily be adjusted to suit other conditions.

Although a strict implementation of Figure 7 would require humidity sensors in every zone, many facilities do not have or require these sensors. Cost, calibration requirements, and concerns over long term accuracy [7] make many engineers reluctant to install humidity sensors in rooms that do not have a critical need for humidity control. Many facilities have implemented the Gnerre & Fuller approach using return air sensors to give an indication of the average humidity level in the rooms served by a particular air handler, or have assumed a humidity level to provide a thermal comfort index that is determined solely by temperature. While perhaps not as accurate as a temperature + humidity index, this approach certainly gives a usable measurement of thermal comfort and is much better than having no index at all.

The table shown in Figure 7 contains no provision for adjusting the comfort index based upon CO2 levels. While CO2 levels do not usually affect comfort directly, they are frequently used as a measure of the amount of ventilation being provided and research has shown a direct link between ventilation and productivity. Furthermore, increased emphasis on providing adequate ventilation for health reasons make this a key variable to monitor in any measurement of HVAC performance. Because ventilation is so important, Gnerre and Fuller chose to create a separate ventilation index based upon the requirements of ASHRAE Standard 62. Whether ventilation is considered part of a comfort index or is given its own index, the bottom line is that facility managers need a measurement that will let them see at a glance whether or not they are maintaining comfortable and healthful conditions within their buildings. The goal of an energy program should be to use the least amount of energy possible while still maintaining these conditions.

Recently, engineers at United Environmental Services (UES) in Pasadena, Texas developed a similar environmental index that provides flexibility to handle different activities, humidity, and CO2 sensors. [8] While not as "fine grained" as the Gnerre & Fuller approach, it was easily implemented with a customer's existing sensors and building management software. Thermal comfort was measured based upon deviation from the heating or cooling setpoint:

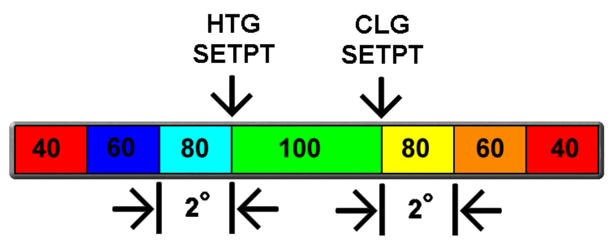

Figure 8: UES Thermal Comfort Index

For this scale to work, the cooling and heating setpoints must be set at the upper and lower limits for thermal comfort. For a typical office building, this might be 72 °F and 77 °F per the Helsinki study. For a classroom environment, it might be 68 °F and 72 °F per the University of Denmark study. Other temperature ranges could easily be chosen to match conditions which occupants find comfortable, but it is important that the limits be based upon thermal comfort. (In some situations it may even make sense to take the heretical step of allowing occupants to adjust the setpoint themselves!) While this index provides the flexibility needed to accommodate different comfort levels, if the setpoints are based upon a mandated energy policy or other arbitrary criteria the system will falsely report that the room is "comfortable" when in fact it may not be providing a productive working or learning environment.

Humidity and CO2 were essentially treated as "pass/fail" criteria for the UES Environmental Index. If a zone had no humidity or CO2 sensors, then the Environmental Index was determined by the thermal comfort index shown above. If humidity and/or CO2 sensors were present, then their index was averaged with the thermal index to provide an overall Environmental Index. A humidity reading between the high and low setpoints yielded an index of "100" to be averaged with the temperature index. A humidity reading outside the alarm points contributed "0" to the Environmental Index. The CO2 index behaved similarly, except that it had a high limit only. CO2 levels below this limit contributed 100 to the average index, and levels above the limit contributed 0. This scheme made it easy to compute an Environmental Index for a group of rooms or an entire building by averaging the indices for all the rooms, even if some rooms had humidity and CO2 sensors while others did not. These instantaneous readings were then integrated over time to give daily, weekly, and monthly summaries of how well the HVAC system was performing.

Is the Gnerre & Fuller Comfort Index or the UES Environmental Index a perfect means of measuring the performance of an HVAC system? No, but they do provide a good indication of how well the system is performing and either index is far better than the standard practice of providing no objective measurement of the environment inside a building. If the environment is not being measured, it will get ignored and management decisions will be skewed to favor factors which are being measured such as energy cost.

CASE STUDY

How can an energy management program utilize both energy and environmental indices? One example is the Crosby Independent School District (ISD) in the Houston TX metropolitan area. This school district includes six school buildings plus administrative offices and serves nearly 4,500 students. The UES Environmental Index was programmed into an existing building automation system, providing information that was "rolled up" into an overall environmental index for each building. Similarly, energy data was normalized by computing the KWH/ ft^2-Occupied Hour consumption for each school. The schools were located close enough to each other so they all experienced the same weather and the data did not have to be normalized for heating or cooling degree days. Normalizing the data based on hours of occupancy did prove to be a significant step toward an "apples to apples" comparison, as it prevented schools with extensive extra-curricular programs from being penalized for this after-hours consumption when compared to schools with few after hours programs. As a final refinement to ease comparison, a "consumption index" was calculated by assigning a grade of 100 to the school with the lowest KWH/ ft^2-HR usage and dividing that usage by the usage of every other school to determine the consumption index for each school. This produced an index where 100 represented the best score, and lower numbers indicated room for improvement. This index could also be easily compared to the Environmental Index, which similarly used 100 to indicate the best possible performance. A seven month comparison of school performance is shown in Figure 9:

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 Elem	99.2	92.8
Operations Center	100.0	94.0

Figure 9: Crosby ISD Performance Indices

Using the data as presented in Figure 9 it's easy to see at a glance how each school is doing both in terms of saving energy and providing a good learning environment for the students. The Operations Center, for example, has the best energy consumption index of any building and the second best Environmental Index. That system is definitely providing "cost effective HVAC." Crosby Middle School, on the other hand, has the second worst Consumption Index and the worst Environmental Index. That school would be an obvious choice for more in-depth analysis, as the HVAC system is burning up a lot of energy and still not providing a good learning environment. School officials used these indices to help focus their building maintenance and upgrade efforts. Some examples of projects they undertook as a result of this analysis are as follows:

Crosby Middle School: Further investigations pinpointed an HVAC system that was badly out of balance, with some classrooms being starved for air while others were freezing due to too much air. An air balancing firm was hired to re-balance the system and the utility costs dropped $5,000 in two months. Overall the energy savings had a simple payback period of 2.1 years and the Environmental Index improved from 89.2 to 95.8. (Note: the time periods for the projects being described do not coincide with the time period for Figure 9, so the index numbers will be different.)

Crosby High School: Initially, neither the Consumption Index nor the Environmental Index was as high as is shown in Figure 9. Investigations showed a multitude of minor problems such as unnecessary after hours schedules, underutilized optimum start routines, and locked equipment. A "software recommissioning" project was performed which cut utility costs by $22,000 in 3 months. It also raised the Environmental Index from 82.9 to 96.9.

Crosby Kindergarten: The Consumption Index for this school was the third worst, but it had the highest Environmental Index of any school. Nevertheless, there were many "too hot" and "too cold" complaints from students and teachers. An investigation showed the temperature sensors were badly out of calibration. Calibrating the sensors saved $1900 in energy costs over 2 months, which meant the project paid for itself in only 3 months. Not surprisingly, the Environmental Index remained virtually unchanged as the system thought it was providing comfortable temperatures to begin with. This was a classic case of the "garbage in = garbage out" computer axiom and an example of why facility managers need to listen to occupants and not just focus on the numbers.

Overall, by using the Consumption Index and Environmental Index to help guide their efforts and by undertaking a number of small projects like those described above, the Crosby ISD cut their energy use by 1.6 Million KWH during the 6 month period from May through October 2006. This saved $131,000 in utility costs, yielding an overall payback period of less than 4 months. Just as important, the district improved the overall Environmental Index in their schools by 11 points.

CONCLUSION

Traditional energy management programs focus on the cost of running HVAC systems but provide no way of measuring how effective these systems are at maintaining a productive working environment. This can cause facility management programs to place too much focus on programs that reduce costs while ignoring performance issues, or worse yet to implement programs that actually decrease performance in favor of short term cost savings. Since research shows a direct link between the quality of the indoor environment and the productivity of the people who work in a building, and since personnel costs typically dwarf energy costs, this lack of balance can be counterproductive in the long run.

Simple methods of measuring HVAC performance like the Gnerre & Fuller Comfort Index or the UES Environmental Index can provide facility managers with an effective decision making tool. Facility programs that analyze both cost and performance of HVAC systems, like those at the Crosby Independent School District, can achieve impressive cost savings while improving the indoor environment.

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