White Paper

Environmental Satisfaction, Personal Control and the Positive Correlation to Increased Productivity

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EXECUTIVE SUMMARY

Workplace Productivity, Environmental Comfort and Individual Control: A Direct Relationship

This paper documents the positive relationship between environmental comfort, individual control and workplace productivity.

- In the past 15 years, dozens of scientific studies on productivity in the workplace[1] prove that individuals respond very differently to their own environment.
- Widespread dissatisfaction with indoor environmental conditions, as high as 60% in some cases,[2] has been shown in study after study done in North America and Europe.
- Managers everywhere are acknowledging that increased environmental satisfaction and individual control help increase worker productivity.[3]
- Advances in indoor environmental technology and products can now provide employees with control over their own comfort.[4]

Several important facts prove the relationship.

- One important study of 6,000 workers in 70 U.S. organizations during a five-year period proved that when numerous environmental factors are taken together the outcome can produce productivity gains as much as 15% of salary for managers and 17% for clerical staff.[5]
- By giving individuals control of their environment, rather than trying to achieve an “acceptable” temperature for a group of employees, one researcher predicts that group performance can improve by 2.7% to 8.6%.[6]
- Improvement to the workplace environment is a highly cost-effective way of enhancing employee satisfaction, productivity and the company bottom line. According to two researchers, the ratio of building operation costs to average salary costs is 1:13.[7] A

company would have to eliminate more than a month's worth of building operating costs to pay for just two days of lost worker productivity.[8] A little investment in building operations will have a large return on investment in worker productivity with short payback periods.

- Even a small increase in productivity can mean thousands of dollars in savings. In one example, a Midwest insurance company realized a 2.8% increase in productivity just by giving employees environmentally responsive workstations, and thus control over their own comfort. With a $13-million annual salary base, the savings amounted to $260,000, and return on investment was achieved in less than two years![9]

Personal Environments® environmentally responsive workstations provide individual adjustment of comfort in one's own environment. Complete control is at employees' fingertips in their individual workstations over air flow and filtration, temperature, background noise masking and lighting. All these controls are integrated with a sensor that turns everything off when the workstation is unoccupied for more than 10 to 15 minutes.

THE POSITIVE LINK BETWEEN ENVIRONMENTAL SATISFACTION, CONTROL, PRODUCTIVITY AND THE BOTTOM LINE

The time has come to raise expectations for building performance and aim for 100 percent satisfaction with the indoor environment. For decades, industry standard for buildings has been set to satisfy only four-out-of-five occupants at any one time at a fixed temperature of 22° C (72° F).

"We're still designing buildings for the 'driver' not all the occupants," said Vivian Loftness, professor and head of the Department of Architecture at Carnegie Mellon University, Pittsburgh, in speaking at the first annual National Summit for Building Performance.[10] She was comparing the buildings industry to the auto industry, which has in recent years designed cars for all the occupants.

When office workers *are* satisfied with their environmental conditions, when they can work in greater comfort and control, they will be more productive. Additionally, the cost of employment per worker will drop, and the cost of facilities operation will decrease. This paper shows strong evidence that a growing body of research supports these conclusions.

When environmental comfort can be linked to increased productivity, the economic implications of office worker satisfaction are clear. In one landmark study of 6,000 office buildings throughout the United States during a five-year period,[11] people costs were shown to outweigh facility costs by a ratio of 13:1 for owner-occupied buildings and 5:1 for leased office space. As Lorsch and Abdou have noted:

- "If the design and operation of the building (a low-cost component) affects the productivity of the office workers (the highest-cost component), a substantial economic leverage effect can be expected through carefully conceived building design and operation. In other words, improving the office environment could be a highly cost-effective strategy if it enhanced the performance and satisfaction of the occupants."[12]

Even a small increase in office worker productivity will make a positive financial impact for an organization. In one study, which will be examined in detail, a Midwest insurance company realized nearly 3% productivity increase just by giving employees control over their own comfort. With a multimillion dollar annual salary base, the increase amounted to a savings of thousands of dollars. Environmental satisfaction provides savings in other ways. For example, it helps retain

tenants and occupants, thereby reducing turnover cost; satisfaction also lowers hundreds of dollars in maintenance costs each time staff has to investigate comfort problems.

Through a review of several major research studies, this paper shows a direct correlation between environmental satisfaction, control and productivity and offers proof that an investment in this area makes prudent economic sense.

Three conditions have converged to make this the time for raising the bar of building performance expectations. First, widespread dissatisfaction with office air quality and comfort, which has a direct effect on productivity, is as high as 60 percent, according to some studies. Second, more and more managers are recognizing the important role that improved office environmental conditions play in increasing productivity and hence increasing revenue. Third, the technology and products are available to provide employees with control over their own comfort.

THE MODERN WORKPLACE AND CURRENT BUILDING PERFORMANCE NORMS

Building performance is an emerging classification which helps describe and measure the relationship of the physical workplace with the goals of organizations within the facility. Facility owners, managers and other executives are becoming increasingly interested in how all aspects of the workplace environment impact goals such as productivity, cost reduction, quality, adapting to change and employee satisfaction.

Several categories of building performance have been studied including white collar productivity, zone conditioning, tenant and occupant retention and factors involving indoor air quality.

White Collar Productivity: Few would argue that life at the office has become busier. There are fewer people spending longer hours doing more work. Yet, numerous studies have shown that there has been no significant gain in white collar productivity in the last 20 years, despite the desktop computer revolution.[13] As an example, manufacturing productivity in the United States rose nearly 5% in 1994, yet overall productivity including white collar workers rose less than 1%.[14] This may be due to the complex and diverse nature of work in offices, unlike work in a manufacturing plant that is efficiently measured. Office can be defined as everything from number of forms processed to ideas generated in a given period.

While it may seem that white collar productivity has not increased, the consequences on productivity if building and office systems failed would be far more drastic today than in the past. For example, a sudden disconnection of a corporate data network or failure of a building's heating and cooling system anytime would not only reduce productivity but have a significantly negative impact on a business's bottom line.

As metrics for measuring white collar productivity are continually being refined, a 1995 White House report[15] suggests that better constructed facilities could increase employee productivity and comfort up to 30% nationwide.

Zone Conditioning: Conventional environmental systems are designed to satisfy the needs of the "average" person. Zones of conditioned space often serve dozens of people. Yet no one is average. People are different. Their needs for thermal conditions, air flow, lighting and acoustic privacy are significantly different and are even different over the course of a day. Individual differences in reactions to environmental conditions can be due to age, sex, personality, metabolism, allergy or hypersensitivity.[16] For example, older employees typically need more light.[17] Women generally prefer warmer temperatures.[18] In addition, because tasks for some

employees require them to be at their desks for much longer periods than others, the impact of these comfort levels variances are not equal.

Hence, the concept of average comfort is antiquated, especially in an era of enormous individual options. A one-temperature-fits-all approach was the only option 100 years ago when central heating was invented. But today, because of technological advances in all fields, consumers are increasingly sophisticated about product and service choices, and building occupants, who are consumers of indoor environmental conditions, are also becoming increasingly aware and demanding of opportunities for individual choice and control.

Tenant and Occupant Retention: Dissatisfaction with environmental comfort is only one of many reasons why individuals choose to leave their place of employment. However, it is a major factor in a company's decision not to renew a lease, as well as being an important relocation consideration. A 1986 tenant survey conducted by the Trane Company revealed that half of all tenants consider comfort an important part of a relocation decision, and discomfort was a major contributor to nonrenewals.[19]

The 1985 BOMA study showed that comfort was the number two complaint after building maintenance. Tenants have an 18% expectation that a major service interruption such as power, phone, HVAC or water will occur in a given year. The real probability, however, is fifty-fifty that these interruptions will occur. There was a greater than 50% probability that a tenant would leave if three interruptions of service occurred.[20]

In reviewing the issue of marketing comfort, a paper delivered at the International Business and Technology Conference in 1990 recognized the key role comfort plays in retaining tenants. "Although the market is not directly driven by comfort issues, decisions to stay or move are influenced by tenant perceptions of comfort. Dissatisfaction contributes to the impulse to leave as does a lack of response to service problems (too warm or too cold), which are primarily caused by environmental systems."[21]

While retention of tenants is important to facilities owners and managers, retaining occupants or employees is important to the organizations that work in the buildings. Other research has assessed the costs of employee turnover. One study determined that on average (in 1991) it cost $6,000 to hire a new employee, which does not include costs of training, which vary with the job.[22] Douglas Phillips found turnover costs for a middle manager to be an average of 1.5 times salary.[23]

Whether tenant or employee, turnover is a costly factor that improvement in indoor environments can help deter.

Indoor Air Quality: Poor air quality within the office workplace can have an enormous economic impact in costs as a result of lost productivity. According to various estimates, approximately one-third of all government and commercial office buildings in the United States may be regarded as "unhealthy."[24] These indoor conditions have a negative effect on the productivity of workers in businesses and organizations that occupy these unhealthy environments. Lost productivity is measured in absences, health costs, quality of work, production costs, employee attitude and downtime. The US Environmental Protection Agency (EPA) is developing a computer model for predicting these costs.

The EPA also reports that 20% to 35% of American office workers are exposed to poor air quality; 80% of workers in Britain suffer from at least one complaint linked to poor office environments; and in Canada 80% of the 3,500 annual complaints investigated by the Alberta Union of Provincial Employees are related to inferior office working conditions.[25] Clearly, poor indoor air quality is a problem.

Equating increases in productivity with improvements in acceptable environments may be challenging, as noted by James Woods of the Virginia Polytechnic Institute.[26] (Later, we will examine studies that have taken on this challenge.) As Woods indicates, it is much easier to show that poor indoor environments have a negative impact on productivity. Occupant dissatisfaction with the indoor environment likewise has a negative impact on work.

THE GROWING DISSATISFACTION WITH OFFICE CONDITIONS

A large percentage of office workers are dissatisfied with the environmental conditions in which they must function. Yet, few facilities or business executives, who often may not hear the complaints directly, are aware of the extent of the discontentment. Managers may often look to the human resources factors and overlook the facility factors when considering ways to positively influence worker productivity. As two authors have pointed out, "managers often try new and improved management techniques when productivity problems are rooted in poorly designed and maintained office space."[27] Dissatisfaction with facilities by occupants are consistently revealed in studies of various types of buildings throughout the world.

The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) defines acceptable indoor air quality as, "Air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction," when temperature is fixed at 22° C (72° F).[28]

The building industry can do better than a one-in-five level of customer dissatisfaction. On-the-job dissatisfaction no matter what causes it dulls the competitive edge of the business operation in a number of ways. People are less motivated and therefore less productive. In the case of comfort, dissatisfied employees place a greater burden on the facilities management staff to correct problems, which interrupts them from their other tasks such as preventative maintenance. Comfort is often expressed in measuring temperature, humidity, air circulation, lighting, acoustics and physical space.

How widespread is dissatisfaction? Research has consistently shown a wide percentage of employees in various office workplaces and job responsibilities are not happy with their environment. Worse yet, this percentage is dynamic, and changes with modifications in the indoor environment. For instance, raising the temperature will cause dissatisfaction in a certain percentage of workers different than if the temperature is lowered. Given this dynamic reality, it could be argued that nearly everyone working indoors has something to complain about at one time or another. A review of several key studies will demonstrate how widespread the problem is.

Taking Research into the Field

Breaking out of the laboratory, researchers from the Center for Environmental Design Research, University of California, Berkeley, conducted a field study on thermal environments and comfort in 10 San Francisco office buildings located in two different Bay-area climates coastal and valley.[29] Physical measurements and occupant responses were assessed from 264 workstations during one week in winter and 221 workstations one week in summer. A total of 304 people in the same number of workstations participated in the study.

Thermal sensation and acceptability were examined by comparing responses from the ASHRAE Thermal Sensation and McIntyre Scales. The first measures actual sensations that people report in response to environmental conditions, while the second focuses on thermal satisfaction by

asking participants to judge whether conditions are acceptable and if they would like to change the conditions.

The study concludes that temperatures for both seasons in the "neutral range" of 20.5 to 24° C (68.9° to 75.2° F) were unacceptable by 15% to 20% of the participants. Further, as many as 40% of the people were dissatisfied in this range in either season when measured on the McIntyre Scale. Additionally, the study concluded that "rated ventilation and temperature were more strongly related to comfort than rated lighting or humidity. The ability to control the environment was also positively correlated to comfort."[30]

DOE Realizes Dissatisfaction

As part of an effort to upgrade and improve the working environments of two buildings at the Department of Energy, employee surveys were conducted to measure levels of satisfaction with a wide range of working conditions.[31] A total of 1,212 responses were tabulated from employees in the Forrestal Building and 704 responses from those in the Germantown Building. More than 55% to 60% of the respondents at Forrestal were dissatisfied or very dissatisfied with factors such as air freshness, air movement and temperature. Germantown respondents were similarly dissatisfied but at 8% to 10% less. About 85% said they have no control over conditions such as air movement, air freshness, heating, cooling, humidity and daylight. More than 30% said they suffer tiredness, eye strain and stress. Employees seated near windows had the fewest health complaints.

A Strong Argument for Individual Control

A study that replicated the ASHRAE-sponsored San Francisco field experiment was conducted in 12 air-conditioned offices in the tropical city of Townsville, Australia.[32] Conducting the study in both the wet and dry seasons, 836 participants provided 1,234 sets of data. Similar to the San Francisco study, 21% (156) of these participants said thermal environment at the thermally neutral temperature of 24.4° C (75.92° F) was unacceptable. Of the 21%, more than half (52%) had measured environmental conditions that were within the ASHRAE standard for neutral range. Conversely, of the subjects who found their environments acceptable, 42% were actually in conditions outside of the ASHRAE standard. Participants were further asked whether they would prefer to be warmer or cooler. Even at the optimum preferred temperature (23.5° C or 74.3° F), 34% to 38% (depending on season) of the subjects preferred either warmer or cooler conditions. These results offer a dynamic argument for a workplace environment that can be individually controlled for a level of comfort as defined by the worker.

A Quick Glance at Other Key Studies

Dissatisfaction with environmental conditions clearly de-motivates employees. A survey of several sources reveals worker dissatisfaction with indoor environments. In quick succession, they include a 1983 study by Merck which showed a 43% dissatisfaction with HVAC and 20% dissatisfaction with lighting;[33] a 1988 study by Public Works Canada that put HVAC at 2.8 and Privacy at 2.3 on a scale of zero to five with zero being the most negative;[34] a 1989 Building Operators and Managers Association study that showed HVAC to be the number-one tenant problem;[35] a 1989 Lou Harris office survey that discovered 28% of employees are not happy with their workspace quality;[36] and a 1992 Social Security Administration study that showed 56% to 89% of these government workers recognize HVAC is a problem.[37]

Conversely, greater satisfaction means fewer maintenance calls. While costs vary, costs may average $75 to process a call and up to $375 in staff time to investigate HVAC problems.[38]

Another important factor causing dissatisfaction in the work place is noise. A recent article in Today's Facility Manager cites a study by the American Society of Interior Designers (ASID) that found noise reduction to be a major concern of office workers, 70% of whom said they would be more productive if their offices were quieter. "It's interesting to note," the article states, "that issues related to noise are more evident and frequently more disruptive in open plan offices than in any other work environment. In fact, as the use of open plan office environments has grown over the past three decades, workers' concerns and complaints about the negative impacts of noise on their work performance have also increased dramatically."[39]

ENVIRONMENTAL SATISFACTION, CONTROL AND INCREASED PRODUCTIVITY

We have examined many of the factors that define comfort or environmental satisfaction. Yet what is productivity?

While it has been gauged in many ways, productivity is primarily a measure of what can be achieved by human beings with the least effort, according to Lorsch and Abdou.[40] Some activities allow straightforward measures to be used, such as the number of error-free forms completed by clerical staff per unit of time. Other activities are more difficult to quantify, such as the quantity and quality of ideas generated by an engineer or an account manager.

While the most obvious measures of performance are usually expressed in terms of speed, accuracy or both of production, measurements of the consequences of performance in terms of fatigue, absenteeism, and the incidence of complaints have also been made (NEMA 1989).[41] According to that document, increased productivity occurs when people:

- Perform tasks more accurately
- Perform faster without loss of accuracy
- Can perform for longer time periods without tiring
- Can learn more effectively
- Are more creative
- Can sustain stress more effectively
- Can work together more harmoniously
- Are more able to cope with unforeseen circumstances
- Feel healthier, and therefore spend more time at work
- Are drawn toward accepting more responsibility
- Respond more positively to requests

Regardless of the measurements used by a business or organization, steps taken to increase productivity must be cost effective. Concentrating on improving the workplace environment can potentially be the most cost-effective expenditures of all for increasing productivity. Facility-related costs are only a fraction of employee-related costs. As the NEMA[41] study states:

- "A 1995 study of annual average building costs showed that rent, utilities and taxes cost building owners between $14.24 and $43.09 per square foot ($ft^2$), depending on the geographic location. Another study indicated an overall average building operating cost of $26.30/$ft^2$. Of this, rent represents the greatest portion ($21), while utilities cost $1.80; taxes $2; and maintenance $1.50.

  "On the other hand, employee costs are much greater. Assuming a salary of $30,000 and a space allotment of 150 ft^2 per person, employees could cost $200/$ft^2$ annually. It easy to see that even a 1% drop in occupant productivity costs considerably more than such building expenses as utilities or maintenance."[42]

The following sample chart (which can be developed into a spreadsheet analysis) demonstrates how productivity loss can affect income:[43]

Productivity Economic Analysis - Cost to Employer		
Building Area (ft^2)		10,000
Number of Employees:		65
Avg. Occupancy Density: (ft^2/per)		154
Building Operating Costs:		
	Rent ($/$ft^2$/yr.)	$21.00
	Utilities ($/$ft^2$/yr.)	$1.80
	Taxes ($/$ft^2$/yr.)	$2.00
	Total ($/$ft^2$/yr.)	$24.80
	Total Annual	$248,000
Salary Costs:		
	Hourly Pay	$11.54
	Benefits (+30%)	$3.46
	Total Hourly	$15.00
	Total Annual (per person)	$30,004
	Total Annual	$1,950,260
	($/$ft^2$/person/yr.)	$195.00
	Ratio of Salary Cost to Bldg. Oper. Cost	8
Productivity loss due to poor thermal comfort, absenteeism, etc. (%)		3*
Lost Productivity Cost:		
	($/$ft^2$/person/yr.)	$5.85
	Total Building	$58,508.00
ROI of HVAC Upgrade Cost		146%
Simple Payback Period (yrs.)		0.68

*The $/$ft^2$/person/yr costs for 1% loss in productivity in this example equals $1.95. for 2% the loss is $3.90; for 4%, $7.80; and for 5%, $9.75 for a total building loss of almost $100,000.

Office worker productivity *is* affected by environmental conditions. Numerous studies show that investing in the indoor environment can be justified on the basis of productivity improvements alone. In order to bridge the gap between research and solutions, the results of numerous studies which correlate comfort and productivity have been organized into four general categories:

- Thermal Comfort
- Lighting
- Lack of Individual Control
- Acoustics

(See table in appendix.)

A Closer Examination of Key Resources

Several of these resources include classic studies and are most important for the present discussion for showing the relationship between environmental satisfaction, control and productivity. These include the BOSTI Study (1984), a survey of The Office of the Environment in

the United Kingdom, a report by David Wyon of the National Institute of Occupational Health, Copenhagen, Denmark and a review of studies by Mao-Lin Chiu of the Department of Architecture at Carnegie Mellon University.

Overview of the BOSTI Study

The Buffalo Organization for Social and Technological Innovation (BOSTI) Study (1984)[44] analyzed 18 basic design factors such as lighting, accessibility and temperature and concluded that a well-planned design is essential for increased productivity. The 18 facets are listed on the chart on the following page. The BOSTI study's most significant effort was to quantify the physical and performance factors by dollar values and provide further implications for office design. The cost benefit analysis proved that the additional investment on building performance can be justified. BOSTI further suggested that productivity depends as much on the environment as on management and equipment, and encourages thinking of the "office as a tool and not just a place to house tools."

The BOSTI study's five-year research program was nationwide, involving some 6,000 workers in about 70 organizations. People were grouped into three major job types: managers, professional and technical workers, and clerical workers. The questionnaire used had people describe their environments and their behavior in them, evaluate their environments, and then rate job satisfaction. Most facets of the environment were found to contribute to people's satisfaction with their environment. About half of the facets contributed to ease of communication and job satisfaction.

	Bottom Line Measures		
Facets of Environment	**Environmental Satisfaction**	**Ease of Communication**	**Job Satisfaction**
Enclosure	*	*	
Layout	*	*	
Furniture	*	*	*
Noise	*	*	*
Flexibility	*	*	*
Participation	*		*
Comfort	*		*
Communication	*		*
Lighting	*		*
Temp/Air Quality	*		*
Floor Area		*	*
Privacy	*	*	
Status	*	*	
Pathfinding	*	*	
Display	*		
Appearance	*		
Occupancy		*	

Windows	Possibly		Possibly

[44]Brill, (BOSTI)

Values were assigned and calculated for the various environmental facets at three job levels: managers (avg. salary $41,500), professional/technical (avg. salary $31,600) and clerical (avg. salary $17,400). (NPV= Net Present Value) The chart below shows the annual dollar value impact of various environmental factors on each job function. Estimated values represent changes in absenteeism and turnover and reflect both the positive impact of improvement and negative impact of facet decline on job performance.

	Managers		**Prof/Tech**		**Clerical**	
Improvement to Facet	**Annual Value**	**NPV 5 Yrs**	**Annual Value**	**NPV 5 Yrs**	**Annual Value**	**NPV 5 Yrs**
Noise	472	1,789	282	1,068	148	560
Temp. Fluctuation	270	1,023	162	613	85	322
Glare	275	1,023	165	625	87	329
Comfort	-	-	234	886	-	-
Relocation Freq.	450	1,705	271	1,026	142	538
Enclosure	3,423	12,971	2,606	9,873	1,438	5,447
Layout	2,491	9,438	1,646	6,236	1,046	3,964

	Managers		**Prof/Tech**		**Clerical**	
Cost of Decline In Facet	**Annual Value**	**NPV 5 Yrs**	**Annual Value**	**NPV 5 Yrs**	**Annual Value**	**NPV 5 Yrs**
Noise	850	3,221	509	1,928	267	1,011
Temp. Fluctuation	692	2,281	361	1,367	189	716
Glare	194	735	116	439	61	231
Comfort	-	-	701	2,656	-	-
Relocation Freq.	471	5,574	880	3,334	461	1,746
Enclosure	2,568	9,729	1,954	7,405	1,079	4,087
Layout	-	-	-	-	-	-

(- indicates does not apply)

Finally, the BOSTI researchers calculated the value of improvements collectively from all facets of the environment on each job:

	Managers		**Prof/Tech**		**Clerical**	
Value of Facets Taken Together	**Annual Value**	**NPV 5 Yrs**	**Annual Value**	**NPV 5 Yrs**	**Annual Value**	**NPV 5 Yrs**
	6,316	23,931	4,650	17,668	3,042	11,526
% of annual salary	15%		15%		17%	

The BOSTI study has examined a comprehensive number of environmental factors that, when taken together, can have a productivity impact of as much as 15% to 17% of salary impact. These percentages represent significant contributions to a business' bottom line.

UK Office of the Environment Survey

The Office of the Environment Survey looked at three variables and the effect of each on productivity: 1) The number of building-related health symptoms experienced by workers; 2) the number of people in a room and job type; 3) personal control over the office environment.[45]

The study's methodology included a questionnaire survey of 4,373 public and private sector employees in 46 UK office buildings of varied age, type, and quality, with a range of ventilation systems. Productivity was subjectively assessed using a 1 to 9 Likert scale analysis with 1 representing the most positive effect and 9 the most negative.

The analysis shows there is a significant linear correlation ($r=0.98$, $p < 0.001$) between the number of building-related symptoms (i.e., dry, itching, or watering eyes; dry throat; lethargy; headache; blocked, stuffy, or runny nose; flu-like illness; difficulty breathing; and chest tightness) and Worker Evaluation of Productivity (WEP). Results indicate that the indoor environment should be improved so as to reduce building-related symptoms to fewer than three (WEP<5).

Symptoms	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Mean WEP	4.42	4.93	5.07	5.28	5.54	5.80	5.94	6.12	6.05	6.52	6.90

The probability that productivity decreases as the number of people in a room increases is significant. ($F=8.77$, $df=4058, 4$, $p<0.001$). This is attributed to a number of factors, including control over lighting, ventilation and temperature, noise and privacy. Using a ResWEP score (the difference between each individual's WEP score and the mean WEP for his/her building), results indicate that office environments should aim for five people or fewer sharing a room unless there is at least a moderate degree of control over the indoor environment.

Number of people in a room	**Mean ResWEP**
1	0.34
2-4	0.09
5-9	-0.08
10-29	-0.17
30+	-0.09

Note: The higher the ResWEP means a more positive effect on productivity.

A significant effect was shown on productivity in terms of respondents control over their own temperature, ventilation and lighting (temperature: $F=16.21$, $df=4358,6$, $p<0.001$; ventilation: $F=8.73$, $df=4357,6$, $p<0.001$; lighting: $F=7.19$, $df=4346,6$, $p<0.001$). In the case of temperature (and to a lesser extent ventilation) there is a marked increase in productivity at the highest level of control.

The analysis confirms that productivity increases with level of control whatever the number of people in the room (the difference is largest between medium and high control). An intermediate number of people is associated with low productivity at low control levels, but associated with high productivity with high levels of control.

Respondents also rated various aspects of their typical office working conditions (i.e., comfort, temperature, ventilation, air quality, humidity, and satisfaction) in both winter and summer using a 1 to 7 Likert scale analysis. Ratings all indicated that productivity was higher when the conditions were better ($F=14.88$, $df=3437, 1$, $p<0.001$).

Implications in this study are that improving personal control over the indoor environment over lighting, openable windows and local temperature improves self-rated productivity.

Providing for Differences Leads to Increased Productivity

There are very large individual differences in the tolerance of suboptimal thermal and air-quality conditions, according to Dr. David Wyon.[46] Productivity is probably reduced more when large numbers of employees work at reduced efficiency than when a few hypersensitive individuals are on sick leave. Commonly occurring thermal conditions, within the 80% thermal comfort zone, can reduce key aspects of human efficiency such as reading, thinking logically and performing arithmetic by 5 to 15%.

In another study, Wyon looked at four types of work.[47] Work requiring concentration decreased 30% in performance when temperatures rose to the sweating threshold (27-30°C) (80.6°F-86°F) vs. 20°C (68°F). Routine office work (typing) decreased 30% at 24°C (75.2°F) vs. 20°C. Work involving manual dexterity decreased a maximum of 20% at a temperature 12°C (21.6°F) below neutrality. In tasks requiring finger speed and sensitivity (rapid keyboard operation, paper sorting, repair and assembly) performance was maximized at 6°C (10.8°F) above neutrality and decreased 50% at 12°C below neutrality.

Targeting a “group-average” acceptable temperature can have a significantly unfavorable effect on group performance. Wyon calculated the weighted average number of degrees above or below the temperature at which maximum group performance is expected for each of the four tasks. Performance decrement was then predicted using regression analysis based on test experience noted above. He then calculated expected performance improvement for each task based on individual ability to adjust temperature control within a range of 3±°C (5.4±°F). The following table summarizes expected group performance increase percentage when individuals are allowed 3±°C of individual control, even when room temperature is equal to a group average neutral temperature.

Increased Group Performance by Activity Type				
Thinking	**Typing**	**Skill**	**Speed**	**Mean**
2.7%	7.0%	3.4%	8.6%	5.4%

Personal differences in thermal comfort show significant variation. Most (95%) of a normally distributed population should be comfortable within a range of four standard deviations, or 6.4°C (11.52°F)(using PMV equation procedure). However, Grivel and Candas[48] found a 95% neutral range of 10.4°C (18.72°F) among French subjects and Rohles[49] found a neutral range of 13.6°C (24.48°F) among American subjects.

Wyon goes on to demonstrate that individual control of the workplace environment can lead to a reduction in time away caused by Sick Building Syndrome and to an increase in the level employees self-estimate their own productivity. “These positive effects on measures related to

productivity," he states, " indicate how important it is for individuals with differing requirements of the indoor environment to be able to make their own compromises, instead of having to put up with the compromises that have been found to be optimal for the group to which they belong."[50]

A Short History of Productivity Measures

Mao-Lin Chiu re-caps a number of productivity studies in his 1991 Carnegie Mellon dissertation.[51] Adams, et al. noted a 3 to 7% increase in reading speed and error reduction when glare was reduced.[52] The Federal Energy Administration saw a 5% increase in proofreading speed and accuracy due to increased illumination. In a Pennsylvania Power & Light study, there was a 13% increase in the number of drafting drawings produced per hour with a lighting redesign.[53] A number of studies document the effect of the environment on typing. Wisner found a 30% decrease in typing errors with a 20dB reduction in noise. The GSA saw a 2.5 to 9% increase in typing speed through the effect of air conditioning.[54]

It is clear from all studies cited in this section that the physical environment can have a measurable impact on worker productivity of about 3% to 15%. In addition to showing the relationship between environmental satisfaction and productivity, this section has discussed the importance of individual control especially as it relates to diverse responses to environmental conditions. In the next section, we examine the role of the environmentally responsive workstation (ERW) which provides workers with complete control over such conditions as air flow, filtration, temperature, lighting and acoustics.

ENVIRONMENTALLY RESPONSIVE WORKSTATIONS (ERWS) AS A CRITICAL SOLUTION: THE WEST BEND MUTUAL STUDY

One of the most carefully documented studies on increases in productivity as a result of improved environmental satisfaction is the study of the West Bend Mutual Insurance Company, which examined 300 employees, and was based on existing internal productivity measurements.[55] In 1991, the company moved into a new 150,000-square-foot headquarters that incorporated an integrated intelligent design, the centerpiece of which were environmentally responsive workstations.

Productivity measurements using a system that had been generated by the company and had been in place for more than two years were made for 27 weeks in the old building and for 24 weeks in the new building. Results of the study documented the productivity directly tied to the ERWs increased by 2.8%. West Bend Mutual managers felt the increase was more like 5 to 6%. Productivity dropped 12.8% when ERWs were disconnected as a test. The ERWs were randomly disabled to determine their effect on productivity. While lighting and overall ventilation were maintained, heating, cooling and air velocity were affected. Some workers objected so strongly that their ERWs had to be re-connected.

Using the conservative 2.8% figure, productivity savings amounted to an annual amount of $260,000, based on the company's $13 million salary total. The ERWs paid for themselves in less than two years.

Individual workstation controls enable employees to adjust temperature, air flow, lighting and other environmental conditions. As has been stated, zone heating, cooling and ventilation of open-plan offices at best create an environment that satisfies the "average" building occupant. This paper has shown that building systems, which inadequately provide good thermal conditions, air quality, lighting, noise levels and a sense of privacy, create significant levels of occupant *dissatisfaction* with the indoor environment and hence negatively affect productivity and the company's or organization's bottom line.

Updating HVAC systems, retrofitting lighting, offering flexible workstations, finding ways to dampen noise levels all on a system-wide basis will generally help increase levels of productivity. Yet, recent advances in controls technology have broken the play-by-the-averages barrier. Environmentally responsive workstation technology has turned over much control of the above factors into the hands of individual workers. Turning control of lighting, temperature, ventilation and acoustics over to the “experts” individuals who occupy the workspaces for several hours a day has been shown to have dramatic effects on productivity, as was demonstrated in the West Bend Study.

Also in the study, employee satisfaction with the work space was also measured. In the old building, 46% of workers were dissatisfied with their work space, 13% were satisfied, and 41% were neutral. After four months in the new facility, 4% were dissatisfied, 75% were satisfied, and 20% were neutral. Mean change in satisfaction was 33% greater for the group whose productivity increased compared to the group whose productivity decreased.

Ongoing annual internal studies commissioned by management of West Bend Mutual have shown that employees continue to be highly satisfied with their working conditions (90% in 1996). In the years following the initial comprehensive study, maintaining a high level of satisfaction, which has a positive impact on productivity at West Bend Mutual, is an indication that effects on productivity merely due to the scrutiny of a study (the Hawthorne Effect) are not happening at this company. Because of the successful impact these changes to the workplace environment have had on productivity, the company now has 450 ERWs in place, and has installed units in offices elsewhere, which they lease in other cities for their local West Bend Mutual sales staff.

PERSONAL ENVIRONMENTS® IN THE WORKPLACE

Environmentally responsive workstations (ERWs) provide individualized environmental conditioning. These systems allow office workers to easily adjust conditions to their liking at any time. ERW products, such as Johnson Controls Personal Environments® environmentally responsive workstations, have been available for some time, and today there are thousands of units in place in diverse locations worldwide such as manufacturer headquarters of professional maintenance products and pharmaceutical company offices. Johnson Controls also has installed units through their own facilities.

A Personal Environments system, the Johnson Controls solution, is an easy-to-use desktop control unit that gives each person the flexibility to adjust temperature, lighting, air flow and acoustic characteristics as often as necessary to maintain personal comfort levels. Individual workers can adjust the air temperature at their desktop, as well as control the amount and direction of air flow. A heating panel under the desk is available for adjusting temperature to the legs and feet. Personal Environments also allow for individual control of task lighting and background noise masking, which helps enhance a sense of privacy. All units are integrated with a sensor that turns off all functions when the workstation is unoccupied for more than 10 to 15 minutes.

Within an organization, individual control systems provide equal opportunity to thousands of office workers who today are too hot or too cold or have poor lighting or poor ventilation or disturbing noise. Personal Environments will further advance the business through increased productivity and reduced costs of employment caused by absenteeism, turnover and dissatisfaction. Hence, ERWs can be a significant competitive advantage for a business operation.

The environmentally responsive workstation is a concept whose time has come. Individual performance will be enhanced by a workplace that fulfills personal requirements, where environmental factors such as lighting, temperature, air flow, noise levels can be quickly

controlled by workers individually. A collaborative mode of interaction between building and occupant, between centralized systems and individual workspaces, may confidently be expected to raise individual productivity substantially and thus to pay for itself several times over.

PUTTING SATISFACTION TO WORK

Environmental satisfaction and individual control in the workplace is essential to achieving business goals. As this paper has shown, comfort makes a direct impact on increased productivity, as much as 15% to 17% depending on the job type, as noted earlier. And thousands of dollars can be realized from increased productivity, even 3% as the West Bend Case study proved. Satisfaction works because installing such systems as ERWs will pay for themselves in a short period of time. Also, a study conducted by FORTUNE Magazine has estimated that there is at least a 10% savings hidden in buildings and can be realized through retrofits and enhancements.[56]

While the metrics for measuring productivity and environmental comfort are not yet universally standardized, there is a growing body of evidence from physical science which demonstrates that comfort of one's own personal environment in the workplace has a positive impact on productivity.

Just as important as the physical measures of comfort is the perception of control of one's own environment in the work place. Together control and comfort have a positive impact on productivity. Building owners and managers, as well as organizational executives and employees, must increasingly aim for 100% in occupant satisfaction. When satisfaction has a direct impact on increasing productivity, then that is the best measure for building performance.

The technologies exist both on the large scale with increasingly sophisticated building automated systems and on the small scale with ERWs to provide maximum comfort and control for occupants. All managers need to do is insist that these technologies and products be put in place. Then will a relatively small investment improved controls in the facility have a great impact on a much larger return on investment people and the work they produce.

APPENDIX

Analysis of Environmental Satisfaction-Productivity Studies

Study	Environmental Condition	Result
Greening the Buildings & Bottom Line 1994	Lighting Noise & Daylighting New Building	6% prod. gain, reduced defects, $25k increase in product quality, 13% prod. gain, 25% less absenteeism 15% prod. gain + 15% less absenteeism 15% less absenteeism
West Bend Mutual 1992	Individual Control	2.8% prod. gain/could be up to 6% 12.8% prod. drop when disconnected
Mau-Lin Chiu/Carnegie Mellon 1991 According to Chiu, six factors influence office	Lighting Noise Temp & Air Quality	Cites 4 Studies Cites 5 Studies Cites 5 Studies

productivity: (1) Spatial Quality (2) Thermal Quality (3) Visual Quality (4) Acoustic Quality (5) Air Quality (6) Long-Term Building Integrity		
Economic Benefits of a Healthy Indoor Environment (Wyon) 1994	Thermal Air Quality Individual Control	5-15% incr. efficiency in concentration 34% improvement in Sick Building Syndrome
Predicting the Effects of Individual Control on Productivity (Wyon) 1995	Individual Control	3-25% efficiency gains 3-15% for concentration and 7-25% for routine office tasks
Indoor Air ’96 Conference (Wyon)1996	Individual Control	2-10% increase in group efficiency
BOSTI 1984	Noise Temperature/Air Quality Lighting Comfort	These each have dollar figures for 3 job types representing improvements to absenteeism and turnover.
Center Core 1993		