Personal Environments and Productivity in the Intelligent Building

Wayne Morrow
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The simple premise behind the movement towards better working environments is that comfortable people are more productive. Comfort, however, is one of those catch words that is easy to use and hard to define. People are comfortable when they feel comfortable, which is a state of mind dependent on both physical sensations and emotional states. Creating effective personal environments must account for both these elements together with the constraints of cost and technology. Sometimes it is a difficult balancing act and efforts to enhance the personal environment can actually diminish it. Designers must understand and take into account human constraints and design flexible systems which can adapt to changing needs and perceptions.

Productivity and the Working Environment

Productivity is and always will be the most important issue in business. Organizations that produce an attractive rate of return on investment prosper, those that don't fail. From this purely functional perspective, people are processing units creating outputs from inputs. Whether it be manufacturing or knowledge work, the issue is the same. Productivity is organizational effectiveness.

In the information age, success is related to creativity and the ability to leverage knowledge. Like the agricultural revolution, deterministic elements of production are increasingly being automated with the result that the 1992 World Competitiveness Report found that only 15% of the active population in the industrialized world touches a product during its development or manufacture. The other 85% direct the flow of capital, services, and products. Following this trend and probably driving it, the 1991 Harris/Steelcase poll found that 88% of office workers now have a personal computer or terminal on their desk --up from 24% in just five years and of those, 27% use their computer more than five hours a day.

Humans are doing the work that computers and robots can't. As machines take over more of the actual production, a larger portion of the cost of production and distribution is being spent on the human element. It is not surprising then that factors potentially affecting human productivity are receiving increased attention. Research and empirical studies going back as far as the thirties have attempted to quantify environmental effects. In the classical field study at the Hawthorne lighting factory, Roethlisberger and Dickson (1939) attempted to correlate productivity with illumination. As expected, a relationship was found but paradoxically the relationship held for both increases and decreases in lighting levels as well as for neutral changes lamps where replaced with identical lamps.

The Hawthorne effect as it has come to be called, demonstrates that productivity is a multifaceted issue. Humans and other life forms are not completely predictable. We interact with our environments in complex and dynamic ways which can only partially be explained by physical factors. The ASHRAE Comfort Standards recognize the non-deterministic aspects of this relationship by making a distinction between thermal sensation, 'a conscious experience', and thermal comfort defined as a 'state of mind'.

Comfort has both psychological and physiological elements. Glass and Singer (1972) evaluating the effect of loud noise on human performance found a significant correlation to performance. Loud unpredictable sounds resulted in decreased scores of subjects taking written tests. However, subjects who could predict the noise or who were given control over it where able to mitigate the negative impacts. *Actually turning off the noise was not necessary. Just the perception of control was enough to mitigate the effect*.

Hardy (1982) found a similar psychological factor in studying the thermal comfort of workers moved from closed to open plan offices. Even with very similar thermal conditions in the two types of space, worker's perception of thermal comfort in the open plan offices decreased by 50%. The only factor that could account for the difference was a loss in personal control caused by the move to the open plan offices.

A move to higher quality working environments has been the result of these and a great many other studies. Environment affects comfort, which affects human performance, which effects productivity. This relationship is not surprising for anyone who has tried typing on a keyboard with cold fingers. A recent study by the Rocky Mountain Institute and the Department of Energy (Romm & Browning, 1994) found a mean productivity increase of about 15% during post-occupancy evaluations of lighting retrofit projects. Eight projects where evaluated using available performance factors for companies doing a range of tasks from sorting mail to engineering design. Productivity increases where accomplished through decreased absenteeism, faster throughput, and fewer errors.

Personal needs change with task, age, gender, and many other factors. Light intensity preference ranges for VDT workers range from 5-10 footcandles for a young programmer to 50+ footcandles for older workers. Light color, outside brightness, and even mood also have an effect. The net result is that providing a 'neutral' or 'optimal' environment is not possible. Instead, designers need to provide an appropriate range of response and a means for users to customize their space to meet their needs.

Creating Personal Environments

Creating personal environments within traditional facilities can be challenging to impossible. Large zone HVAC and lighting must be broken into office-sized zones with personal controls provided. There are issues of open vs closed space, degree of control, and personal perceptions. The unifying factor is service. The facilities function is to provide a supportive working environment. IFMA qualifies this as a physical environment but the literature of behavioral psychology suggests that the final objective is a supportive state of mind. Both physical and psychological factors must be considered. Intelligent building technology is providing new and powerful tools for creating and maintaining the personal working environment at an affordable cost.

Five years ago UCAR[1] decided to use available technology to create individually controlled personal environments. We were remodeling a campus of three buildings with a total of 250,000 square feet from partitioned space into closed offices and labs. Management directed that each office have individual temperature and lighting control and that the building would meet high standards of energy efficiency. A variable air volume (VAV) system was chosen to provide air flow and cooling while radiant heat ceiling panels along perimeter walls provide heating. 24 hour a day operation was also required so we needed an occupancy controlled system to allow users to use their spaces at their convenience.

Particularly unique to the building is the use of fluorescent dimming ballasts in conjunction with a specially designed lighting controller providing desk-top dimming control, daylighting, and occupancy management. Lighting was also integrated into the HVAC DDC system using spare channel capacity in order to share motion sensor data and to provide host level monitoring and programming.

The system ended up having over 10,000 data channels on 8 subnets with a cost of about $50 per channel. This level of control and integration would have been impossible with conventional mechanical controls. The system came on-line two years ago with both predictable and some surprising results. The first reaction is that creating this level of personal control and automated response is very complex. Thermostat control is fairly simple and has worked well but as we began to interact more directly with users through occupancy and lighting, problems started to appear. Programming errors, equipment failures, bad terminations, improper adjustments, and user expectations became issues that had to be contented with. In a traditional installation without host level monitoring and control, we probably would have lost the system.

Early problems with the motion sensors and control logic were visible and fixable only with the help of wide-scale host-level monitoring and trending. Complaints of cold conference rooms revealed an obvious problem caused by continuously providing minimum airflow into an unoccupied and unheated space. During weekends the temperature would drop to the low sixties and only gradually return to a comfortable level after several days of use. Meanwhile, users would turn up the room thermostat to maximum in the expectation that non-existent heaters would relieve their discomfort. The rooms would eventually become too hot at which point new users would turn the thermostat all the way down and start another cycle.

Solutions to these problems, and many more, were eventually found. More importantly, they reveal the necessity of host-level analysis for complex systems. Simple tasks like setting the time-out of a motion sensor become major issue when hundreds and even thousands of sensors are involved. In the UCAR system occupancy delay timers are programed in software at the host level. This gives us the ability to reset time delays without visiting the office. At one point, sensor problems required this and we were able to reset 900 sensors with a few quick software changes.

The UCAR system monitors office temperature, motion, and light level. Taken together, this gives

[1] UCAR is the University Corporation for Atmospheric Research, which operates the National Center for Atmospheric Research under sponsorship of the National Science Foundation.

us the ability to do stimulus-response testing to perform real-time diagnostics. Attempts by users to defeat the system can be detected and the real problems fixed. From our experiences, I suspect that installations without this capacity are routinely bypassed. Providing service to users requires the ability to sustain the environmental support system in good working order. Rapid response and a sense of maintenance competence are also required. Without intelligent building technology the complex building systems necessary to provide for individual needs would not be possible.

How Much Control

Creating personal environments requires creating a sense of personal control. Paradoxically, Paciuk (1987) found that actually exercising this control can have negative effects. Users expect building systems to service their needs without being intrusive or demanding. Barnes (1981) suggests that controls be decisive. Function should be obvious, consistent, and provide immediate feedback. Light switches are a good examples. Thermostats are not. Background processes like occupancy and daylighting which do not provide direct user benefits need to be invisible.

Dimming ballasts in the UCAR system are very effective in providing users with a range of control down to 10% of full light output. Users are provided with a light control rheostat that plugs into a telephone type outlet located in the same telcom box with telephone and network outlets. The control has a 12-foot cord and a double stick backing to allow it to be attached to a computer terminal or desk. Overhead light is adjusted by turning a knob and feedback is immediately provided through variation of the light level. Focus group tests showed that VDT users are very sensitive to light levels, so wall mounted controls were not sufficient to provide the necessary level of fine tuning and convenience.

Usage of the lighting control varies widely. Some users don't even know it exists while others couldn't live without it. Many set the light level where they like it and leave it. Almost everyone would like to have manual on/off control, which we did not provide. From a personal control perspective we made a mistake in assuming that automatic control with motion sensors would be a feature. Instead, we found that we had actually reduced personal control. Traditional lighting control is a light switch at the entry door. This is a baseline expectation that we did not sufficiently replace.

Training

A building control system that requires formal user training is too complex. Users must be able to learn how to use the system with little or no instruction using very obvious and simple instructions and/or immediate feedback. Thermostats provide this with a numbered scale, light switches with an immediate change in room light. Most importantly the system must work in an expected way. Initially we provided light switch buttons in conference and other public rooms. These are momentary contact buttons and there is a short (200ms) delay before the lights respond. Pushing the button a second time before the start-up sequence finishes, turns the lights off. After several tries, some users would just give up in a clear case of personal control meltdown.

Occupancy

Occupancy deserves special consideration because it is potentially so intrusive and has little if any direct user benefit. Motion sensors unfortunately do not monitor occupancy. Motion is often a good surrogate for occupancy but only if small motions can be sensed. In laying out motion sensors, we assumed typical seating patterns. As usual, users found their own ways to inhabit their space. IR motion sensors are line of sight only. They must be mounted where they can see and detect the type of motion that occurs in the space they are monitoring. For offices they must be able to detect fingers typing on a keyboard. Without this level of detection, motion sensor are useless. Wall-mounted sensors mounted in the place of a traditional light switch are particularly suspect.

Motion sensors in the UCAR system are used only as sensors. Lighting and HVAC are controlled indirectly through their associated controllers. This approach allowed us to use a less expensive sensor making it very reasonable to add a second sensor. Tying to limp by on one sensor can create great user frustration and additional deterioration of the sense of personal control.

Daylighting

This has been an effective energy measure that also seems to work for occupants. Acting like a light thermostat, daylighting modulates lights up or down to reduce power consumption as daylight becomes available. With dimming ballasts it has been possible to achieve a smooth and usually imperceptible lighting response. Users have complained if the threshold light level is set too low but there have been few problems and it appears that many users appreciate having the lights self-regulate.

Towards the Service Environment

The move to and need for personal environments will not be disputed by most owners and designers. Ultimately all environments are personal along the lines of form follows function. Computer rooms meet computer needs and factories meet production equipment needs. Likewise, office and lab spaces must meet the needs of the people and equipment who occupy them. But people and even equipment are adaptable. They function well over a range of conditions. The real issue, as always, is rate of return. Do the benefits justify the cost and risk?

Realistically, productivity is only partially dependent on physical environment. Management experts like Deming and Drucker don't even mention it specifically. But they do mention creating a larger environment of positive attitude and personal support which the behavioral science literature cooroborates. People need to be in active interaction with their environment. They need to feel in control even if they aren't doing the control themselves. Part of the dynamic is to be able to get a response to problems and to feel like someone is watching out for their well being.

Studies in nursing homes (Langer & Rodin, 1976) showed that patients who were asked to take an active, decisive part in the upkeep of their environments were happier, healthier, and lived longer than patients who were told that the staff would take care of them. Certainly, offices are not nursing homes (some may dispute this) but the issue of personal control keeps reoccurring through a variety of tests and conditions. Taken to its end, a lack of personal control can lead to the condition of 'learned helplessness' where people and lab animals just give up. (Seligman & Maier, 1967).

With the move towards open space and space flexibility, designers assumed that the impact of large zone control of temperature and lighting in a field of partitioned cubicals would not significantly effect productivity. In some cases they are no doubt right. Where work is exciting and management effective the effects of a poor physical work environment will be mitigated. This is especially true if the cost of building the better environment is very high. But the truth is that open plan offices have failed to meet many worker needs. In the Harris/Steelcase poll 55% of workers say that privacy and quiet are very important but only 16% say they get it Similar statistics for lighting and HVAC rate these as very important but only about than half feel like they get it (Harris/Steelcase Poll, 1991).

The picture that emerges from the Harris/Steelcase polls is one of workers concerned with quality and effectiveness and who want to work in supportive, productive environments. Of those polled, 93% favor continuous improvement and 88% favor measuring customer satisfaction. Physical environments are part of an overall management and quality strategy. They send a message about management attitudes and expectation to employees and customers. In some areas of the world just having a 40 watt light bulb and plastic on the windows might be enough. What's enough in our world is a strategic decision made every time a new facility is built.

Going back as little as a single decade, the technology to create personalized environments was limited and the costs high. Controls were mechanical and computer networks where just beginning to appear. In 1990 when UCAR was considering control options, pneumatics were still a viable option. Benefits like host-level management and the issue of complexity were not even considered in the cost equation. No one we could find had actually done a full building with individually controlled offices and dimming fluorescents.

Costs and risk factors to accomplish the same level of service have greatly improved over the ensuing five years to a point where just the energy savings and capital cost reductions will be sufficient to justify most incremental costs. Meeting energy regulations in some states and for federal buildings may actually require the efficiencies inherent in small space management. On an office-by-office basis the typical building is only 70% occupied at any given time. As offices are lumped into zones the occupancy rate increases at an exponential rate so that even with only two or three offices in a zone, the building is almost fully occupied all the time.

The UCAR lighting system has reduced peak lighting energy demand by 58% and cooling by 20%. Eliminating simultaneous heating and cooling of spaces and variable speed fans have further improved these numbers. Reducing cooling requirements by 200 tons resulted in an $80,000 capital savings. An additional chiller and cooling tower which were installed for a cost of $300,000, have never even been turned on. This compares to $250,000 incremental lighting and HVAC installation costs.

The most significant issue is risk. Installing new technology is inherently risky and hard to evaluate. Several of the major components in the lighting system have had to be replaced or reworked to fix both product and workmanship problems. UCAR was not a willing participant or investor in any beta test program. Except for the lighting controller, we purchased only standard, but relatively new, products. With technology changing so rapidly, the situation is similar to that encountered in software sales. Specifications and marketing claims mean little. Warranties are difficult to enforce and there is little recourse against designers and engineers.

Owners truly are on their own. Pilot installations and engineering analysis are as essential for this type of design as they are for any other high tech purchase. For buildings however, the impact of failed products and poor installation can be devastating. The best approach is to be conservative but of course that's relative. Waiting until all the bugs are worked out might mean waiting forever and constructing obsolete buildings. The alterative strategy is to closely evaluate new products and technology in combination with a comprehensive risk management strategy. DDC and other networked controllers help meet these requirements with a host-local hierarchy and remote diagnostics so that loss of the host does not debilitate the local control and problems can be evaluated remotely.

Greater personal control and many other factors are requiring buildings that are inherently more complex. Risk and equipment failures in these buildings is unavoidable. The best strategy is to plan for it and to build in the flexibility to respond.

Conclusion

Enhancing productivity through better personal environments is part of a greater organizational strategy of quality and service. Designers and building operators will be challenged to provide building services that meet user expectations. Greater personal control means greater complexity and a requirement for higher performance building systems. Potential benefits will be lost if users become confused and frustrated with systems that do no respond in a consistent, unobtrusive manner. Intelligent building technology makes greater personal control possible by enabling the creation of more complex systems along with the means to manage and adapt to meet changing needs and perceptions.

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