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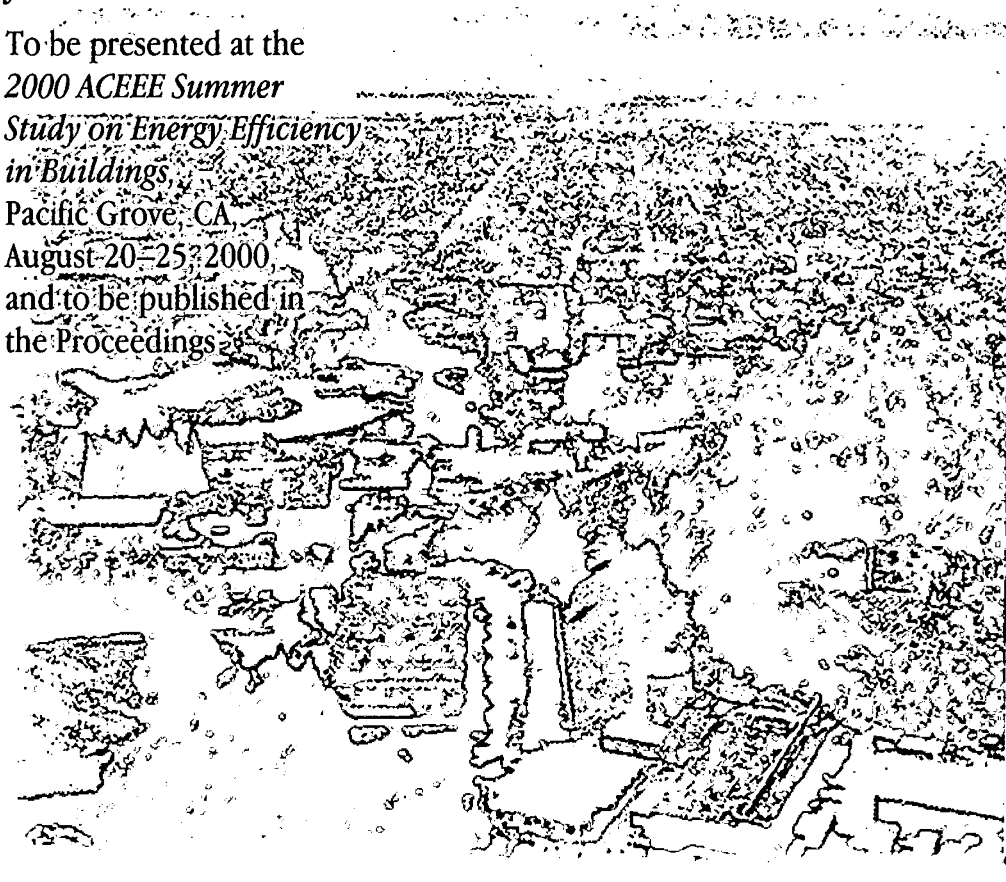

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IBECS: An Integrated Building Environmental Communications System—It's Not Your Father's Network

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IBECS: An Integrated Building Environmental Communications System—It's Not Your Father's Network

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Abstract

The paper presents the technical design concept for a low-cost building communications network that will allow most building equipment loads, including individual light fixtures, operable window blinds, motors and environmental sensors, to be controlled and monitored from an existing Ethernet. IBECS (Integrated Building Environmental Communications System) is a practical networking system that will provide building managers with an unprecedented degree of control over most building electrical loads, allowing them to implement load shedding, real time pricing and aggregated building load strategies with confidence. At the same time, IBECS will let individual occupants exert appropriate control over their environmental conditions (light and, ultimately, heat), initially using a virtual control panel served from their web browser, and eventually through voice command. Recent developments in hardware and software have enabled this new networking concept. New manufacturing techniques can produce semiconductor devices that incorporate a microprocessor, unique IP address, controller, and simple LAN communications for $0.25/chip. The private sector is already hugely invested in software that makes appliances, peripherals and telecommunications devices addressable via the Internet (e.g., Sun Microsystem's Jini technology—a software infrastructure for providing services on a network). Because it directly exploits recent developments in hardware and software that are far beyond the development capabilities of the building industry, IBECS could provide the infrastructure that, for the first time, truly integrates the operation of building equipment to improve both human and building performance.

Introduction

Electric lighting is often the largest single load in commercial buildings, typically consuming nearly 40% of electric energy. By renovating older fluorescent lighting systems with electronic ballasts and T-8 fluorescent lamps, consumers have saved over $1 billion in avoided energy costs (Geller 1996). Despite these improvements in equipment efficiency, lighting energy is still squandered because it is not managed effectively. Previous research indicates that lighting controls that use occupancy sensors and scheduling to reduce lighting of unoccupied spaces and photosensors to integrate daylight and electric light can reduce lighting energy consumption by at least 35% compared to an already efficient electronic ballast system (Rubinstein 1991). Compared to older, magnetically-ballasted, fluorescent systems, the savings from integrated lighting controls is well over 50%. The energy savings attributable to improved lighting controls is therefore at least as large as the energy savings that has resulted from the successful deployment of the electronic ballast. A concerted effort to reduce wasted lighting through the use of advanced controls would not only save consumers billions of dollars annually in avoided energy costs (Rubinstein 1999) but also potentially improve satisfaction with the workplace environment by providing occupants with dimming control of their lighting. Improved lighting controls offer the most economical path to capturing this enormous energy savings, thereby achieving the next step in lighting energy efficiency while bettering the workplace environment.

Background

Until recently, the main motivation for adding lighting controls to a commercial building was to provide building managers and facilities operators with better tools for controlling building electric loads. These systems have proved somewhat useful for this function, but lighting controls provide little benefit for the building occupants, for whom buildings are designed and constructed.

One way to provide occupants with some sense of control over their environment is to let them influence the local lighting in their own work area. It is known that tastes in light level, tolerance for glare, and so forth, differ between individuals. For example, in our advanced controls testbed at 450 Golden Gate Avenue in San Francisco (Jennings 1999), workers in one office are content with 200-300 lux during the day while another worker in a nearby office wants 2000 lux. Lighting in most buildings is not conducive to accommodating different lighting preferences. General overhead lighting in buildings often consists of 3-lamp fluorescent fixtures on 8' x 8' centers—a prosaic design that creates relatively uniform illumination of 500-800 lux everywhere. Occupants have no ability to adjust these light levels to their taste, because most lighting systems cannot be dimmed and only zone on-off control is provided.

The current high cost of dimming electronic ballasts and poor interoperability of lighting control components and systems has prevented dimmable fluorescent lighting from penetrating the commercial building market to any significant degree. (Dimming ballasts are currently estimated to be 2% of annual fluorescent ballast shipments in the U.S. By contrast, 25% of high-frequency fluorescent ballasts sold in Europe are dimmable (Williams 2000). The dimming electronic ballast should be viewed as an enabling technology which, when combined with user control of light intensity and automatic controls for energy cost savings, can bring about a fundamental shift in how we light buildings. At the present time, controllable ballasts are relatively expensive (typically at least twice the cost of an equivalent non-dimming ballast). However, this high cost is not intrinsic to the technology but rather to low sales volume that keeps unit prices high. With high demand for dimming, the price of controllable ballasts would be only marginally higher than standard ballasts.

But transforming the market to dynamic lighting requires more than just a good, controllable ballast at a competitive price. In order to save energy and reduce building operating costs, the lighting must be controllable based on a range of different inputs. Well-designed, automatic controls should dim the lighting based on occupancy, available daylight or even the instantaneous cost of electric energy. Previous field studies have shown that properly commissioned lighting control systems can reduce lighting energy consumption by 35% compared to high efficiency lighting systems (i.e., with electronic ballasts and T-8 fluorescent lamps) and over 50% compared to older magnetically-ballasted lighting systems (Rubinstein 1991, Jennings 1999).

The ability to dim lights represents a major potential benefit to building occupants. With changing visual task requirements common in modern building environments (such as the mixing of computer and paper-based tasks), lighting users could come to view the ability to adjust light levels as an asset. Business managers may even begin to see occupant controlled lighting as an added amenity that would justify higher lease rates.

This paper presents the conceptual framework for an integrated building equipment communications network that will allow appropriate automation of lighting and other building systems to increase energy efficiency and improve building performance while simultaneously providing a low-cost method for the occupants to control local lighting and other systems to enhance workplace quality.

The IBECS Concept

System Architecture

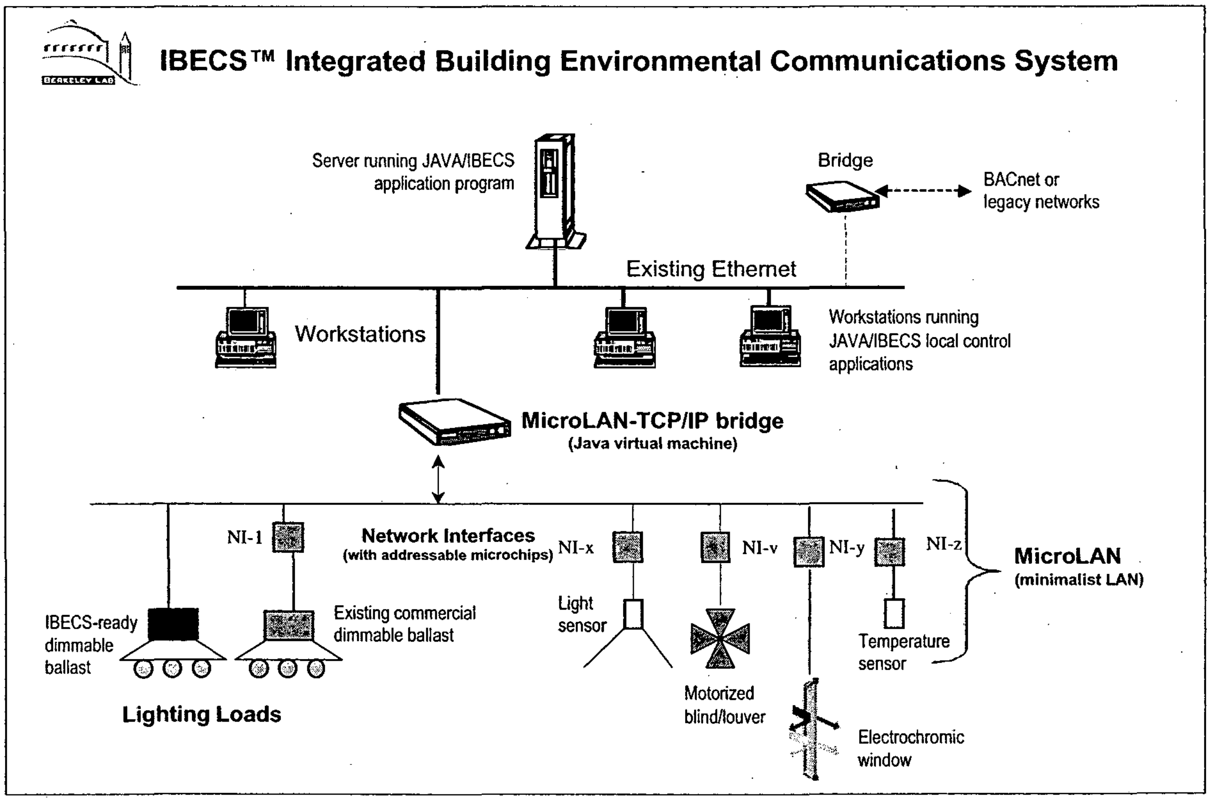

Figure 1. The IBECS network architecture. The microLAN bridge intermediates data flow between the facility's Ethernet and the microLANs that control and communicate with individual building loads. Today's controllable ballasts and other loads would require addressable network interfaces.

The figure above illustrates a comprehensive view of the entire IBECS architecture as applied to the operation of building lighting and dynamic envelope systems. As indicated in the diagram, it is assumed that IBECS will be installed in a building that already has a TCP/IP network for the facility's computer LAN (local area network). IBECS piggybacks onto the enterprise's IT network using bridges to connect the facility's computer LAN to smaller sub-networks, called microLANs. Each microLAN is a minimalist digital network (low speed, minimal number of conductors) that physically interconnects all the lighting and other loads within one physical zone. The MicroLAN bridge controls and monitors lighting equipment attached to each microLAN and transfers collected control and status information over the existing TCP/IP network to client browsers or databases. The bridge controls multiple equipment loads on one side and accepts and transmits data back to the TCP/IP side. This architecture allows control of many small sub-networks that are directly connected to the load interfaces that they control. Each major element of the IBECS concept is detailed below.

MicroLAN

Each microLAN consists of a two-wire network that runs to all loads in that building zone, the network interfaces in that zone, and the bridge that controls it. These zones may be individual work spaces, suites of rooms or entire quadrants depending on the logistical constraints in the complex. Each MicroLAN requires its own bridge that links that microLAN to the TCP/IP network. An example of microLAN is the 1-wire™ LAN from Dallas Semiconductor. It can support communications with potentially hundreds of devices over thousands of feet. In practice, the number of devices on the network and the network length are dictated by constraints such as the physical separation of the different devices and wiring access issues. In the general case of application to office environments, each microLAN would probably be hundreds of feet long and consist of 10-100 devices. It is important to note that each device on the microLAN is individually addressable through its network interface. In this way, the digital microLAN differs significantly from the low-voltage analog wiring currently used for controllable ballasts. In the latter case, all ballasts on the same low voltage circuit are controlled in unison, not individually.

Today's Controllable Ballasts

To understand how IBECS can interface with the building's lighting system, it is useful to understand how today's controllable ballasts are currently wired and controlled. Most controllable ballasts have two extra low voltage leads. Every ballast to be similarly controlled is connected in parallel to the low-voltage circuit. All ballasts that are wired to this low voltage circuit form a zone in which all ballasts respond similarly to the change in control voltage. Most controllable ballasts use an analog 0-10 VDC signal to control fluorescent light output although a few manufacturers use an AC square wave design in which the lights are controlled either by changing the square wave duty cycle or changing the amplitude. Different network interfaces will need to be developed to accommodate the differing control requirements of commercially available controllable ballasts.

Network Interfaces

Until purely digitally controlled ballasts are available, 0-10VDC analog control is the most common means for controlling fluorescent lamp output. To connect today's dimmable lighting equipment to the microLAN requires that each ballast be individually equipped with a network interface that bridges the digital microLAN to the ballast 0-10VDC control. The network interface is therefore a critical component to making IBECS work with existing lighting hardware. Each network interface must have an individual address so that individual ballasts can be controlled and monitored. In the IBECS model, each network interface would incorporate at least one inexpensive microchip to provide a unique address and control capabilities for that interface. The conversion between microLAN on the one side and the analog 0-10 VDC control on the other would take place at the network interface, which is directly connected to each ballast. In IBECS, the low-voltage 0-10VDC control wiring is largely replaced with the digital microLAN and the analog control "pushed close" to the ballast.

IBECS network interfaces are designed to be simple and inexpensive. Previous efforts to create building communications networks from general purpose integrated circuits, such as Echelon's Neuron™ chip (Echelon), while clearly ahead of their time, resulted in individual chip costs of $10-15—too expensive to consider for individual ballast control. To keep the cost of each addressable control point to a minimum, an IBECS network interface uses newly available microchips (~$0.25/chip) that have a unique address and provide simple control and communications functions. Simply put, these chips provide addressable digital-to-analog conversion. In April, 1999, one of the authors (Pettler) demonstrated a prototype system that used interfaces constructed from these chips to control the light intensity of a fluorescent fixture from a virtual control panel running on a PC laptop. The demonstration system included lamp status annunciators that indicated whether each lamp was on or off, thus demonstrating the principle of bi-directional data flow. By selecting a chip that is not "too smart" for the necessary functionality, we have minimized the point cost. Using one or two of these new microchips per network interface, every lighting fixture will have its own IP address and be addressable from the computer LAN in the same way that one today controls a printer, computer peripheral or cell phone. The cost of the network interface for an electronic ballast will be about $0.75/interface device (assuming each interface holds two microchips at $0.25/chip and allowing $0.25/interface for packaging). At this price, it will be economical to control most lighting fixtures individually and potentially other electrical loads in a building.

Bridge

The network interfaces discussed above are simple in operation: they have one digital input and one analog output. The task of communicating with multiple network interfaces over a LAN requires a more intelligent device, such as a bridge. The bridge is a microcomputer in its own right and must be capable of digitally communicating with many network interfaces as well as collecting data and communicating this back to the main LAN. We had originally thought that the cost of this bridge would be sufficiently high (say, hundreds of dollars) that it would require many interfaces per bridge to keep the cost per control point down. However, recent improvements in chip production has brought the cost of this type of bridge to well under $50/unit. An example of hardware that is available today that would serve as an IBECS bridge is the TINI bridge from Dallas Semiconductor.

The TINI bridge is a computer (Java virtual machine) that includes RAM and all necessary interface ports to link between TCP/IP and MicroLAN. This bridge executes Java code and speaks TCP/IP, exactly what we need to implement IBECS for building equipment. With this type of bridge technology, manufacturers can develop Java applications quickly and easily to provide an Internet or intranet interface to building lighting equipment. Since Java applications run under any web browser, the bridge can be communicated with from any authorized computer without regard to platform.

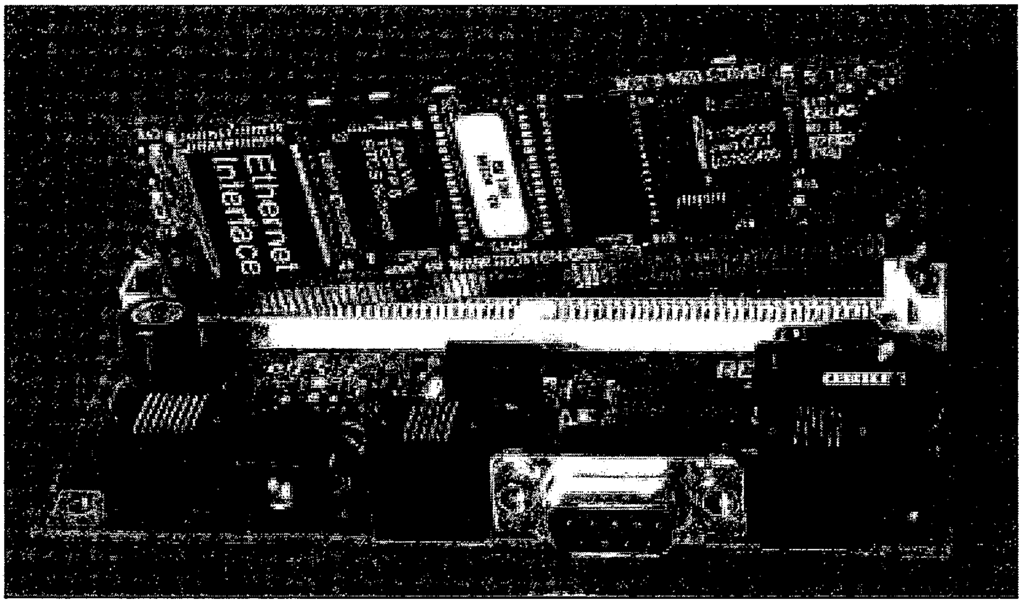

Figure 2. An example of an Internet interface bridge. In lighting applications, the bridge controls and monitors attached lighting equipment and transfers collected control and status information over a corporate IT network to client browsers or databases.

Networking Software

By combining the network interfaces, bridges and microLAN network wiring as described above, installing an IBECS-ready lighting system should be similar in complexity to installing a telecommunications system. But a useful networking system is built more of software than hardware. Since lighting services must be provided to different people with differing capabilities, needs and access requirements, a rich body of robust software must be created to support this network concept. Fortunately, much of the "roadbuilding" has been done by others. Because IBECS uses Java as its underlying programming language, software development tools available to support Java applications developers are also available to lighting manufacturers who want to develop useful applications to control their lighting equipment from the Internet. In terms of adopting a standardized Java description of lighting objects, the work that has been done to provide BACnet object type definitions (Bushby 1997) provides the foundation for describing lighting components (as well as most other building equipment) as Java objects. These object definitions can be quickly approved by manufacturers allowing them to write Java applications that will communicate with their equipment under IBECS.

Although good tools to serve the above needs are important to the success of IBECS, there is critical need for an overarching network structure to bind all these pieces together. We propose that this structure be something akin to the Jini system—a networking technology of Sun Microsystems. Jini is a simple infrastructure for providing *services* in a network and for creating spontaneous interactions between programs that use these services. [At the time of this writing, there is a least one major competitor to Jini; specifically Universal Plug and Play (UPnP) from Microsoft. The authors believe that it is too early to choose one "standard" over the other. Thus when we refer to a "Jini system" it should be interpreted as a "Jini-like" system]. In this context, service has a very broad definition; a service is an entity that can be used by a person, a program or even another service. A service might be a hardware device (such as a printer or a MicroLAN bridge), a network interface operating a controllable ballast or another user. Two additional example of services are printing a document or dimming an overhead light from the desktop.

A Jini system consists of a collection of services that work together to perform useful tasks. Services may use other services in turn and an entity that is a client of a service may be a service itself to other clients. (The microLAN bridge is an example of the latter). Most importantly, services can be added or withdrawn at any time according to demand, need or changes in hardware. This is a critical feature of Jini system; if a service must fail, it fails gracefully. A Jini system is designed to be tolerant to network devices being added to and withdrawn from the network.

The critical requirement for the networking software for IBECS, regardless of whether it is Jini, UPnP or some other standard, is that it support the concepts of lookup, discovery and join. Discovery and join occur when a device is plugged in. Discovery occurs when a service is looking for a lookup service with which to register. Join occurs when a service has located a lookup service and wishes to join it. Lookup occurs when a client or user needs to locate and invoke a service described by its interface type (written in the Java programming language) and possibly other attributes. Good implementation of lookup, discovery and join will help assure that the networking software that underlies IBECS will not require user configuration and will be robust even if devices are dynamically added or removed from the network.

Discussion

The IBECS concept exploits recent developments in hardware and software to arrive at a robust networking solution. The choice of hardware is dictated by the need to keep the cost per point as cheap as possible. The Neuron chip, though clearly ahead of its time, does too much and costs too much to be economical for large numbers of individually addressable control points.

IBECS will reduce the cost of lighting controls because it eliminates the lighting controller required for today's "integrated" systems and replaces it with software residing on the microLAN bridge or even at the network interface level. Also since the relationships between components and the controlling algorithms will be software-based, IBECS will be more flexible and responsive to needs of particular buildings, zones and individuals. The component devices to be upgraded for inclusion in this system will include different types of commercially-available controllable ballasts, bi-level wall switches, and occupancy sensors.

Additional work includes developing working prototypes of advanced multi-functional sensors and power-metering devices. Each hardware device will be furnished with a software interface (currently Jini/Java) for linking to the system and applications developed (Jini/Java applets) will be built to run local controls each device within the MicroLAN. LBNL is making the entire IBECS networking topology operational on a prototypical basis to determine viability and cost-effectiveness within a commercial building environment.

Integrating Zonal and Personal Controls

IBECS was conceived of to provide a low cost means of controlling individual dimmable lighting fixtures from an existing IT network. Because lighting is not that different from other loads in a building, the IBECS concept can in principle be extended to move past lighting and encompass other building equipment as well. For example, IBECS could provide the infrastructure necessary to economically integrate motorized window blinds at the building envelope with dimmable electric lighting system operation. Advanced electrochromic glazings are another emerging technology that will be useful to control sunlight and glare in interior spaces. These kinds of dynamically controlled envelope elements could reduce peak electric loads by 20-30% in many buildings as well as improve comfort and potentially enhance productivity. Customer choice and options will be further enhanced if they have the flexibility to dynamically control envelope-driven cooling loads and lighting loads.

Some dynamic window systems have local (single-zone) envelope-specific control systems, with minimal integration with other building systems. To more completely exploit their energy-savings potential, the dynamic window systems should be integrated with HVAC and lighting systems at the local and whole-building levels. Optimizing the action of smart windows with other systems and assuring their proper action with local lighting systems is a major challenge to making these systems more appealing to the broader market of potential users. For this new technology to function at a market level, it must work well with other building systems and provide features such as automated operation, commissioning, maintenance and diagnostics to enhance its cost effectiveness.

Although many of occupant complaints in buildings stem from feelings from thermal discomfort (cold calls and hot calls), the large HVAC zone sizes generally precludes the "one fixture to each individual" control possible with lighting. Lighting is a unique load in the sense that it is a localized phenomenon. Unlike HVAC systems, there is often nearly a one-to-one relationship between worker and light fixture. In many building spaces, the light from one or two fixtures serves the lighting needs of one (or possibly) two occupants. Recent development in "personal environmental control" systems may offer individual thermal comfort control in the future, but in the meantime, lighting is a better candidate for economical personal control than HVAC systems.

Summary

We have presented a concept for a building communications network (IBECS) that uses the latest in hardware and software to create a robust networking architecture to support control of building lighting services from the Internet. By building on recent developments in hardware and software that are far beyond the development capabilities of the building industry, IBECS could provide the infrastructure that, for the first time, truly integrates the operation of lighting and other building equipment to improve both human and building performance.

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