Buildings as Networks: Danger, Opportunity, and Guiding Principles for Energy Efficiency

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Summary

The coming twenty years will see a dramatic transformation in the patterns of energy consumption in buildings. Each year an increasing proportion of both devices and end uses in buildings will be influenced or dominated by controls that are defined by digital networks. Some of these networks will be established specifically to save energy but more often the controls and networks will be installed for other reasons, and can just as easily increase rather than reduce consumption. The efficiency community needs to be a lead actor in defining these networks' creation and evolution, to assure that efficiency is a primary goal in their design and deployment. The alternative is to forever try to tame the energy consumption of networked products and technologies after they have been designed and installed.

The past twenty years of increasing networking of electronics shows the danger of a lack of attention to energy minimisation. Apart from niche wireless devices, energy has not often been a concern of the electronics industry in the myriad ways that devices are networked with each other. Consumption of electronics has risen dramatically in this time, partly due to increases in the stock of devices and services delivered, but a significant amount is wasted from lack of considering energy in network design. We should expect a similar outcome for other energy end uses.

Engaging with the industries that create the products — and the standards they will rely on to operate — will require significant investment by the efficiency community. However, in most cases there will be no incremental cost for manufacturing or deploying the more efficient products. Furthermore, there are likely to be few available projects for industrialized countries that rival efficient networks as an energy efficiency resource in terms of size and cost-effectiveness. The most effective and least costly time to address this issue is now.

Background

> **Direct and Induced Consumption**
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> Networks increase energy consumption in two ways. There is **direct** consumption from network interface components, and products whose only function is to provide network connectivity. In addition, networks **induce** consumption by causing products to be in a higher power state than they would otherwise be due to being connected to the network (key examples are PCs and set-top boxes).

The electricity delivery system is a vast and extraordinarily complex network — one we have had for over a century. Information networks are also not new; for example the telegraph network arose over 150 years ago. Traditional light switches and thermostats are very simple network examples. The telephone system is also quite old, though originally — and still partially — analog rather than digital. Computer networks emerged as entirely digital from the beginning. Consumer electronic devices have long been networked — until recently almost entirely through analog connections, though they are now undergoing a rapid shift to digital. The **digital** nature of current network developments is the key to their power and potential for energy efficiency. Computer networks, in particular the Internet, were not designed with energy use or efficiency in mind. The number of network nodes was small, and consequently, so was the aggregate **direct** consumption of network hardware; also, the fact of being networked did not change the consumption of devices on the network. So, the lack of attention to energy use was completely understandable[2]. When power management was introduced into personal computers, network connectivity was not considered in its design; it was simply lost when going to sleep. When connectivity was acknowledged, with the introduction of "Wake On LAN", the energy efficiency community was not involved (while Wake On LAN "works", it is not widely used and so saves only a modest amount of energy). Meanwhile, most energy used by desktop PCs (at least in the U.S.) occurs when no one is present. There is an enormous infrastructure of hardware, software, protocols, applications, users, expectations, and the like which do not support energy efficiency of networked PCs in allowing them to go to sleep without compromising a basic — and often desired —

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[2] While it is excusable and understandable that energy was not considered the first time the Internet was invented, to repeat this the second time would not be. See the "Future Internet" project at http://www.nsf.gov/pubs/2007/nsf07507/nsf07507.htm

capability to stay connected to the network. Fixing this problem after the fact is possible, but much more difficult and expensive than doing so when the network technologies were originally developed.

Building Networks

While we can expect the various networks to be interconnected and interoperate, it is helpful to think of them as distinct networks to assess consumption and savings, requirements for efficiency, and policy needs. The network types are:

- **Electronic networks**
  These are oriented to either information technology, or to audio/visual entertainment – consumer electronics. These two are merging and are characterized by large volumes of data.
- **Lighting networks**
  Lighting is not traditionally considered a heavily networked end use, but it is arguably the first (albeit non-digital) example of networking in buildings with multiple fixtures often attached to a set of controls (switches, sometimes multiple). More recently occupancy and other sensors have been added, along with controls like dimming. Data rates are usually very low.
- **Climate control networks**
  Heating and cooling systems have sensors, actuators, thermal systems, and human interfaces. Like lighting, these are also a crude network, and also have yet to enter the digital age in most buildings. These networks have been traditionally closed but would benefit from greater interaction and integration with other building networks. Data rates also low.
- **Security networks**
  These include smoke and carbon monoxide detectors, fire alarms, security systems (window/door sensors, occupancy sensors), doorbells, security cameras, and leak detectors. Except for some cameras, all tend to have dedicated wiring.
- **Other networks**
  These cover principally appliances, and miscellaneous controls such as for windows. These are likely to be appended to other networks, not a driver of networks on their own.

In many buildings these networks will share information from sensors about occupancy and special states such as fire or other emergency. Expressing preferences and monitoring of building operation also will require interconnections.

For consumer electronics (CE), people have long been accustomed to powering on and off televisions and devices connected to them with remote controls, and manually with power buttons. For devices other than the TV display, this is an annoyance (if consumers are even aware that other devices are on), with the result that devices are often left powered on during times of non-use. As CE devices become cheaper, and can be more easily networked with others (that may be in different rooms), the likelihood of devices being on when not in active use is rising. TV set-top boxes are typically on continuously, to provide connectivity both upstream and downstream. As with computers, those concerned with energy use and efficiency have not been involved in developing the standards for inter-device control. Manufacturers who do so are more focused on simply making things work at all, content protection, and with features which appeal to consumers — rather than to any focused effort on power controls (which is unlikely to increase sales).

In both cases, there has been additional confusion sown by poorly-designed and inconsistent user interfaces around power controls. Industry did not address this topic, but energy efficiency motivated work did (IEEE 1621) and has had success in rectifying this problem.

While there is little about networked electronics to indicate that energy efficiency will be a cost burden, the reality is that without specific attention to energy efficiency, it usually doesn't happen. The only entities likely to bring this specific focus are those whose primary concern is efficiency; however these organizations struggles to deal with the highly technical nature of integrating power management into networks.

The Traditional End Uses

Energy use in buildings is largely a matter of assembling and operating many individual and isolated components, with most of these are largely static. Products put into buildings are generally independent of each other in that the efficiency of one won't affect the consumption of another (aside from internal loads affecting space conditioning). By contrast, digital networks make behavior of one product a factor in the energy consumption of others on the network, possibly driving it up *or* down.

In a Perfect World

Consider a room in an office building or house that today that has space conditioning that serves an entire floor, and a single ordinary light switch. A future version of this room might include:

- Sensors for occupancy, temperature, and ambient light.

- Controls that take into account presence (including *who* is present), time of day and week, past preferences, past occupancy patterns, and provide for control from diverse locations (including computers and phones present, mobile phones, and remote devices).
- Dynamic capabilities that control the temperature and volume of heat or cool delivered, automatic window opening, shading control, and diverse (now solid state) lighting control.
- Lighting patterns that change depending on what the occupant is doing — using a computer, meeting with someone, eating lunch, or sleeping.
- Climate control designed to follow preferences, the outdoor climate (as an indicator of clothing), and occupancy (allowing greatest deviation from target conditions when an occupant is least likely to be present).
- Preferences expressed through many means, including perhaps hand gestures, to make control of the space as unobtrusive and natural as possible.
- Displays for electronic information coordinated with occupancy and lighting, and — being quite large — may be the largest user of energy in the space. With widespread availability and use of videoconferencing, lighting will similarly adjust when cameras are in use.

Presence

Consider the concept of "presence". In future, we will want building spaces (and even some outdoor spaces) in residences and commercial buildings to be responsive to the presence of people, to assure that desired services are delivered (e.g. light, thermal comfort, vision, monitoring, information displays) and that unneeded services are not delivered.

We will often want all services to be driven off a common base of "presence"; this requires sensors which assess presence characteristics, and methods to determine just how present someone is (e.g. you don't want the person emptying rubbish bins in the evening to "wake up" every office he/she visits). Presence could be responsive to factors such as: who enters a room, how many people do, what time of day or day of the week it is, and any gestures the people make. We will want a common platform for 'presence' to avoid proliferation of sensors and controls, a common method of setting this across energy services, and user interface standards (so that when you want into a room in a building you've never been into you have a good idea how it works, as you do for cars). This requires integration at many layers of the network hierarchy.

Some key characteristics of this future are that it is highly dynamic, to follow conditions to optimise the service delivered, and (ideally) to minimise energy requirements. The dynamic nature will mostly occur in how each devices operates. However, as people move devices into our out of spaces — or within the space — the mix of which products are present will also change, possibly changing the behavior of all devices. Devices include controls (e.g. a mobile phone), task lights, and displays. As conditions in the space and outdoors change, and as energy prices change, the space will continually readjust. Another key aspect of dynamic systems is to respond to anomalous conditions, be they those of the user (e.g. a guest or unusual usage), or to error conditions as when devices malfunction or are removed, to both respond as well as possible, and to diagnose and report the malfunction.

The Default Future

As with the introduction of electronics, and most high-tech building controls to date, the forces driving building networking will be to improve the quality of the space for the benefit of the occupant, *not* saving energy. Other lessons from electronics will also likely apply in the absence of efforts to the contrary:

- Promoters of specific technologies will ignore or resist opportunities for interoperability, as they try to gain maximum market share for their unique technologies.
- Efficiency will be an afterthought, with other features driving the process (trade publications and trade shows provide overwhelming evidence for this).
- Standards will be critical to facilitate some degree of interoperability, but aspects of these standards that could aid energy efficiency will generally be absent or ill-formed. Clear opportunities for harmonization across standards (e.g. in terminology) will not be taken.
- User interfaces will be neglected, with individual manufacturers seeing this as an opportunity to differentiate their products, at the expense of users and of energy efficiency.
- Little or no coordination will occur across

User Interfaces

The traditional ISO 7-layer OSI model of interoperable networks only addresses how electronic devices on the network interact with each other, but since these networks ultimately serve to deliver services to people, humans can be seen as the missing "8th layer" with standards for that communication needed to make it happen effectively.

Lighting control user interfaces are an area that will shortly require standards for to avoid widespread confusion as different companies develop incompatible and/or confusing systems of terms, symbols, colors, metaphors, etc.

domains. In electronics this manifests itself as the "IT" and "CE" domains, with different physical, application, and device infrastructure. For buildings, this is the end-use domains such as space conditioning, lighting, security, electronics, and others.

Achieving a Better Future

To arrive at a future in which digital networks optimally support energy efficiency, we should place ourselves into that long-run future — perhaps the year 2027 — and identify those features of network architecture not widely present in 2007 that are most important for energy efficiency. We can then begin to describe key details of these features, how to develop them further as ideas, and how to market them to industry (many), standards organizations, and energy policy organizations.

Guiding Principles

Energy efficiency efforts around building-related networks need some "guiding principles" that can be used to evaluate existing and proposed network technologies. These need further development, but an initial list of Guiding Principles are as follows:

A. The existence of one device on a network should not cause another device to stay awake when it might otherwise go to sleep.
B. The network should be designed such that a legacy or incompatible device will not prevent the rest of the network from effectively using power management.
C. Devices should expose their own power state to the rest of the network and be able to report estimated or actual power use levels.
D. Product interfaces — for people or other products — should follow (international) standard principles and designs.
E. Products or devices that influence energy consumption should adhere to (international) standards for behavior and communication appropriate to their function.
F. Products and connections should have the ability to modulate energy use in response to the amount of service required.
G. Energy efficiency efforts should not favor any particular hardware — or even software — technology. All network technologies must be the target for efficiency efforts. Future buildings will include many different technologies; those in any particular building will be diverse, and always changing.
H. Harmonization of basic principles underlying efficient design for networked devices should cross all end uses and be global.

Conclusions

For the past two decades, we have seen an inexorable increase in the degree and sophistication of digital networking across electronics (both information technology and consumer electronics). This has greatly increased the services they provide, but spawned the creation of devices whose only function is to provide connectivity, increased the power levels drawn by these devices, and critically, driven up the time spent fully on for many of them. Electronic networks have been designed and implemented with little regard for energy consumption, and without the involvement of the energy efficiency community, so the resulting large increases in consumption are no surprise. Many aspects of set-top box energy consumption will apply to emerging networks in appliances and equipment.

Appliances and equipment in buildings are just beginning this transformation, a path which will lead to them becoming highly networked and controllable, across the major traditional end uses such as space conditioning, lighting, and security. As in the past, for the most part this will be done for reasons other than saving energy, such as greater comfort, control, security, productivity, and entertainment. A likely outcome is *increased* energy use, even aside from the energy needed to power the network itself.

This future is not inevitable. Action now can lay a strong foundation for devices to be interoperable with each other and with people in ways that facilitate maximum energy efficiency. This action will require careful attention from an efficiency perspective to many diverse standards that accomplish this interoperability — a few of these already exist but can be amended; many others are yet to be developed. The efficiency community is not generally literate or involved in network standards development.