Necessary design infrastructure for energy-efficient networked buildings

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Summary

Electronic products within residential and commercial buildings are already widely networked, and efforts are underway to reduce the energy consequences of that network connectivity. Non-electronic end uses (climate control, lighting, appliances, etc.) are at the early stages of being digitally networked on a wide scale[1]. Accomplishing this will require significant investment in wiring, in wired and wireless network interface hardware, in network equipment, in control software, and in training of building professionals to install, use, and maintain it all. This will all be done building-by-building over time. Less well appreciated is infrastructure in network architecture necessary for all these networked devices to work well with each other, and with the people who occupy residential and commercial buildings. This must be researched, developed, and standardized before the physical elements are created. As this process has not yet begun in any significant way, we can expect large interoperability problems among building elements and with occupants, leading to increases in energy consumption, in many cases more than wiping out the energy saving potential that networking holds. A large effort to design the network architecture could lead to significant energy savings in future, without increasing the manufacturing cost of future building components making it enormously cost-effective. The key is to create new global standards for "real-world" concepts and objects.

Background

Networking of IT equipment was developed over several decades, with design and protocols evolving with increasing ability and decreasing cost of hardware. The resulting design is embodied in the layered OSI reference model and the suite of Internet protocols that define several of the layers. Backing this up was research on network architecture that evolved many key principles about how networks can and should be constructed.

Accomplishing this was greatly aided by the fact that IT equipment has relatively short (for energy-using devices) useful lifetime so that the hardware evolves as it needs to. In addition, routine software updates ensure compliance with evolving standards. In most cases, dedicated IT staff make sure this all happens as required and troubleshoot problems (at great expense).

Building Networks

For many elements, building networking has and will continue to draw on general network design directly, or with modest adaptation. Examples include network interface hardware, routing algorithms, and the general layering of protocols. However, building networking has several characteristics distinct from that of IT equipment which lead to new requirements. One of these is the relatively slow turnover of building components (lifetimes of several decades rather than several years is common and desirable); another is the fact that

[1] For a related discussion, see "Buildings as Networks: Danger, Opportunity, and Guiding Principles for Energy Efficiency" available as a link from: http://eetd.lbl.gov/ea/nordman/bldgsasnetworks.html

building elements are connected to the "real world" in ways completely unlike the great majority of IT networked devices.

From all this, several critical needs are clear. One is a version of the OSI model adapted to the needs of building networks. Another is application-layer standards that facilitate interoperability. There are no doubt other key needs, but this discussion is limited to those two.

In the past, building components were dominantly produced and sold in national markets, and interoperability was limited to issues such as having the proper power cord connector and expected voltage[2]. IT products are significantly global in their marketing, and most of the components which go into those products are standardized globally. Energy-related building elements — in particular the components which enable networking — will be dominated by globally traded devices. Thus, interoperability of building components will require global standards.

A Modest Proposal

There is an enormous tension between standardization and innovation in electronics and networking. Each cannot exist without the other, and having the wrong balance in either direction creates large problems. Thus, it is necessary to standardize as much as is needed and no more (the challenge of course is to identify just where this optimum lies). The OSI model is designed to isolate design details to individual layers to facilitate interoperability at other layers. A similar approach is needed for building networks. While in theory there are seven layers in the OSI model: Application, Presentation, Session, Transport, Network, Data link, and Physical — others identify only five basic layers (Kurose/Ross): Application, Transport, Network, Link, Physical. For building networks we propose the layers shown in Figure 1.

	User Interface	⇐ Standards
Diversity ⇒	Applications	
	Concepts	⇐ Standards
Diversity ⇒	Transport	

Figure 1. Key network layers for building-related components

This model shows two layers at which standardization is needed — the UI and Concepts. For the other two layers, innovation and diversity will be embraced.

The **Transport** layer embodies the four layers up through the transport layer in existing networking, and embraces the standardization and diversity present today in networks. That is, we do and will continue to have many different types of physical network interfaces (wired and wireless). With the long life of building components, and the evolution of new network interface types, it is a guarantee that any building will have many different types of physical networks operating. While it cannot be ruled out entirely, network interfaces novel to building elements are unlikely to be helpful or successful; they will instead be drawn from interface types developed initially for electronic products or generic sensors. Thus, no building-specific standardization is anticipated at this level.

[2] Some interoperability is accomplished through physical dimensions of boxes, devices, lamp sockets, and such.

Examples include physical layer network interfaces (e.g. Ethernet, WiFi, ZigBee) and protocols built on top of these (e.g. TCP/IP). We can expect IP-based networking to be used in all buildings and by many (perhaps most) individual devices in each building. We should expect continued use of both wired and wireless network links

The **Concept** level in the building stack is where entities in the real world are defined and represented. Information transported among networked devices needs to represent these real-world concepts in ways that can be translated / adapted among protocols and applications. This requires standardization of core ideas, terms, and underlying metaphors. This standard can then be implemented in protocols and applications in ways specific to each. That is, the standardization is about the *meaning* of the information, not the ways that it is encoded or represented. That is the business of the subsidiary standards.

Examples include the building elements themselves (energy using or not) such as lights, climate control devices, windows, and appliances. Other concepts are more abstract such as presence, schedules, prices, and events. Each will have subsidiary concepts such as how to represent dimming levels (e.g. relative vs. absolute, linear vs. eye-response scales), presence and status of window shading devices, what activities that someone present is engaged in, etc.

The **Application** layer is where control functions and decision-making occur. This is an area in which standardization is not required or at least less necessary at this time. Innovation will be critical here, and as a (mostly or entirely) software construct, updating applications will be easier as they evolve. Part of the application layer is assignment of the locations of control function authority — what decisions are made local to the individual device, what is manual by the user, what is made at a room or building level, and what information from outside comes into play. There will always be a need for diversity at this level.

Examples include policies used to put building elements into different states, price-responsiveness, weather optimization, security, etc.

The **User Interface** (UI) layer has been called the "8^{th} layer" of the OSI model. People interact intensively with the UI for their personal phone or personal computer (and the applications they load onto them). The UI is in the service of accomplishing tasks they are actively trying to do, such as opening files, editing documents, browsing the web, or making a phone call. For building elements, in most cases we will want them to operate autonomously, and minimize ongoing interaction, though when interaction does occur, it needs to be crisp, simple, and obvious. In addition, every day people will inhabit residential and commercial spaces other than their own personal ones, and so potentially interact with their UIs. Inconsistent and confusing UIs would be a disaster for energy efficiency, and for usability. In effect, people are entities on building networks as much as a window or light is, and efficiency requires interoperability. For devices to be interoperable to people, the UIs need to be simple, clear, and (most important) *consistent*. Since much of this covers the same ground as the Concept layer, it makes sense to have the elements of the concept layer be the same as those of the UI layer, using the same terms.

At the core of needed UI standardization is ideas, terms, symbols, colors, and underlying metaphors. These show up on the outside of products, on displays for status or configuration, and in user manuals that explain how controls work. Some examples from other contexts that show good standardization are: tape transport control terms and symbols (play, pause, rewind, stop, etc.); color indications for hot and cold (red and blue); the convention that turning a knob clockwise increases the value being controlled; and many aspects of traffic signals. UI consistency will be especially critical for lighting, climate control, presence, and price responsiveness.

Status

A number of companies have proprietary building systems which define the Concepts and User Interface layers. Several physical layer network technologies have recognized the need for standardization at the concept layer to enable interoperability and defined some of these elements; examples include Zigbee, UPnP, and BACNET. However, the organizations which define these standards are motivated to view and use them to advance their particular hardware platforms and technologies — not necessarily for interoperability generally.

For the user interface, some standards exist de facto (though not always globally) such as climate controls from automobiles, lighting conventions (e.g. whether up is on or off), and scheduling conventions used for non-energy controls. However, these are incomplete, not always utilized, and not keeping pace with the rapid pace of innovation, particularly in areas such as lighting control.

Next Steps

Standardization of concepts and ideas related to global networked devices is not new. One example is the user interface for power control of electronic products — that is, turning your PC or TV on or off, or it automatically going to sleep. The IEEE 1621 standard[3] specifies elements for this UI for any electronic product. The research project which led to this standard took as its reference data the elements present in existing standards and existing products. Standardizing the best and most common of what already exists is usually better than inventing something novel.

Key questions and next steps are as follows:

- Creation of initial lists of the items to be potentially covered by standards in this area.
- Consideration of standardization paths for the development of the content of these standards and the institutions that might host them. The global nature of the need makes this a particularly difficult issue.
- Communicating the idea to wide audiences to create a critical mass of interest and support for the work.
- Detailed review of selected individual topics. Lighting seems the best single place to start for several reasons: the systems are more easily understood than others (such as climate control), the resulting behavior is clearly apparent, the need for simplicity and potential for complexity are obvious, and we already have widespread examples of confusing and inconsistent UIs.

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[3] See http://eetd.LBL.gov/Controls/1621 for more information.

- Research and development to create draft international standards. This includes comprehensive review of relevant standards, technologies, and products, analysis of these, and proposals for the “best” solutions to each conceptual and user interface topic.

Notes on the OSI model and layers

The table below illustrates the relationship between the OSI and buildings layers. Concepts are shown not as a layer unto themselves in OSI terms, but rather a common reference point for the actual layers above and below. Where the concepts sub-layer resides is unclear; it is possible that it should really be between higher layers.

OSI layer	OSI name	Building layers
		User Interface
7	Application layer	Applications
6	Presentation layer	
5	Session layer	
		Concepts
4	Transport layer	Transport
3	Network layer	
2	Data link layer	
1	Physical layer	

Further research needed on

- Multi-modal user interfaces
- Applicability of “digital shadow” concept
- Industry Foundation Classes
- IEC TC 8