Networks in Buildings: Which Path Forward?

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ABSTRACT

To date, digital networks have principally been installed for connecting information technology devices, with more modest use in consumer electronics, security, and large building control systems. The next 20 years will see much greater deployment of networks in buildings of all types, and across all end uses. Most of these are likely to be introduced primarily for reasons other than energy efficiency, and add energy use for network interfaces and network products. Widespread networking could easily lead to increased energy use, and experience with IT and CE networks suggests this may be likely. Active engagement by energy efficiency professionals in the architecture and design of future networks could lead to their being a large and highly cost-effective tool for efficiency. However, network standards are complex and take many years to develop and negotiate so that lack of action on this in the near term may foreclose important opportunities for years or decades to come. Digital networks need to be common globally, providing another challenge to building systems and elements that are more commonly designed only for national or regional markets. Key future networks are lighting, climate control, and security/presence. This paper reviews some examples of past network designs and use and the lessons they hold for future building networks. It also highlights key needed areas for research, policy, and standards development.

Introduction

The coming twenty years will see a dramatic transformation of energy consumption patterns in buildings. Each year an increasing portion 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 easily increase rather than reduce consumption.

The past twenty years of increasing networking of electronics shows the danger of a lack of attention to energy minimization. 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 waste resulting from lack of considering energy in network design. A similar outcome is quite possible for other energy end uses.

Non-electronic end uses (e.g. climate control, lighting, and appliances) are at the early stages of being digitally networked on a wide scale. 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. 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 buildings. 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.

Building Networks

Buildings in future will have a variety of network hardware and capability. While the various networks will be interconnected and interoperate, it is helpful to think of them as distinct to assess consumption and savings, requirements for efficiency, and policy needs. The basic network types can be categorized as follows.

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 and rates 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, though latency needs to be close to or below the level of human perception.

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 need greater interaction, integration, and interoperability with other building networks. Climate control also extends to ventilation, window and door opening, and shading. Data rates are also low, and latency is not a concern.

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. Some security functions are indistinguishable from general electronic network functionality but may be segregated for operational or legal reasons.

Other networks. These principally cover appliances and miscellaneous devices (e.g. irrigation), and are most likely to be appended to other networks.

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

Other Network concepts

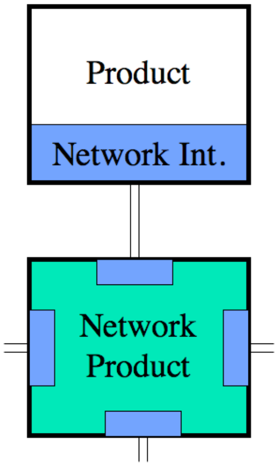
Layers. Digital networks are designed with layered protocols. The original OSI model has seven layers, but for many purposes it is sufficient to define only five as shown in Table 1. The user interface has commonly been called the “8th layer”, atop the traditional seven.

Table 1. The Internet Protocol Stack (Kurose & Ross 2005)

Layer	Core function
Application	Interfaces directly to applications
Transport	Moves data reliably from one end device to another
Network	Moves packets from one end device to another
Link	Moves data across a single network link
Physical	Move bits along a wire or through the air

Direct and Induced Consumption. Networks increase energy consumption in two ways. There is **direct** consumption from network interface components, and products whose only (or primary) 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). Figure 1 shows the relationship among non-network products, interfaces, and network products (the thin lines are links, wired or wireless).

Figure 1. Network product and network connected product energy use (Nordman 2008)



Digital building networks to date have been largely of two forms. In the commercial sector, technologies such as BACnet brought existing analog control elements into the digital networked realm, with a variety of energy and operational benefits. BACnet is generally used only on large buildings. In the residential sector, networks are most commonly installed for “home automation” in high-end houses with extensive audio and video distribution capability.

Past experience with networks and energy

The electricity delivery system is a vast and extraordinarily complex network, and over a century old. Traditional light switches and thermostats are very simple network examples. Information networks are also not new — the telegraph network arose over 150 years ago. 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, and this is the key to their power and potential for energy efficiency. Consumer electronic devices have long been networked with analog connections, and are now undergoing a rapid shift to digital.

Information Technology (IT)

When power management was introduced into personal computers, network connectivity was not considered in its design; it was simply lost when in a sleep mode. 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 U.S. desktop PCs occurs when no one is present. There is a huge infrastructure of hardware, software, protocols, applications, users, expectations, and the like which presumes continuous network connectivity. As current systems cannot simultaneously sleep and be fully connected, they lose their most important mechanism to save energy. Fixing this problem after the fact is possible, but much more difficult and expensive than to have done it when the network technologies were originally developed.

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 (often to 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 in the network. As with computers, those concerned with energy use and efficiency have not been involved in developing the standards for CE inter-device control. Manufacturers who are involved are more focused on simply making things work at all, content protection, and features which appeal to consumers, rather than to any significant effort on power controls.

Network architecture

Computer networks, in particular the Internet, were not designed with energy use or efficiency in mind. At the time of design, 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.

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, the suite of Internet protocols that define several of the layers, and physical layer technologies such as Ethernet and WiFi. This was derived from considerable public research on network architecture that evolved many key principles about how networks can and should be constructed.

Efficiency

While there is little about networked electronics to indicate that greater energy efficiency will be a significant cost burden, the reality is that without specific attention to energy efficiency, it usually doesn't happen. For both IT and CE, confusion has been sown by poorly-designed and inconsistent user interfaces around power control. The only entities likely to bring this specific focus are those whose primary concern is efficiency, but energy organizations are generally unfamiliar with the highly technical nature of the technology and institutions which create it. An example of efficiency-motivated work can be found at (Nordman 2007).

The development of high performance and robust IT networks was greatly aided by the fact that IT equipment has relatively short (for energy-using devices) useful lifetime so that the hardware evolved as it needed to. In addition, routine software updates ensured compliance with evolving standards. In most cases, dedicated IT staff make sure this all happens as required and troubleshoot problems (at great expense).

Future Scenarios

In 20 years, there will certainly be far more networking of building elements than today. However, how those networks are constructed and deployed, and what they mean for energy efficiency, is much less clear. Following are two scenarios that represent the extremes of the range of likely futures. Reality will lie somewhere in between, but whether it ends up closer to one end or the other will make a large difference in future buildings energy use.

A "Darwinian" future

It is 2028, and most buildings have a significant network infrastructure. Unexpectedly, the average highly networked building uses more energy than the comparable building with little or no network infrastructure. Vendors of network technology touted the energy saving potential as one of its benefits. What went wrong? The following are some key factors.

- Building networks have been principally installed to improve the quality of the space for the occupants, *not* saving energy. This pattern repeats what occurred with the initial networking of electronics (1985 through 2005), as well as the early days of high-tech residential building controls in that same period.
- Promoters of specific technologies ignore and resist opportunities for interoperability, as they try to gain maximum market share for their unique technologies. This continues the trend to proprietary solutions long found in controls for large buildings.
- Efficiency has been an afterthought in network and product design, with other features driving the process (trade publications and trade shows continue to show this).
- Standards are critical to facilitate interoperability, but aspects that are needed for energy efficiency are often absent or ill-formed. Clear opportunities for harmonization across standards (e.g. in terminology) have not been taken.

- User interfaces have been neglected, with individual manufacturers seeing this as an opportunity to differentiate their products, at the expense of users and efficiency.
- Little coordination has occurred across end uses. In electronics at the turn of the century this manifested itself as the "IT" and "CE" domains, with different physical, application, and device infrastructure, though by the mid teens, these achieved clear convergence. For buildings, the end-use domains remain largely separate and mis-aligned, with convergence occurring very slowly and some parallel infrastructure required.

While some argue for a converged network architecture standard, there are trillions of dollars of investment in equipment that would then become non-interoperable "legacy" devices, wasting energy and imposing large human and capital costs in getting them to work correctly with the new network. Some use the word "fiasco" to describe the predicament.

An "Intelligent Design" future

It is 2028, and most buildings have a significant network infrastructure. While there is an energy burden in network interfaces and products, studies have shown that highly networked buildings use considerably less energy than those that lack the infrastructure, as well as being healthier, more satisfying to occupy, and facilitating higher productivity. New, higher ventilation requirements mean that buildings with fine-grained occupancy sensing save large amounts of space conditioning energy.

Because the networking is based on open international standards, using any sort of networked room (residential or commercial) in any country of the world is a simple, satisfying, and energy efficient experience. In 2008, office buildings and houses typically had space conditioning that served an entire floor uniformly, and a few ordinary light switches for each (sometimes large) space. Today, rooms typically 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, and past occupancy patterns, and that 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, cooling, or ventilation, window opening, shading, and diverse (now solid state) lighting.
- Lighting patterns that change automatically, depending on what the occupant is doing (e.g. using a computer, watching TV, meeting with someone, eating lunch, or sleeping).
- Climate control that follows preferences, outdoor climate (to indicate clothing), and occupancy (allowing the likelihood of occupancy to drive deviations from the target).
- Preferences expressed through many means, including hand gestures, voice, and any display, to make control of the space as unobtrusive and natural as possible.
- Displays coordinated with occupancy and lighting, and — being large —the largest user of energy in many spaces. With widespread availability and use of videoconferencing, lighting adjusts when cameras are in use.
- Diagnostics that identify when a component is performing badly or has failed, to compensate for it as well as possible, and notify people as appropriate.

Building controls today are highly dynamic, to follow conditions to optimize the service delivered, and (usually) to minimize energy requirements. The dynamic nature occurs mostly in how each devices operates itself. As people and devices move into and out of spaces (or within the space) the changing mix present changes the behavior of all devices. The space continually readjusts as conditions in the space, outdoors, and energy prices change. Another key aspect of dynamic control is how it responds to anomalous conditions, be they those of the user (e.g. a guest or unusual usage), or error conditions as when devices malfunction or are removed.

Achieving a Better Future

Back to 2008. The key to having a networked future better for energy efficiency is to design the necessary infrastructure to enable it. Some elements are already in process, particularly physical and transport layer technologies. The remainder of this paper addresses higher-layer needs to enable universal ineroperability. All conclusions apply to both residential and commercial buildings and there should be no difference in them for the fundamental architecture and basic standards.

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 networks have 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 building elements are connected to the "real world" (Gershenfeld 2004) in ways unlike IT devices.

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[1]. IT products are significantly global in their marketing, and most of their components are standardized globally. Energy-related building elements — in particular the components which enable networking — will be dominated by globally traded devices. Thus, interoperability will require global standards.

Other parts of building networking do need attention. For example some (Podgorny et al. 2007) have noted that many existing building control architectures are not designed in ways consistent with those that have made the Internet a success, such as clear layering and the end-to-end principle.

Necessary Design Infrastructure

There is enormous tension between standardization and diversity 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.

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

The rest of this paper is a proposal for how to extend the OSI model approach for building networks. The relevant layers are shown in Figure 2.

Figure 2. Key layers for building networks

	User Interface	⇐ One Standard
Diverse New Standards ⇒	Applications	
	Concepts	⇐ One Standard
Existing Standards ⇒	Transport	

In this proposed model, there are two layers at which a single standard is needed — the UI and Concepts. For the other layers, some innovation and diversity will be embraced. Whether the Concepts should be an explicit ordinary layer, or a meta-standard that is introduced into protocols at the application layer, is not yet clear. The UI layer exposes to the user most of the ideas in the concepts layer, so there is a strong linkage between the two. In most cases the concepts will be adaptations of how people generally understand the building elements today, but in some cases they may be not yet widely in use today.

Transport. The Transport layer embodies the four layers up through the transport layer in existing networking (i.e. also including network, data link, and physical layers), and embraces the standardization and diversity present today in networks. That is, there will continue to be 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, most buildings will have many different types of physical networks operating simultaneously. 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.

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

Concepts. The Concept level in the building network 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 and 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* (semantics) of the information, not the ways that it is encoded or represented (except in the UI). That is the business of the application layer standards.

Examples include the building elements themselves (energy using or not) such as lights, climate control devices, windows, displays, 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, and what activities that someone present is engaged in. Some concepts may be common across devices, such as how to express physical location.

Most information technology is about abstract concepts, such as databases, programs, or security. One example in which IT has addressed real-world entities is in document preparation, since these are routinely rendered to paper form. This has relied on a number of (sometimes de facto) standards, such as ASCII for data representation, names for standard fonts, annotation conventions (bold, italic, underlined), measurement units (e.g. points), and layout conventions. Documents also rely on mechanisms to represent whole pages, notably the Portable Document Format (PDF), and Hypertext Markup Language (HTML)..

Application. The Application layer is where control functions and decision-making occur. This is an area in which standardization is still required, but some diversity of protocols for the same function can be tolerated. Innovation will be critical here, and as a (mostly or entirely) software construct, updating application protocols 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 the building comes into play. There will always be a need for some diversity at this level.

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

User Interface. The UI is the method by which people express the intention to accomplish tasks, and gleaning useful information from a system. For building elements, in most cases they will 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. People are also more mobile than electronics and always are "connected" to their local (networked) environment. 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.

A special case of user interfaces is those used only by people who have a primary job function to manage energy use in a building. This is analogous to the special controls in construction vehicles that are absent from ordinary cars and trucks. Professional interfaces need greater richness and capability than more casual ones, but should build on them.

Presence. In future, building spaces (and even some outdoor spaces and vehicles) should 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.

Most services should 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. so that the person emptying rubbish bins in the evening does not fully "wake up" every office visited). 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. There should be 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 a person enters any room for the first time they will have a good idea how it works, as exists today for cars). This requires integration at many layers of the network hierarchy.

Next Steps

A number of companies have proprietary building systems which define the Concepts and User Interface layers. Several standards organizations 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 up with the rapid pace of innovation, particularly in lighting.

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 a PC or TV on or off, or it automatically going to sleep. The IEEE 1621 standard (IEEE 2004) 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 next steps for a more efficient future are as follows:

- Create of initial lists of the items to be potentially covered by standards in this area.
- Analyze each main concept and its relation to the user interface.
- Develop and better articulate the candidate overall network architecture.
- Consider 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 issue particularly challenging, but even more important.
- Communicate the idea to wide audiences to create a critical mass of interest and support for the work, particularly industry (many), standards organizations, and energy policy organizations (including government agencies).

- Review selected individual topics in detail. Lighting seems the best single place to start for several reasons: the systems are more easily understood than other end uses, the resulting device behavior is clearly apparent, the need for simplicity and potential for complexity are obvious, implementation may be quicker and cheaper, and there are already widespread examples of confusing and inconsistent UIs.
- Settle on an overall architectural design for the network infrastructure.
- Conduct 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.

Notable outstanding questions

The emerging networking of buildings contains some areas that will require further research and experience to make clear what approaches and methods are best to implement and use. These are not the only topics that need focused attention, but should be on any list.

The issue of **authority** is likely to create considerable complexity and difficulty in building networks. Many entities — devices, controllers, and people — within a building may want to express preferences about how energy-relevant devices should behave, and may want to cause specific actions to occur. These range from the end use device itself (e.g. a light), to a local switch, to a floor or building-wide controller, and information will flow in from sensors, price information, security considerations, and building management concerns at possibly multiple levels. Which entity has the final say under each different circumstance?

As with much of IT today, **security** will be a major concern for energy management. People with bad intent may try to manipulate the state of energy-using devices to annoy people, cause local damage, or — by simultaneously increasing or decreasing the demand of many devices in an area — trying to crash the electricity grid. With devices networked, it may be possible to spy on their status from outside a home to glean unwanted insight about occupancy or occupants. For wireless devices, even if packets are encrypted, merely the patterns of when packets are sent, and of what length they are (and the destination if that is not encrypted) may provide clues.

People interact with many devices intensively only when there is some sort of **anomaly**. The automobile provides a good example; for many people it is only when some strange sound, vibration, or emission occurs, or when it stops working entirely, that they pay attention to the inner working of the engine and other parts. The same is true of building controls; they should recede into the background of life for the most part, and only have them come to the fore when there is something anomalous about our needs and desires, or when something goes wrong with one of the building components. Thus, making unusual behaviors work well is as important than making the ordinary use work well.

Conclusions

The past two decades has seen an inexorable increase in the degree and sophistication of digital networking across electronic devices. This has greatly increased the services they provide, but significantly increased their energy use, partly as electronic networks have been designed and implemented with little regard for energy consumption.

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. For the most part this may be done for reasons other than saving energy, such as greater comfort, control, security, productivity, and entertainment. A plausible 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.

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. 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 making this a highly cost-effective investment.

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