Saving energy in unoccupied buildings

Alan Meier
Lawrence Berkeley National Laboratory
Berkeley, California
USA
akmeier@ucdavis.edu

Sadia Gul
Energy Graduate Group
University of California, Davis
USA
gul@ucdavis.edu

Kurt Kornbluth
Department of Biological and Agricultural Engineering
University of California, Davis
USA
kkorn@ucdavis.edu

Josh Morejohn
Energy and Engineering, Facilities Management
University of California, Davis
USA
jdmorejohn@ucdavis.edu

Keywords

building design, equipment, appliances, codes, occupancy

Abstract

This paper describes a means of reducing the energy use of miscellaneous electrical loads (MELs) in buildings during times when nobody is in them. Reducing energy use in "vacant" buildings is an attractive target for policy initiatives because nobody is present to complain about reduced services. At one university campus, the buildings were fully vacant about 29 % of the time. These times mostly corresponded to nights, weekends, and holidays (and, more recently, pandemics). About 24 % of the buildings' electricity use occurred during these times, even though no people were in the buildings. The electricity consumed by uncontrolled MELs appears to be responsible for much of this consumption. This study investigates opportunities to save electricity in buildings during these unoccupied periods. We also identified many devices that are presently not fully controlled and could be operated at much lower power levels during periods of total vacancy. Many of these devices can be modified to greatly reduce their energy use during vacant periods, yet quickly recover to normal operation if somebody enters the building. The energy savings potential ranged up to 90 % during vacant periods.

Introduction

Miscellaneous Electrical Loads (MELs) are responsible for over 30 % of electricity use in commercial buildings (U.S. Department of Energy 2015). Appliances and devices except those used for heating, ventilation, air conditioning, lighting, water heating, and refrigeration are considered as MELs (Sofos 2016). These loads include plug loads, network equipment, security systems, lifts, and even some components in HVAC systems. Most of these devices are not controlled. This results in empty buildings having high MELs electricity use during nights, weekends, and holidays. The absence of controls was made evident during the pandemic where, for example, the Empire State Building's MELs electricity use fell only 28 % even though almost nobody was in the building (Kaplan 2021). This did not include electricity used for cooling and heating. A national survey of office buildings found only a 21 % reduction in electricity use during the pandemic (St. John 2020). This highlighted the fact that the energy consumption of the buildings is not falling with the decreasing occupancy levels. The relationship between the level of occupancy and energy use is depicted in Figure 1. The same phenomenon occurred in smaller commercial buildings and campuses around the United States. In other countries, similar outcomes were observed. For example in a study of administrative buildings in Brazil, the monthly energy consumption dropped only 38.6 % (Geraldi et al. 2021), and a 46.6 % reduction was reported for a University building in the UK (Birch et al. 2020). Reducing electricity consumption when buildings are vacant is an untapped opportunity specifically for MELs with significant potential for electricity savings.

Looking to the future, we can expect many types of commercial buildings to have more variable (and less predictable) occupancy levels, including longer periods of vacancy. Figure 1 also shows the opportunity for energy savings through control of MELs in vacant and sparsely occupied buildings.

This paper outlines a means of reducing the energy use of miscellaneous electrical loads in buildings when vacant. The

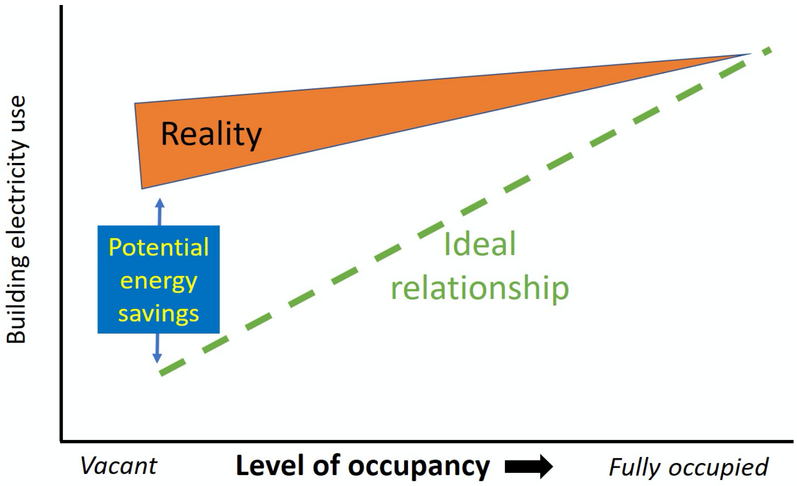

Figure 1. Qualitative depiction of energy savings potential from making buildings more vacancy responsive.

presence of wasted energy was demonstrated at one campus of the University of California. This campus, with about 35,000 students contains over 600 buildings with a wide range of activities, so findings are likely to apply elsewhere. The research undertaken so far, along with a broader strategy to reduce energy in vacant buildings, is presented below.

Approach

The general approach to saving energy in buildings during unoccupied periods has 5 steps: 1) Understanding if there is a vacancy problem, 2) accurately predicting vacancy, 3) identifying eligible equipment and controls, 4) Developing a strategy to turn equipment off, and 5) restarting equipment. Here we will focus on steps 1–3 at a university campus in California.

HOW DOES ELECTRICITY CONSUMPTION CHANGE WHEN BUILDINGS ARE EMPTY?

Thus, the first goal of our research was to determine the reality of the relationship shown in Figure 1. In addition to the "normal" vacancies caused by nights, weekends, and holidays, the UC Davis campus has experienced unprecedented events that forced unplanned vacancies. The pandemic of 2020/2021 was of course the greatest event, but this was preceded by a week-long closure in 2018 caused by air quality problems resulting from nearby wildfires. A series of regional power failures also caused briefer shutdowns. In all cases, nearly all buildings were closed to staff and students. The impact of the pandemic closure is shown in Figure 2. During the pandemic, there was a 90 % reduction in occupancy but only a 15 % reduction in electricity use. The electricity consumption was caused by HVAC equipment, MELs, laboratory equipment, and other devices. Steam and chilled water are supplied to the buildings (and can be controlled) by a central facility, but much of this electricity consumption is presently outside the control of the campus energy manager.

These data show that electricity use did not substantially fall during vacant periods. However, it does not show the potential savings. In other words, how close to the "ideal relationship" shown in Figure 1 are the UC Davis buildings? To answer this question, we examined the energy use in buildings while they are vacant (Sloan 2019). Figure 3 shows the ratios of power use during vacant and occupied periods for a subset of the buildings. The vacancy was determined by the number of Wi-Fi connections. Wi-Fi connections have been shown to be a powerful (though not perfect) indicator of occupancy (Ouf et al. 2017). Periods with fewer than three devices connected to the Wi-Fi network were treated as vacant though many buildings achieved periods with zero connected devices. (Note that some buildings have more "baseload" Wi-Fi connections – but it is clear they are not occupants because they never leave.) Some buildings used essentially the same electricity occupied or vacant. A high continuous consumption was (partially) justifiable because these buildings had laboratories with refrigerators and special research apparatus. But many others were offices, classrooms, and gyms with few or no laboratories; nevertheless, only one building's electricity use fell more than 50 % while vacant. Overall, the buildings were fully vacant about 29 % of the time. These times mostly corresponded to nights, weekends, and holidays (and, more recently, pandemics). About 24 % of the buildings' electricity use occurred during these times.

What systems and equipment are operating even though their services are not required? Most of the lighting is centrally controlled and had been switched off, so more detailed investigations were required. We found, for example, classrooms with rows of monitors (for teaching computer courses) still switched on and not even in sleep mode. Domestic hot water circulation pumps (to service faucets and showers) were operating continuously, even though there were no demands for hot water. We investigated one building, Giedt Hall, that was entirely dedicated to classrooms and lecture halls because we were certain it was completely unused during the pandemic and other vacant periods (Figure 4). Devices connected to the Wi-Fi network dropped to zero during the nights and spring vacation. Giedt Hall's electricity consumption did drop during nights, weekends, and pandemics, but was still not appreciably below occupied periods. We found that the audio-video equipment (used for powerpoints, videos, and other media) was responsible for almost a third of the electricity use. These "racks" consisted of many components but were never switched off. Each drew up

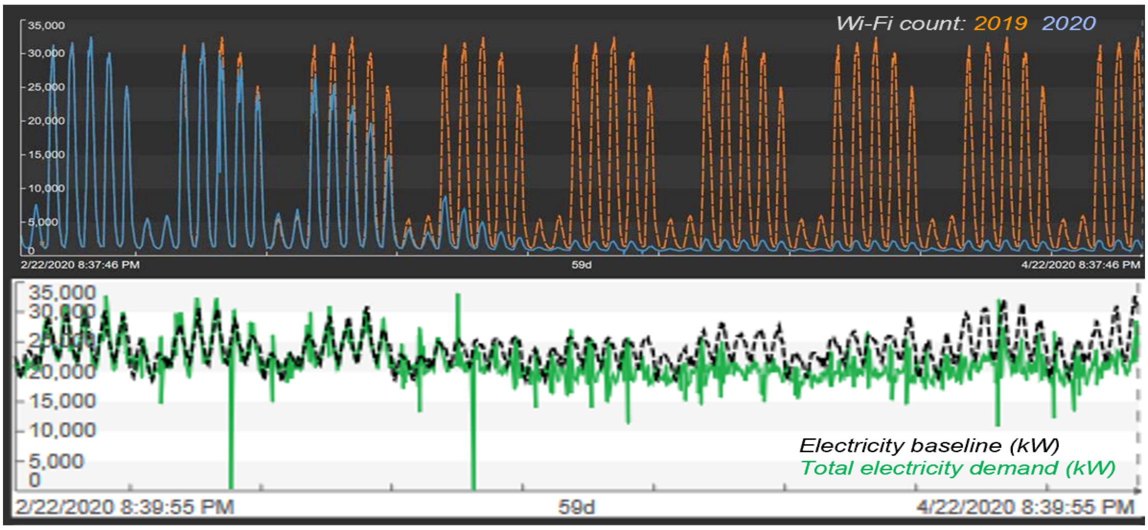

Figure 2. UC Davis electricity consumption before and during the pandemic, with counts of Wi-Fi connections shown to demonstrate drops in occupancy.

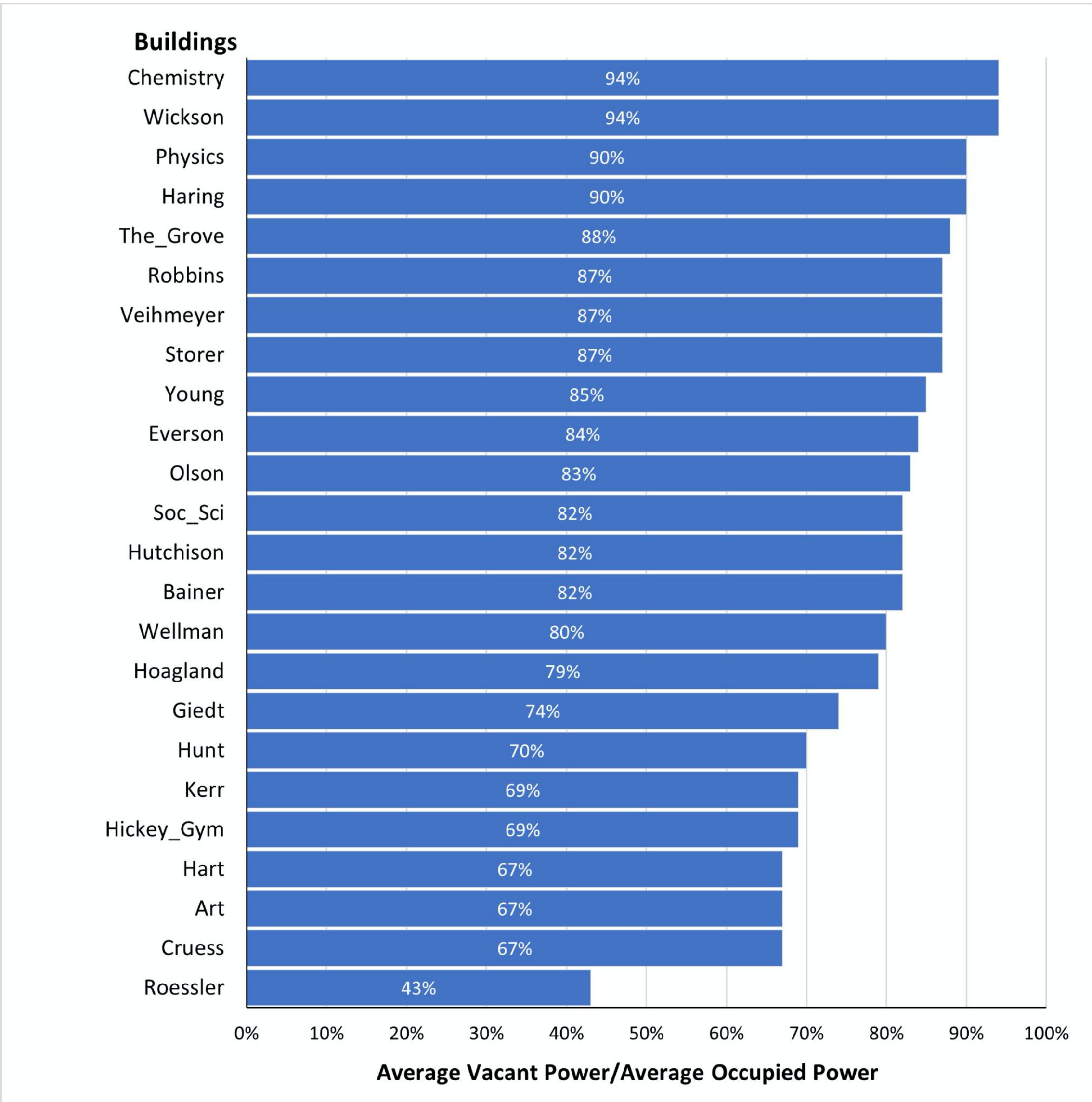

Figure 3. Ratios of vacant/occupied power use for selected buildings at the UC Davis campus.

to 600 W. One of our projects is now to work with our IT department and equipment vendors to reduce power use because electricity consumed by the server and the Wi-Fi router network accounted for a surprisingly high consumption, too.

Developing a Strategy to Reduce MELs Electricity Use in Vacant Buildings

As a consequence of these investigations, we realized that a new strategy was required to reduce electricity use in vacant buildings. We targeted the vacant condition because more equipment could be switched off (or reduced to a very low level of service) without inconveniencing anybody. However, "vacancy" is unlike "occupancy" because vacancy is a binary condition: yes or no. In contrast "occupancy" is a wide range of conditions (including vacancy). Worse, there are no "vacancy sensors"; instead, one can only infer vacancy from many sources of information.

We are now developing a "vacancy inference engine" which draws upon existing sensors, schedules, and calendar outputs to identify periods when no people are present and calculates a probability in that identification. The engine will disseminate a vacancy signal to the MELs that contains the engine's calculated probability that the building is indeed empty. Each MEL must be configured to enter into a lower-energy "vacancy mode" based on the confidence level and its operation. Figure 5 explains the full concept.

The concept incorporates three unique innovations:

- A vacancy inference engine (VIE) that uses inputs from multiple sensors/systems, to continuously estimate the confidence that the room, zone, or building is vacant;
- A signal disseminated to MELs communicating the probability level that the room, zone, or building served by the MEL is vacant;
- MELs, each with the ability of determining whether the VIE's probability level has exceeded its own threshold value and then switching to a new, lower-power, vacancy mode.

These innovations are described below.

THE VACANCY INFERENCE ENGINE (VIE)

The VIE combines information from available building information sources and calculates the likelihood that the building is vacant. If we are confident that nobody is in the building, then MELs can be switched to much lower power levels and save energy that would otherwise be inaccessible. Buildings already have many sensors that detect occupancy but this information is not directly useful for determining vacancy – there are no "vacancy sensors". The solution is to *infer* vacancy with an associated probability. This inference can draw upon a wide range of information sources, including occupancy sensors, entry counts, Wi-Fi connections, cameras, etc. Additional sensors or different types of sensors together increase the confidence in the inference. For example, entry monitoring is valuable but not conclusive, but the combination of entry monitoring and Wi-Fi connections will more confidently

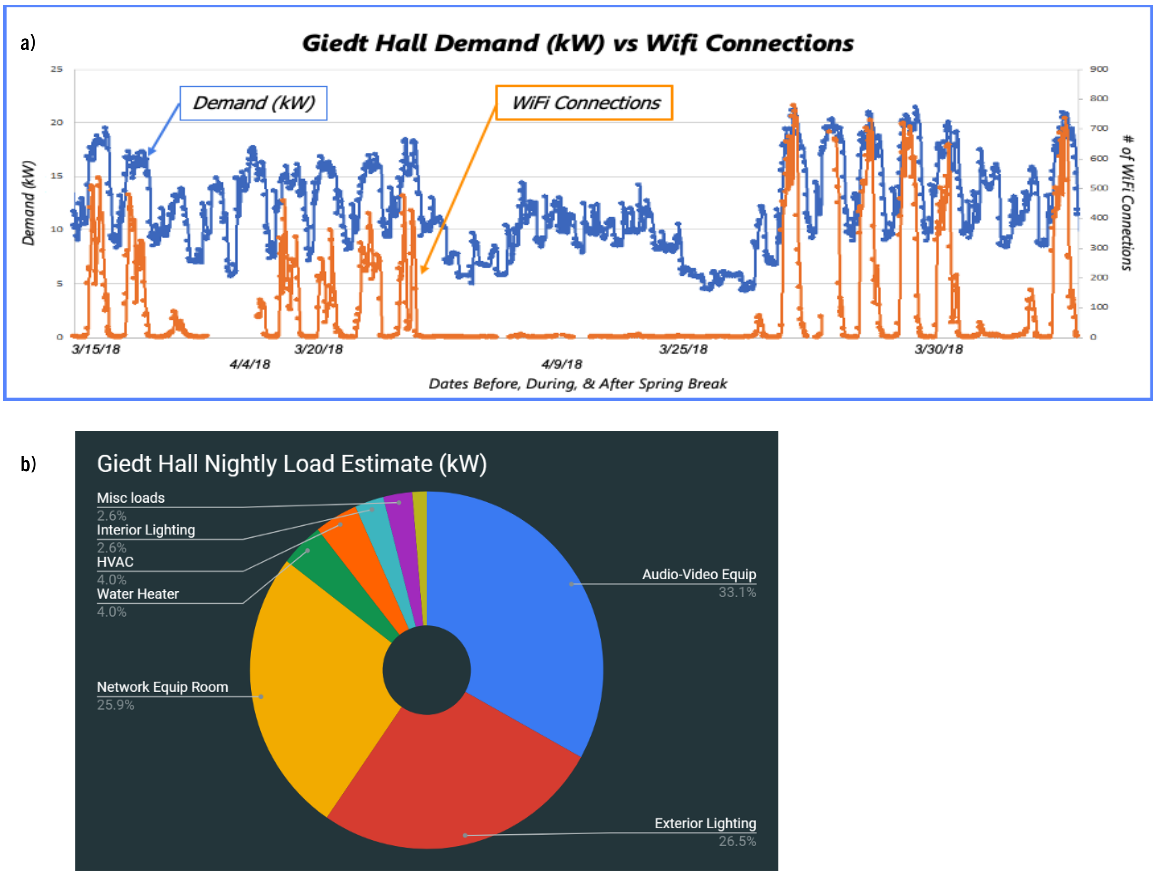

Figure 4. a) Giedt Hall electricity use and Wi-Fi connections; b) Estimated electricity end-use breakdown in Giedt Hall during vacant periods.

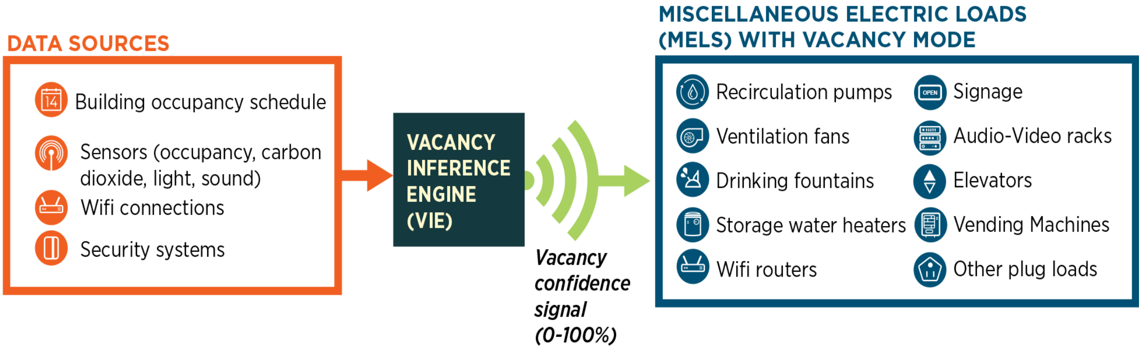

Figure 5. Proposed method to reduce miscellaneous electrical loads in a building.

identify when nobody is present. At least ten potential inputs to the vacancy inference engine are available in commercial buildings today, although not all are present in every building. These sensors generate heterogeneous data, including continuous time-series measurements (each at its own frequency) and scalar, discrete and static records (such as HVAC or classroom schedules).

The VIE relies on a relationship between each sensor's output and the likelihood of vacancy. Based on the type of sensor, this relationship could be expressed as a look-up table generated by a domain expert, training, or a data-driven function approximation. Finally, sensor fusion, based on machine learning and other techniques (Nasir et al. 2015), is used to generate a single probability that the building is vacant. The VIE pushes the probability of vacancy to MELs that are vacancy-responsive. The frequency of updates depends on inputs from the sensors; however, it could be as short as every minute. The vacancy inference engine could stand alone; however, it will ultimately reside in the building automation system (BAS).

THE VACANCY PROBABILITY SIGNAL

The VIE would periodically broadcast an updated signal to all network-connected MELs in the building. This signal will contain a securely encoded vacancy probability value. The signal can be transmitted via ethernet for connected devices or wirelessly for other devices. Wireless protocols will include Wi-Fi or other, lower-power protocols.

Each MEL will use embedded logic to decide if the broadcasted signal exceeds the unique threshold value for that device. The threshold value will depend on the importance of the service provided and the speed at which service can be restored. For example, Wi-Fi networks serving a building could greatly reduce beaconing rate – and power use (García Baquerizo et al. 2019) – when certainty of vacancy rises above 95 % (and then restore full service when the certainty falls again).

VACANCY MODES IN MELS

Most MELs don't know when the building is empty and when their services can be curtailed. Networked equipment may enter sleep modes after a period of non-use, but this action is frequently subverted by other networked equipment. For most MELs, a method to receive vacancy information is needed in a way that permits them to uniquely respond.

Many types of MELs could be modified to include a "vacancy mode" and large savings are possible. Selected MELs and their behavior during the proposed vacancy modes are described in Table 1. All MELs will require communications to enable a vacancy mode; however, those devices already networked may be able to piggyback on the existing system. While most types of electronics would ideally undergo firmware and software modifications, vacancy response can sometimes be implemented via controllable power electronics or smart switches. Fans, drinking fountains, and pumps will need to incorporate both communications, controls, and hardware changes so as to create a vacancy mode, although some could be retrofitted. To be sure, each device must be considered individually but many solutions will benefit from cross-cutting components, logic (and, ultimately, a technical standard). We imagine that ENERGY STAR will play a role in supporting the vacancy mode. The annual energy savings will depend on the number of hours during which the building is vacant. The savings fractions are high because nobody will be in the building to complain that these services are not available.

Potential Electricity Savings

The qualitative performance goal is to scale MELs energy use in proportion to the number of occupants in the building. The target and potential energy savings are conceptually depicted in Figure 1. UC Davis found that campus buildings were fully vacant about 29 % of the time when about 24 % of MELs energy use occurs. We assume that the typical commercial building is vacant 2,500 hours/year (29 % of the time), although operating changes caused by the pandemic may have increased this fraction. Note that some devices may enter vacancy mode for longer times if they accept lower confidence levels of inferred vacancy.

The proposed concept will reduce energy use up to 95 % in participating MELs during vacant periods, but the target level of performance is 50 % savings (see Table 1). If the typical building is vacant 2,500 hours/year, the target performance objective is (.29 * 0.5 =) 15 % reduction in a building's annual MELs electricity use. Much of these savings will occur during the night when no solar-generated electricity is available and thus minimizes demand for storage and non-renewable supplies.

Conclusions

In a post-pandemic world, it is easy to imagine that occupancy levels in buildings will fluctuate more widely and unpredictably. HVAC energy use (and lighting) is relatively easy to manage because it is centrally scheduled and controlled. But MELs

Table 1. Sample MELs, proposed vacancy modes, and estimated savings during vacant periods.

Device	Modification to Create A Vacancy Mode	Estimated Energy Savings During Vacant Periods*
Hot water recirculation pump	Cycle pump 10 % of time	90 %
Wi-Fi router	Reduce beaconing rate	40 %
Restroom Ventilation fan	Cycle fan 20 % of time	80 %
Lab exhaust fan	Turn down to minimum allowable	0–50 %
Drinking fountain compressor	Switch off	75 %
Storage water heater	Switch off or setback temperature	5–50 %
Digital display sign	Switch off display	95 %
Elevator	Switch off fan, lights, some controls	40 %
Audio-Video rack	Switch off	90 %

** Based on estimated reductions in run time during vacant periods, adjusted for recovery times and other operational characteristics. Savings are always less than 100 % because some power will be required to receive the vacancy signal.*

electricity use is becoming increasingly less flexible with respect to levels of occupancy thanks to the proliferation of MELs and other uncontrolled equipment. These devices are also a growing fraction of building energy use. The "vacant" condition was identified as a unique situation where more aggressive management is possible because it causes the least inconvenience. However, this strategy requires methods to reliably identify vacant periods and then switch off non-essential equipment or switch to a lower-power, vacancy mode. We demonstrated a method to infer vacancy and how this information could be communicated to equipment. To be sure, a vacancy-responsive building will require new types of sensors, controls, and MELs but many of the steps can happen incrementally and at modest costs.

References

Birch, Christina, Rodger Edwards, Sarah Mander, and Andy Sheppard. "Electrical Consumption in the Higher Education Sector, during the COVID-19 Shutdown." In *2020 IEEE PES/IAS PowerAfrica*, 1–5, 2020. https://doi.org/10.1109/PowerAfrica49420.2020.9219901.

García Baquerizo, Juan Pablo, Alvaro Suárez, Elsa Macias, and Edgar Salas. 2019. "Hardware Mechanism for Energy Saving in WiFi Access Points." *Sensors* 19 (21): 4745. https://doi.org/10.3390/s19214745.

Geraldi, Matheus Soares, Mateus V. Bavaresco, Maria Andrea Triana, Ana Paula Melo, and Roberto Lamberts. "Addressing the Impact of COVID-19 Lockdown on Energy Use in Municipal Buildings: A Case Study in Florianópolis, Brazil." *Sustainable Cities and Society* 69 (June 1, 2021): 102823. https://doi.org/10.1016/j.scs.2021.102823.

Kaplan, Sarah. 2021. "An Empire State of Green." *Washington Post*, January 14, 2021. https://www.washingtonpost.com/graphics/2020/climate-solutions/empire-state-building-emissions/.

Nasir, Nabeel, Kartik Palani, Amandeep Chugh, Vivek Chil Prakash, Uddhav Arote, Anand P. Krishnan, and Krithi Ramamritham. 2015. "Fusing Sensors for Occupancy Sensing in Smart Buildings." In *Distributed Computing and Internet Technology*, edited by Raja Natarajan, Gautam Barua, and Manas Ranjan Patra, 73–92. Lecture Notes in Computer Science. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-14977-6_5.

Ouf, Mohamed M., Mohamed H. Issa, Afaf Azzouz, and Abdul-Manan Sadick. 2017. "Effectiveness of Using WiFi Technologies to Detect and Predict Building Occupancy." *Sustainable Buildings* 2: 7. https://doi.org/10.1051/sbuild/2017005.

Sloan, Alex. 2019. "Energy Consumption in Campus Buildings When No One Is Around." Energy Graduate Group Masters Thesis, Davis, California: University of California, Davis.

Sofos, Marina. "Miscellaneous Electric Loads: What Are They and Why Should You Care?" Energy.gov, September 15, 2016. https://www.energy.gov/eere/buildings/articles/miscellaneous-electric-loads-what-are-they-and-why-should-you-care.

St. John, Jeff. 2020. "Why Empty Office Buildings Still Consume Lots of Power During a Global Pandemic." Greentech Media. April 14, 2020. https://www.greentechmedia.com/articles/read/how-office-buildings-power-down-during-coronavirus-lockdown.

U.S. Department of Energy. 2015. "Quadrennial-Technology-Review-2015." Washington, D.C.: U.S. DOE.

Acknowledgments

This work was supported by the University of California, Davis, Energy and Efficiency Institute and a grant from the UC Office of the President. This work was also supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Building Technologies Office, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.