

## A Case Study to Automate Demand Response on a University Campus

Thomas Mark LAWRENCE<sup>a</sup>, Rick WATSON<sup>b</sup>, Javad MOHAMMADPOUR<sup>c</sup>, Marie-claude BOURDREAU<sup>d</sup>, Sama AGHNIAEY<sup>e</sup>, Justin HILL<sup>f</sup>

<sup>a</sup> University of Georgia, United States of America, lawrence@engr.uga.edu

<sup>b</sup> University of Georgia, United States of America, rwatson@uga.edu

<sup>c</sup> University of Georgia, United States of America, javadm@uga.edu

<sup>d</sup> University of Georgia, United States of America, mcboudre@uga.edu

<sup>e</sup> University of Georgia, United States of America, sama.agh@uga.edu

<sup>f</sup> Southern Company Services, United States of America, jhill@southernco.com

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### ABSTRACT

There is a growing need for developing buildings and a built environment capable of interacting with the smart grid. One smart grid benefit for buildings includes potential participation in demand response programs. This capability is more readily implemented with new construction or renovations, but is a considerable challenge with older, legacy systems. This paper outlines work being done to identify strategies for implementation of demand response on one university campus in the United States with nearly 300 buildings located on over 300 hectares. The building and campus control systems range from modern controls that could fairly easily be incorporated into a smart grid down to older legacy systems incapable of adapting without significant upgrade and capital investment.

This campus is on a real-time price tariff for electricity and thus can benefit immediately from any improved methods for demand response. We have focused our study to date on the various chilled water distribution networks that provide comfort cooling to campus buildings. We have tested strategies for taking advantage of the inherent ability of the distribution piping to store thermal energy ('coldness') combined with modifications to building HVAC control set points. We are studying thermal comfort perceptions of occupants in real (non-laboratory) settings to help optimize the changes. Initial tests show a minimum reduction in peak electrical demand of 10-15% in these chilled water networks which has the potential for hundreds if not thousands of US dollar cost savings per day for the campus during periods with relatively high real-time prices. Strategies are also being tested to achieve this peak demand reduction while also decreasing (or at least not increasing) total energy consumption through the day. The study is also identifying technical, economic and operational barriers to retrofitting existing campus facilities with the capability to participate in demand response systems.

**Keywords:** demand response, smart grid, thermal comfort perception

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### 1. INTRODUCTION

The potential for automated demand response (ADR) is one of the key benefits of a smart grid connected with smart buildings. Many of the prior studies have focused on the technical aspects for peak energy savings and reduced (or at least not increased) total energy consumption. This paper outlines work on one university campus in the United States to identify strategies for implementation of demand response. This is being done within the context of a campus energy system that has a wide range of control system capabilities. We are also including human factor considerations in these studies, such as thermal comfort perceptions within these real world settings.

#### 1.1. Overview of the smart grid and automated demand response (ADR)

The smart grid and smart buildings are relatively new and evolving terms used in various contexts, and there have been many studies on the interactions between a smart grid and smart buildings, for example Georgievski et al., (2012). These terms are generally used to define a building system that has advanced control systems and technologies that allow for interconnected operability giving the capability to operate efficiently in response to external and internal communications. Smart buildings and their associated controls and equipment are capable of responding to demand response requests from the utility or system operator to manage peak demand. The request for demand response implementation could be done directly via a signal from the grid operator or indirectly using real-time electrical pricing signals. When the request and response are done automatically, this is referred to as "Automated Demand Response" or ADR. The need for demand response can arise when: (a) peak demand is high compared to baseload conditions; (b) a relatively high percentage of the electricity supply comes from

intermittent renewable energy sources, such as wind or solar, requiring flexibility in electricity use (as is the case in Germany now and becoming more so in California); or (c) when trying to manage for lower carbon energy production and avoid the use of inefficient fossil fuel based generation.

Demand response can be run under manual control and operation, but that is not as efficient and can be labor intensive. The interconnectivity that is rapidly developing (the Internet of Things, or IoT) is allowing for the development of ADR. Lawrence, et. al. (2016) provide answers to ten basic questions in the area of how smart buildings will connect to a smart grid.

## 1.2. Implementation of ADR

Implementation of ADR is being driven by several mechanisms. Capacity driven models ensure that sufficient capacity is available in terms of a built-in reserve margin and use of various mechanisms to curtail peak loads. Market-based programs focus on economic benefits gained by participating customers; e.g., with real-time pricing or incentive based programs. Utilities and system operators may use other ancillary methods to maintain grid operations such as energy storage. Participation in ADR programs may also be required by regulations, for example with the International Green Construction Code or IgCC (ICC, 2015), by market solutions, or voluntary incentives like the U.S. Green Building Council's LEED rating system.

The methods chosen for ADR vary based on the energy loads and system types. For example, a university campus or office building will primarily look at the demand for cooling, heating or lighting, etc., within its various buildings whereas an industrial user's response may be heavily weighted toward process loads. The evolution toward automated demand response (ADR) identifies the need for standardized method(s) for communication between electric utilities and agents on the demand side of the meter about grid status, etc. There are a number of developments needed to make ADR work, ranging from policy to economic measures to technology needs. For example, a control protocol is needed to allow equipment and systems from various manufacturers to communicate in a standardized way with each other and with the grid; this is the purpose of OpenADR (OpenADR Alliance, 2015). In addition, a new standard was recently released (ASHRAE, 2016a) that defines an object-oriented information model to enable management of electrical loads and generation sources in response to communication with the smart grid.

Developing methods and algorithms to coordinate building operations in a manner that adequately serves customers and building occupants, factoring in the capabilities of the existing control systems, while improving electric grid efficiency and renewable resource utilization, is also needed. Approaches have often explored top-down strategies where lower-level devices are directed by higher-level coordinating entities.

## 1.3. Challenges with existing facilities

Depending on the age and degree of sophistication with the existing building automation and control systems, ADR may be fairly readily implementable or pose extreme challenges. This situation is magnified in a typical university campus, such as the one discussed in this study, because the building control systems likely vary widely in terms of complexity, vintage, capabilities, and achieved performance. Moreover, individual buildings may have evolved and hybridized organically. This presents a significant barrier to the rapid and full-scale market penetration of smart buildings in such settings. Another key barrier to the transition of legacy buildings is the cost of upgrading building control system(s). Few small to medium sized buildings are equipped with a centralized Building Energy Management Systems (BEMS), impeding smart grid functionality. Instead, for those legacy buildings, smart grid control features are increasingly offered at the component and subsystem level. One new technology can allow for legacy pneumatic thermostats to be wirelessly connected to building control systems, thus giving control functionality similar to modern direct digital control.

The remainder of this article provides more detail about methods to implement ADR and human factors considerations. In addition, results from initial studies and testing on one university campus in the United States are also presented.

## 2. METHODS FOR IMPLEMENTATION OF DEMAND RESPONSE IN BUILDINGS

Control systems for building HVACs have evolved from simple on-off switching. For much of the 20th century, pneumatic controls were the dominant technology. They offered adapting proportional, integrative and derivative (PID) control logic and remained popular until the 1990s. They provide reliable and steady control functions but have limited flexibility and are reliant on a steady supply of compressed air, which requires energy. Direct digital control (DDC) development began in the 1960s, but it took time for DDC systems to replace pneumatic control. The development of DDC and the higher level building energy management systems, along with communication protocols between buildings, their equipment and the grid, paved the way for buildings to participate in demand response. Within buildings, the best potential for temporarily adjusting energy demand is with the HVAC, lighting systems, and in some situations other services such as water heating and plug loads.

### 2.1. Heating, ventilation and air conditioning (HVAC) systems

Zone temperature set points can be adjusted to reduce cooling or heating demand, but there are concerns with occupants' thermal comfort perceptions and humidity control. Supply air temperatures and flow rates can also be adjusted. Temporary adjustments can be made in the chilled and hot water or variable refrigerant flow systems. In all cases, there is a need to coordinate actions to achieve the desired reduction in electrical demand. Also, the timing for any changes and transitions needs to be set to avoid problems such as a rebound effect when the demand response event is over and system control reverts to normal operations.

Although each building has a unique set of circumstances regarding usage type, climate, utility demand response programs, regional expectations for occupant acceptance of temperature (and humidity) changes, and occupancy diversity, etc., there can be some generalizations made as to how far HVAC system operations can be temporarily adjusted to reduce demand without adversely affecting equipment operation, occupant thermal comfort, or indoor air quality. Other guidance for the degree of changes that should be acceptable can be found from building codes or standards that relate to demand response. Along these lines, the IgCC requires that HVAC systems with DDC shall have a capability to remotely change the operating temperature set points by 2.2°C (4°F) or more (upward in cooling mode, downward in heating mode) in all non-critical zones given a signal from a centralized contact, such as a building energy management control system (ICC, 2015). This code also requires that the ADR strategy include logic to prevent a rebound peak energy demand. A discussion on thermal comfort perception and demand response is given later in Section 3 of this paper.

Other HVAC system adjustments can be made upstream of the occupied zones, such as setting upper limits on supply fan speeds, changes in supply air, chilled water or hot water temperatures. Any demand response strategy must still provide adequate ventilation rates to maintain acceptable indoor air quality as well as not lead to too high humidity levels in the space. ANSI/ASHRAE Standard 62.1-2016 (ASHRAE, 2016b) requires that relative humidity levels not exceed 65% (unless higher levels are dictated by the space usage type) and also specifies the required ventilation rates to occupied spaces based on occupancy type.

### 2.2. Lighting

It could be argued that in a perfect world, lighting controls would be in place to provide the minimum amount of lighting needed in a space based on the expected occupancy type and occupancy patterns, and that daylighting control would actually be part of that strategy. However, if we were in the perfect world within the built environment then there would be no need for papers such as this. In spaces where daylight responsive controls are not installed and the installed lighting power density is at or exceeds the levels set by relevant energy codes, the ADR strategy could include temporary reductions in the total lighting power in the range of 10-15%. Lighting power density is defined as the total connecting lighting power (Watts) divided by the conditioned floor space, for a resulting W/m<sup>2</sup> metric. This requires luminaires that are dimmable or electrical circuitry to adjust lighting fixtures separately or in small groups. The best options for this exist in business offices, retail stores and educational facilities. Decisions as to exactly what spaces and luminaires to adjust require some thought and engineering analysis, and the lighting power reduction must be set up to ensure that it would not endanger occupant safety or security.

### **2.3. Thermal energy storage**

Thermal energy storage is a common way to shift HVAC demand, particularly for cooling loads. The dominant method probably is through the use of ice or cold water storage systems, although other technologies such as phase change materials are becoming more common. Besides equipment purposely designed and installed to store thermal energy, passive thermal energy storage can be incorporated by methods such as pre-cooling of buildings using mechanical systems or cooler ambient air during evening when possible. Another more novel technique that has been tested at our campus is the pre-cooling of large chilled water distribution networks and then using that stored “coolth” to help reduce cooling load during peak demand periods.

### **2.4. Other measures**

Another argument that can be made concerning demand response is that the building operations should ensure maximum overall energy efficiency as a first step. This reduction in energy consumption naturally carries over into peak demand periods and in many situations may be the most economical method. However, the definition of ‘demand response’ set by the local utility or electrical system operator may be based on the peak demand expected for the “as-built” condition of this building or even just the current demand in real-time.

Additional demand response measures that could be considered include turning off plug loads when not absolutely needed, reducing temperatures of domestic hot water in storage tanks, or encouraging work from home on a particular day when ADR is anticipated (although that may not reduce overall grid demand if the home HVAC systems are then used more).

## **3. INDOOR ENVIRONMENTAL QUALITY AND OCCUPANT THERMAL COMFORT PERCEPTION**

Fanger proposed the concept of the Predicted Mean Vote (PMV) in the 1960's and this has since served as the basis for many of the thermal comfort guidelines and standards. The adaptive principal (Bedford, 1936) is based on the concept that if people are in thermal discomfort, they will react in ways that tend to restore their comfort and thus they are not passive recipients of their thermal environment. The range of comfort temperature in field studies has proven to be wider than that of the rational approach that is used by ASHRAE (2016c) and ISO 7730 (ISO 2005). Nicol and Humphreys (2002) reported that the optimum temperature of comfort strongly correlates with the mean temperature that people have recently experienced, and the predicted mean vote (PMV) is only weakly correlated with the indoor temperature. They relate this discrepancy to the adaptive behavior of subjects as the result of feedback between personal comfort and behavior. Some researchers have also proposed that the range of neutral temperature was too wide to be specified through the PMV equation (Hoyt, et al., 2009). However, the actual thermal comfort experienced by occupants depends greatly on a wide range of factors such as demographics, context, environmental interaction, and cognition as well as the occupant's past thermal history and time of exposure at this the current temperature. When we consider individuals as active agents that go through a series of behavioral, psychological, and physiological adaptations, it should be possible to account for human adaptive capability when implementing ADR programs. Based on the adaptive thermal comfort model “there is no absolute reference point or threshold on comfort continuum” (de Dear and White, 2008). As a result, occupants with repeatedly exposed to increased indoor temperatures eventually increase their tolerance to warmer indoor temperatures as they “re-acclimatize” or get accustomed to those temperatures.

Therefore, making adjustment to the building's HVAC zone temperature set points has significant potential for inclusion in ADR measures. However, the actual level of change needs to factor in a number of parameters. Thus, it is more complicated than just specifying a set temperature change value. The next section briefly describes some of the testing that has been done at one large university in the south-eastern region of the United States.

## **4. TESTING AND RESULTS TO DATE**

To date, most research about the real-world testing of demand response measures has focused on the energy savings alone; indeed, very few studies include an analysis of any corresponding thermal comfort impact. It is, however, impossible to optimize the energy saving potential for ADR without understanding its impact on occupants. Our research group has been investigating methods for implementing ADR and the effects on building occupants

in a “real world” setting, i.e., a major research university in the United States. Cooling for most of the campus’s buildings is provided using a chilled water distribution network, which is itself a potential source of thermal energy storage due to the thousands of meters of relatively large pipes needed to transport chilled water to buildings. Tests were run on several buildings investigating coordinated changes in the HVAC systems, such as zone set point changes, supply air flow and temperatures and chilled water supply temperatures. Only relatively small changes have been made to date in the coordinated peak demand reduction studies, for example supply air and zone air temperature set points were increased by 1.7°C (3° F). The tests also involved a scheduled pre-cooling of the chilled water supply during the off-peak hours in the morning followed by allowing the chilled water temperatures to gradually rise in the network during the peak cooling hours, thus effectively tapping into the thermal energy storage capacity built into the network.

Figure 1 below depicts sample results for energy saving at one of the central chilled water plants from a test run in August 2015. The results revealed that a decrease of 11.1% in total energy consumption and 11.5% in peak demand compared to a baseline day (the next day) that had nearly identical weather conditions, and this is significant because changes were only made in a portion of the just a couple of buildings connected to this particular chilled water network. A thermal comfort survey of building occupants during the test date and a baseline date the following day indicated no real difference in thermal comfort perceptions (Figure 2), thus indicating that additional energy savings should be possible without compromising thermal comfort.

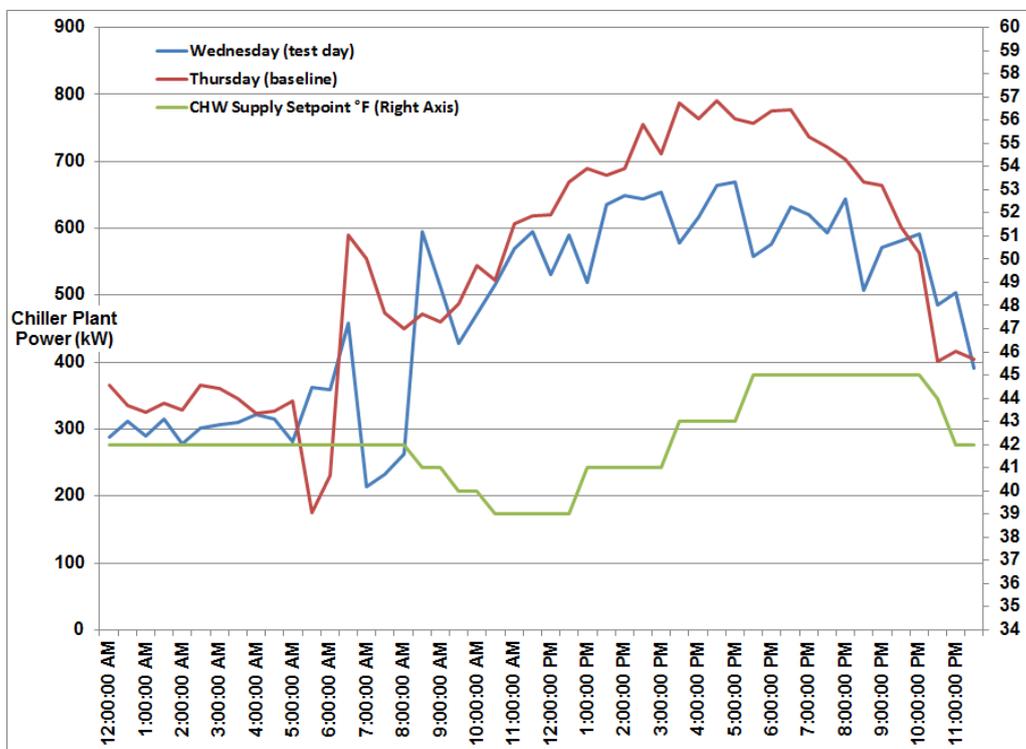


Figure 1: District energy chiller plant power and water temperatures for test day vs. baseline

Thermal Comfort Survey Summary									PPD
Location	Response Summary			Breakdown				Average	% People
	Cold	OK	Hot	Student	Faculty	Male	Female	PMV Calc	Dissatisfied
<b>Baseline</b>									
Tate (8/25)	5	29	3	32	5	16	21	-0.1621622	5.5%
<b>Test Date</b>									
Tate (8/26)	18	144	21	167	16	80	103	0.0491803	5.1%

Figure 2: Occupant thermal comfort survey results for test day vs. baseline

Another study that started in the summer of 2016 is focusing more on human factors and occupant thermal comfort associated with ADR. Several classrooms, offices, lobbies, and one dining hall were investigated with various zone temperature set points of up to 23.3°C without informing the occupants that testing was ongoing. The results revealed that not only was thermal comfort not compromised, but also the PMV value was marginally improved in

some cases. While temperature level may seem still low compared to values used in other regions of the world, it should be considered in context of the current level of expectations for this population and in this region. The next phases of this study will try to reveal more about thermal comfort thresholds in real world for buildings with different applications, enabling a better optimization between energy consumption and occupant thermal comfort.

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