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Creating Energy Independence

Short-Term Curtailment of HVAC Loads in Buildings

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Final Report Executive Summary

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Executive Summary

Rapidly increasing requirements placed on utilities to reduce peak loads has led to utility customer incentives to shift peak demand to non-peak times or reduce peak loads when notified by the utility that the grid is close to capacity. This study investigates methods used to reduce building demand during a fixed time window near a utilities on-peak period. The window was chosen to be 5-9 A.M. in winter and 2-5 P.M. in summer. This study also assumes that a building operator would be notified in advance only a few hours before the start of this window. Keep in mind that this study focused on investigating HVAC system performance over a small window in time for a single day and the statements expressed in this report may not be indicative of energy use over longer periods of time.

The most common methods for reducing building peak demand were reviewed and categorized by their usefulness and wide-spread availability. These methods were reductions in lighting power density, global thermostat set point setback control, chilled water temperature reset, and altering the supply air temperature reset and are herein referred to as "strategies". The first two control strategies are applied to all building types, while the last two are applied to the buildings served by a central plant and include fan and pump speed control. Computer simulations were performed to determine the savings potential when these strategies were used either individually or in combination.

The buildings selected for this study were obtained from the computer simulation reference buildings provided by the United States Department of Energy (DOE). This study included small, medium, and large representations of the office and retail building types. The energy characteristics were selected to meet the minimum for those building types according to ASHRAE Standards 90.1-2004 and 62.1-2004. Table ES-1 summarizes the selected building types and associated HVAC systems. The table also provides building floor areas, cooling and heating types and efficiencies, and fan control modes for each HVAC system.

Table ES-1. Selected HVAC System Types and Associated Building Types

Building Type	**Office**				**Retail**			
	Small	**Medium**	**Large**		**Small**	**Medium**	**Large**	
Area (m^2)	511	4982	46320	46320	174	348	2294	2294
HVAC	PSZ	PVAV	MZ-VAV	Dual Duct	PSZ	PSZ	MZ-VAV	Dual Duct
Cooling Type	DX	DX	Chilled water	Chilled water	DX	DX	Chilled water	Chilled water
COP	3	3	4.45	4.45	3	3	4.45	4.45
Heating Type	Gas furnace	Gas furnace	Hot water	Hot water	Gas furnace	Gas furnace	Hot water	Hot water

Eff. (%)	80	80	80	80	80	80	80	80
Fan control	Constant	Variable	Variable	Constant	Constant	Constant	Variable	Constant

Note: PSZ - packaged single zone system. PVAV – Packaged variable air volume system with DX cooling and furnace heating. MZ-VAV - multizone variable air volume fan system with chilled water cooling and hot water heating. Dual Duct - constant volume dual duct system, DX – direct expansion refrigeration system.

Two types of building constructions were chosen to represent light and heavy thermal mass buildings to examine the impact that thermal mass would have on a building's peak demand reduction potential. Five geographical regions were chosen to study climate specific variations in the results. The cities selected are: Miami - hot and humid, Baltimore - mixed humid, Albuquerque - mixed dry, Phoenix - hot dry, and Minneapolis - cold.

Over 30,000 Energy Plus computer simulations were performed. These simulations reported building peak demand savings potential by building type, geographical location, and day type (e.g., summer peak, winter peak, etc.) for individual control strategies as well as combinations of strategies where two or more individual strategies were used. To reduce the time required for numerous simulations, prototype days were selected to represent typical working days in different seasons. Choosing these prototype days and simulating only a 10 consecutive day period for each prototype day, instead of a full annual simulation, dramatically reduced the time required to compute the results. For each simulation, the last day in the 10 consecutive day period provides the results for the specific prototype day. The selected prototype days are Summer Peak, Summer Mid, Summer Low, Fall Cool High, Winter Peak, Winter Mid, Winter Low, and Fall Heat High.

Simulation results show that the thermal mass impacts are relatively small for the building types selected for this study. In this study it was assumed that utility notification of a demand reduction event would occur only a few hours in advance and insufficient time was available to pre-condition the building. The relatively small peak demand savings associated with thermal mass were found to be insignificant (<2%) compared to the percent demand reductions obtained from the various control strategies investigated during the course of this project. The thermal mass impacts are also insignificant in buildings served by VAV systems, although the impact with VAV systems is slightly larger than those with other HVAC system types. Therefore, the impacts of thermal mass on peak demand reduction need not be considered a significant contributor to savings found for control strategies investigated during this project.

The lighting power density (LPD) reduction strategy is an effective way to meet a peak demand reduction requirement. This strategy is easy to implement by simply turning off non-essential lights. Figure ES-1 shows the percent peak reductions of facility electricity averaged over all locations and prototypes days. Lighting power density varied between 70% and 90%. Since the percent peak demand reductions vary linearly with the percent changes of lighting power density, it is very convenient for building operators or control engineers to decide how much lighting power density should be reduced given a specific peak demand reduction target.

The use of a global thermostat temperature set point setback schedule generally provides a building peak demand savings potential for retail buildings of up to 40% for small buildings, 30% for medium buildings, and 20% for large buildings. Office buildings generally showed less savings than retail building types. Peak demand savings potential is approximately 25% for small office buildings, 22% for medium office buildings, and less than 10% for large office buildings. These savings are dependent on geographical location and HVAC system types. The maximum thermostat setback temperature is 3.3^{o}C. Using this control strategy it is possible to achieve these savings even for the simplest of HVAC systems (e.g., PSZ and PVAV). This strategy applies to those buildings using a zone thermostat (analog or digital) and to those using more complex building automation systems. This study also found that the global thermostat strategy had less of an impact on buildings served by a central plant using dual duct systems since this system type would respond to a zone set point temperature increase by reducing the cold deck air flow rate. This in turn would increase the hot deck air flow rate *for this constant volume system* and increase heating energy required to maintain the hot deck supply air temperature set point.

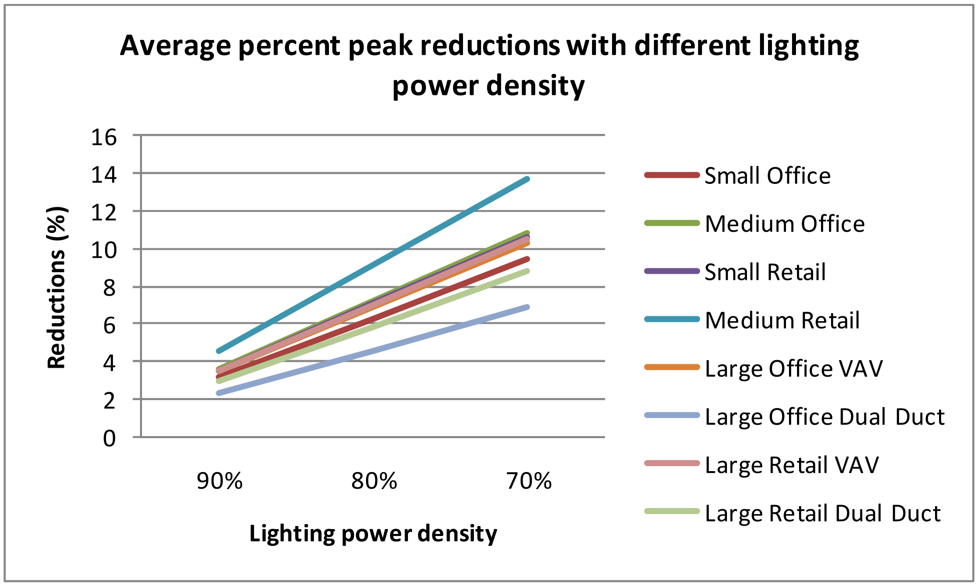

Figure ES-1. Percent peak reduction with different lighting power densities averaged over locations and prototype days

Resetting the control temperature for chilled water plant loops without addressing pump speed control can reduce building peak demand by up to 7%. The maximum reset chilled water temperature is 5^{o}C. Buildings with dual duct systems achieved higher percent reductions than buildings with VAV systems. Although an increase in chilled water temperature will improve the efficiency of chillers, the increase in pump and fan energy could offset these savings in certain instances. For this reason, additional simulations were performed to limit the chilled water pump flow rate to be no greater than the flow rate at the beginning of the peak demand window. When including pump speed control, savings up to 15% can be achieved.

Supply air temperature reset does have the potential to reduce building peak demand, but only for specific HVAC system types. For dual duct systems, results showed up to a 16% savings in building demand for cooling operation. For VAV systems, results generally showed up to a 5% savings, however, building peak demand could actually increase up to 10% for the SummerPeak or SummerMid day types for certain climate locations. VAV systems will increase fan speed in response to an increase in supply air temperature which can increase energy use. For this reason, additional simulations were performed to limit the VAV fan flow rate to be no greater than the flow rate at the beginning of the peak demand window. When implementing a fan speed control strategy for VAV systems, building peak demand reductions up to 7% were possible. This same phenomenon was found in dual duct systems. Dual duct systems mix the cool and hot air streams before entering the spaces. The sum of the cold and hot deck air stream flow rates is constant. When the cold deck supply air temperature is increased, the cold deck air flow rate also increases to meet the same load. As a result, the hot deck air flow rate decreases and energy savings is primarily due to a reduction in the hot deck heating requirement. Since this is a constant volume system, fan speed control is not applicable.

As previously described, demand savings due to each individual strategy provided a reasonable savings in building peak demand for specific building and HVAC system types. In general, a single control strategy did not provide the maximum possible savings and various combinations of these strategies were investigated to determine how these control strategies worked in combination. Computer simulations also showed that combining thermostat reset strategies with chilled water or supply air temperature reset strategies did not provide savings equal to the sum of the savings for the individual strategies. This result applies whether or not a speed control strategy is used since a reset in thermostat temperature reduces zone loads, and therefore the required supply air or chilled water flow rate, which eliminated savings due to the water or air reset strategies.

The combined control strategies of lighting power density and global thermostat set point setback control apply to small office, small retail, medium office and medium retail buildings. The combined control strategies of lighting power density, global thermostat set point setback control, chilled water temperature reset, and supply air temperature adjustment apply to large office and retail buildings.

The percent reductions of electrical demand savings during peak demand periods in a summer peak day using all possible control strategies is shown in Figure ES-2. The peak demand reductions vary between 9% and 42%.

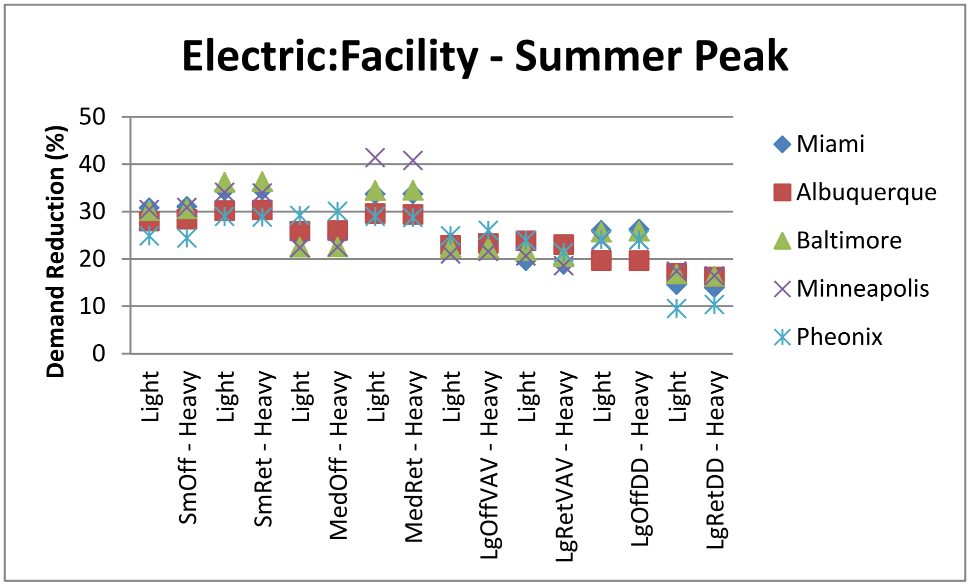

Figure ES-2. Electrical Demand Window Savings Potential for a Summer Peak Prototype Day

Figure ES-3 presents averaged percent reductions using all possible control strategies for different building and HVAC system types. The values are averaged over all prototype days and geographical locations. The difference between Figures ES-2 and ES-3 is that Fig. ES-2 presents average results from a summer peak day, while Fig. ES-3 presents average results from all prototype days.

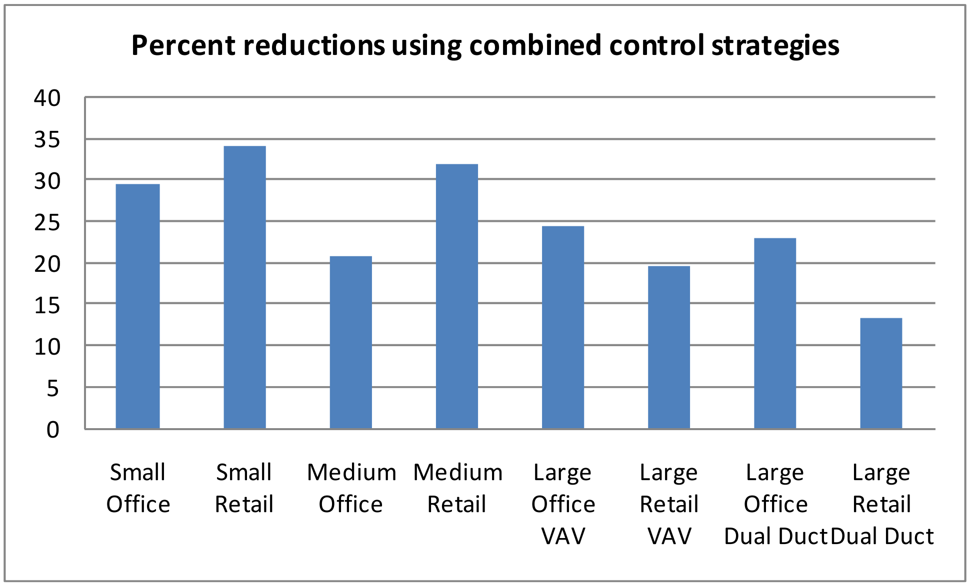

Figure ES-3. Averaged percent reduction using combined control strategies

In addition to percent cooling energy savings, utility companies may also be interested in absolute savings. Table ES-2 presents absolute energy savings during the three hour peak demand period using individual and combined control strategies. The values with units kWh are averaged over all prototype days and geographical locations during cooling demand reduction periods. It is observed that for combined control strategies, the energy savings range from 4.6 kWh for a small retail building to 1162 kWh for a large office building with dual duct systems. These values may be used to estimate how much peak demand can be reduced when the building type is known. For example, the combined demand savings for a small office building during an average cooling prototype day is 4.8 kW (14.3 kWh / 3 hours).

Table ES-2 Absolute cooling energy savings (kWh) using individual and combined control strategies during a 3 hour peak demand period

Building type	LPD	TST	CWT	SAT	Combined
Small Office	5.0	9.4			14.3
Small Retail	1.7	3.0			4.6
Medium Office	49.4	58.3			102.8
Medium Retail	7.2	8.9			15.9
Large Office with VAV	306.4	223.3	319.6	338.6	928.4
Large Office with Dual Duct	291.5	85.5	562.0	556.8	1162.5
Large Retail with VAV	17.9	27.5	14.2	25.0	47.1
Large Retail with Dual Duct	16.7	7.8	17.9	22.5	45.0

The results of this study provided the following conclusions. These conclusions are based on the results of the entire project and are not based entirely on the results presented in this section:

- The percent reductions in building peak demand were nearly constant for the large office building type. These savings are relatively independent of prototype days and geographical locations. However, different HVAC system types may have slightly different values.
- Higher percent reductions were achieved for the smaller buildings and medium retail building which used the PSZ HVAC system type.
- The average values of percent reductions shown in Figure ES-3 may be generally applied to small office, small retail, medium office, medium retail and large office with dual duct systems. The values for each of these building and HVAC system types varied in a narrow range for all prototype days and locations simulated. Results for large retail VAV and dual duct systems were more dependent on prototype days and geographical location.

In order to reach the maximum peak demand reductions, it was essential to combine different control strategy types. Since there are many possible combinations, it was impossible to simulate all possible variations. The selected combined control strategies were based on the best performance of each individual control strategy. If savings from individual strategies were found to be additive, percent reductions from combined control strategies could be derived from the reductions of single measures. After performing a statistical analysis for individual control strategies and combinations of these strategies, the results for combined control strategies may be calculated from the individual savings found for small and medium office building types where only lighting and thermostat control strategies were used. However, for large office and retail building types, the savings for combinations of control strategies should not be calculated using the results for individual strategies (i.e., individual results are not additive when thermostat reset is combined with air or water reset strategies).

Assuming that the use of thermostat setback can adversely affect occupant comfort, a summary of simulated occupant comfort for the same summer demand simulations presented in Figure ES-2 was also compiled and is shown in Figure ES-4. For this study, a setback temperature difference of 3.3^{o}C was used to limit the maximum possible offset from the original thermostat temperature schedule. Of all day types simulated, the simulation results for a summer peak day is presented here as the summarized data set given that the most likely time for discomfort is in the summer months (i.e., clothing removal is generally not an option), and that light building construction will most likely cause a broader change in indoor temperatures (i.e., less thermal lag). The Fanger comfort model is used to describe occupant thermal comfort as a people-weighted average for the entire building.

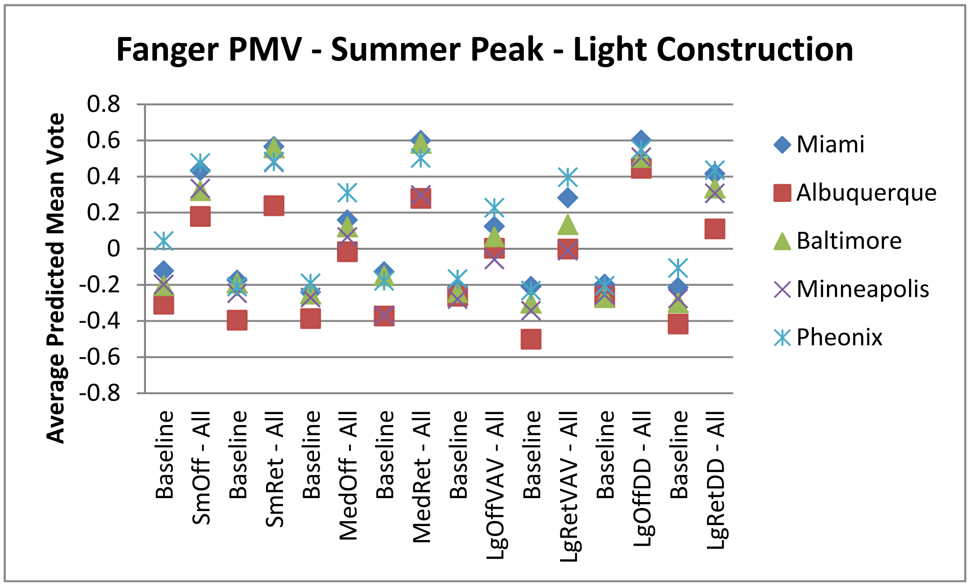

Figure ES-4. Fanger Predicted Mean Vote Comparison to Baseline Values for a Summer Peak Prototype Day

ASHRAE Standard 55-2010 specifies the acceptable predicted mean vote (PMV) range is between -0.5 and +0.5. Figure ES-4 shows that the comfort levels for the Summer Peak light construction baseline simulations are in the range of -0.5 to 0.1 for all building types (each “Baseline” result in the figure). This range is between a slightly cool (slightly cool = -1) perception to just barely warmer than a neutral perception (neutral = 0) of how occupants perceive the indoor environment. Comparing the baseline thermal comfort to that simulated when all control strategies were combined shows an increase in the PMV value towards the warm comfort region (i.e., comparing the “Baseline” results to the “All” results for each building type). The Fanger PMV values range from -0.1 to 0.6 for the combined simulations (each "* - All" result in the figure) and is primarily due to higher indoor temperatures. Since these values do not exceed the slightly warm criteria (slightly warm = 1), and only a few are slightly higher than the maximum value specified by ASHRAE Standard 55-2010, it is assumed that the control strategies selected for this study are considered feasible for use when implemented as building demand reductions strategies. However, note that these summary values are averages over the entire building (i.e., multiple zones) and specific zones will have lower or higher values than reflected in these average data.