Quantification of Peak Demand Reduction Potential in Commercial Buildings due to HVAC Set Point and Brightness Adjustment

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***Abstract*—Quantification of peak demand reduction potential of buildings is critical for demand response (DR) analysis in a microgrid (MG) environment. Due to the varying nature of electricity consumption throughout the day over different seasons, DR periods affect the energy savings and peak demand reduction potentials of a building in different ways. This paper investigates peak reduction potential of selected commercial buildings within a MG environment through HVAC set point and brightness adjustment. Building models are simulated in EnergyPlus and validated against monthly, daily and 30-minute building electrical consumption with the actual consumption from the smart meter data. The study is conducted over two different DR periods for a winter and a summer week to understand how time of the day and different weather conditions influence building peak demand. Results show that with the proper choice of the DR period along with the set point and the brightness adjustments, significant hourly peak demand reduction can be achieved for different types of commercial buildings.**

***Index Terms*—Demand response, peak load reduction, EnergyPlus, HVAC, brightness adjustment.**

I. Introduction

Power grids are transforming from a relatively simple network designed to deliver electricity from power plants to cities and individual buildings into a more complex decentralized network. With the penetration of distributed energy resources (DERs) at the consumer level, the complexity of the power system operation is increasing. The transformation from a traditional radial power flow in the distribution system to a bidirectional power flow is creating challenges in the overall optimal operational planning of a power grid [1].

To overcome these challenges, microgrids (MG) are gaining popularity because of their different modes of operation i.e., islanded and grid-connected. MG can be utilized to ensure maximum DER utilization and overall grid stability [2]. A properly designed MG generally provides mechanisms to overcome operational challenges and can effectively increase the participation of DERs [3]. However, it is important to keep the peak demand of the MG under a certain level to avoid expensive generations i.e., gas turbine generators to serve the short-term peaks. These peaks pose significant challenges to the economically efficient operation of the MG and can cause the risk of equipment failure and power outages because of overloading. Demand Response (DR) generally refers to programs that encourage participants to make short-term reductions in energy demand triggered by price signals from the electricity hourly market. DR periods can last from a couple of minutes to multiple hours depending on the DR program, and might include turning off or dimming lighting, adjusting HVAC levels, or shutting down a non-critical load. The main objective of DR is to reduce peak demand, and increase the efficiency of the electrical power system. DR additionally provides financial incentives to the customers, who compromise part of their power usage needs to reach the targeted energy savings or peak load reductions [4].

Commercial and residential buildings are the largest consumers of electricity in US, contributing to about 75% of the total electricity consumption [5]. According to the US DoE, during the peak period from 2PM-8PM, HVAC and lighting consumes around 65% of the total electricity consumed within buildings [6]. However, there is no reasonable strategy for selecting the optimal HVAC thermostatic control or the optimal brightness control due to the lack of knowledge that maps the set point change and the brightness control with the expected energy savings and peak demand reductions.

Due to the high energy consumption of HVAC systems, the HVAC control in commercial buildings has attracted a lot of attention [7], [8]. A peak load reduction method using a direct load control method is presented in [9]. The model aims to maximize the thermostatically controlled load reduction over the dispatch horizon without noticeably disturbing the customer's thermal comfort levels. Similarly, a study is conducted about load forecasting using multi-layered feed-forward neural network technology to analyze peak load reduction through load scheduling with predicted information [10]. A DR management scheme is presented in [11] to reduce peak load while taking consumer constraints into account such as user comfort and willingness to participate. A cyber-physical management of smart buildings based on smart-gateway network with distributed and real-time energy data collection and analytics is presented in [12]. A multiagent minority-game based DR is used to reduce peak demand on the main electricity grid. A smart grid economic dispatch problem at peak hours is solved by finding an economic and reliable method of allocating the load on available generation units and choose the least expensive area or consumers to apply the DR [13]. Five different methods are presented in [14] to identify opportunities for DR, energy efficiency, and peak load management by analyzing commercial and industrial facility 15-min-interval electric load data. These methods can be used by building managers for real-time feedback control of DR resources.

Based on the literature review, it is noted that during the DR period, energy savings and peak load reduction is achieved through a prefixed DR plan execution. Utility sends DR signal to the building owners to reduce their load consumption for a certain period and the building owners shut down their prefixed electrical equipment i.e. HVAC, lights, plug loads to reduce load consumption. Since there is no mechanism to quantify the estimated saving beforehand, there is a possibility that this approach will outperform or underperform the target electrical load reduction. A mechanism that can accurately quantify the saving potential is, therefore, essential to analyze how much saving is expected from an individual building. Within a MG, this mechanism will ensure maximum utilization of DERs while ensuring both grid stability and occupant comfort. This paper demonstrates how a commercial building's digital twin (developed in EnergyPlus and validated against smart meter data) is used to estimate the peak load reduction potential through set point and brightness adjustment. The paper is organized as follows: Section II introduces the building model development process and validation results. Section III discusses setpoint and brightness adjustment for quantification of peak demand reduction during different DR periods. Section IV concludes the work.

II. Building Model Development and Validation

A. Building Description

Thirteen commercial buildings are selected for quantification of peak demand reduction potential due to HVAC set point and brightness adjustment from Bronzeville, Illinois MG (BCM). Due to the page constraint for this paper, the detailed analysis of two buildings are presented here. The 3D layout of the buildings and description is shown in Fig. 1. Building 1 has 81/81 windows toward the East/West direction; 54/84 windows toward the North/South direction, and one long skinny window across entire top floor. The building's normal operation period is 24/7. Additionally, it has four glass type doors of which two facing west and two facing east. External surface has materials mainly brick/concrete/glass. Building 2 is connected buildings (1 Rectangle and 1 L-Shaped) with 60/35 north/south and 122 west side windows. The building operates from 8AM-6PM on weekdays and is closed on the weekend. The building has one glass type door on the west. External wall material is brick/glass. The buildings are designed using Standard ASHRAE 189.1-2009 construction sets, offered by Building Component Library (BCL) [15].

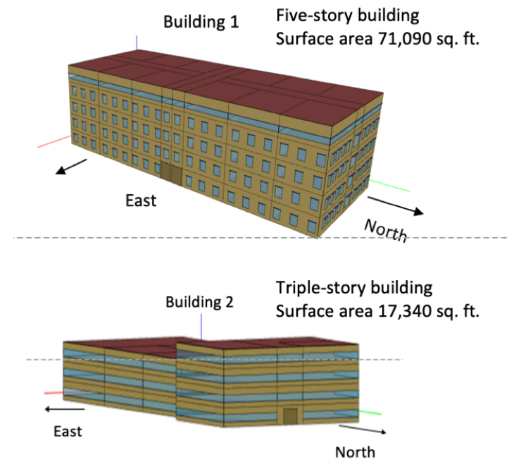

Fig. 1: 3D model of the buildings developed in SketchUp

B. Building Model Development

The building models are developed in Energyplus [16]. OpenStudio modeling platform is used as a Graphical User Interface (GUI) for the EnergyPlus simulation and SketchUp pro software is used to draw the EnergyPlus compatible building envelop. The advantage of using EnergyPlus is that it helps to design the HVAC units efficiently and saves a significant design time.

While developing building energy model, it is challenging to gather a detailed information of the building, therefore, some assumptions are made on building characteristics, which impacts the simulation results. Categories of these assumptions are occupancy distribution, thermal mass, plug loads etc. The calibration process requires tuning some of the assumed parameters influencing building energy consumption. These parameters include building's operating schedules, internal load models (schedules and densities), as well as its operational and control settings. The smart power meter data is collected from Commonwealth Edison (ComEd) and analyzed for consumption patterns which are incorporated into the building model accordingly. The primary load assumptions for the building profile include lighting load, office equipment load, HVAC system load, domestic water heating and miscellaneous loads (unregulated process loads like computer server loads, kitchen loads, receptacle loads, elevator loads, etc.).

Building shell's footprint and location is defined along with the details of heat transfer surfaces which include exterior and interior surfaces. A building operational schedule is also identified together with a percentage area allocation for each activity type and corresponding lighting, plug load density and outside air ventilation. The cooling sources for the HVAC system is identified along with seasonal setpoint and equipment sizes. It is assumed that the buildings use gas for heating purpose.

Outdoor weather profile serves as an input to the EnergyPlus model. The outdoor weather information for the analysis year 2019, including dry bulb temperature, wet bulb temperature, atmospheric pressure, relative humidity, dew point temperature, solar radiation and wind speed (mph), is given as an input to the EnergyPlus model in the form of a binary file. The weather information for the area is obtained from [17].

C. Model Validation

Once the building models are developed, they are validated by comparing the simulated monthly, daily and 30-minute building electrical consumption with the actual consumption from the smart meter data. The acceptable models called digital twins are those in which the difference between daily electrical consumption from smart meter data and simulated data falls within +/-10%. The actual and predicted monthly electricity consumption (kWh) of the buildings for the year 2019 is shown in Fig. 2.

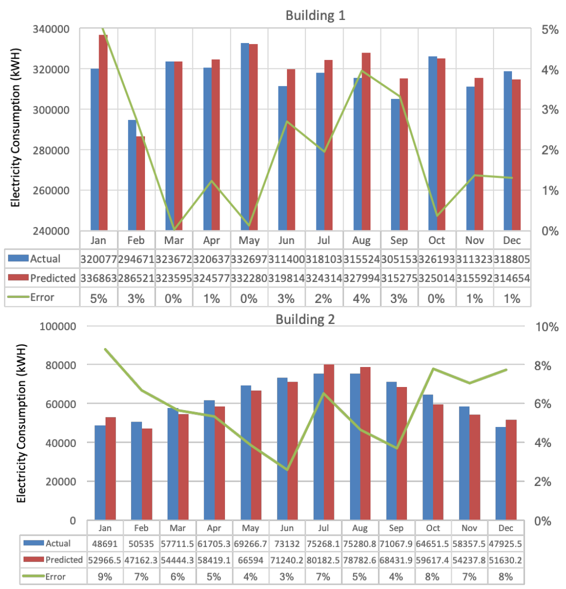

Fig. 2: Actual and Simulated Monthly Electricity Consumption

III. ANALYSIS ON HVAC SETPOINT AND BRIGHTNESS ADJUSTMENT

After building models are developed and validated in EnergyPlus, analysis is conducted for the digital twin of the buildings to understand the peak demand reduction potential. DR potential is represented as:

$$DRPotential = P_{base} - P_{DR} \tag{1}$$

P_{base} is the base power consumption and P_{DR} is the power consumption during the DR period after the setpoint configuration and brightness adjustment. P_{DR} is calculated using the following equation:

$$minimize P_{DR} = P_{HVAC,S_{dr}} + P_{lighting,I_{dr}} + P_{other,dr} \tag{2}$$

subject to:

$$P_{HVAC,S_{dr}}, P_{lighting,I_{dr}}, P_{other,dr} > 0$$

$$S_{min} < S_{dr} < S_{max}$$

$$I_{min} < I_{dr} < I_{max}$$

$P_{HVAC,S_{dr}}$, $P_{lighting,I_{dr}}$, $P_{other,dr}$ are the power consumption due to HVAC, lighting and other loads during the DR period. S_{dr} and I_{dr} are the setpoint and brightness during the DR. S_{min} and S_{max} are the minimum and maximum allowed setpoint. I_{min} and I_{max} are the maximum and minimum allowed brightness. These constraints are imposed to ensure customer comfort. Furthermore, other external factors such as availability of daylight impacts I_{min} and I_{max}. Availability of daylight allows lower values of I_{min}, resulting in greater savings.

Light load is modeled as:

$$b = \frac{L(W)}{4\pi d^2(m^2)} \tag{3}$$

Where, b is the apparent brightness in W/m^2 , L is the luminosity in W, and L is the distance in meter. HVAC is modeled as:

$$P_{th} = m\frac{kg}{sec}c\frac{J}{kgK}\delta(T)(K)1000 \tag{4}$$

Equation 4 represents the thermal power P_{th} provided by standard HVAC unit where, m is the mass flow rate in kg/sec, c represents heat capacity in $J/Kg.K$, and δT is the temperature difference between head dissipation in Kelvin. By varying P_{th}, desired HVAC model is developed for each commercial building to further study DR quantification.

DR analysis is conducted for one winter week Jan 8 – Jan 14, 2019 and for one summer week July 8 – July 14, 2019. Two DR periods are selected to understand how time of day affects the peak demand, and peak savings. DR Window 1: 7AM to 10AM and 5PM to 9PM for the winter week, and 11AM to 7PM for the summer week. DR Window 2: 7AM to 11PM for both summer and winter weeks. Analysis of daily savings aims at determining peak demand reduction (kW) potential of each building by raising HVAC setpoint and by brightness adjustment.

1) HVAC setpoint is raised by 1°F - 5°F during summer week for the two DR periods. For winter, it is assumed that the source for space heating is natural gas, therefore, no savings are observed by lowering the setpoint.
2) Lighting brightness is reduced by 10% to 50% with a 10% increment during the winter and summer week.

A. Analysis of Daily Savings by Setpoint Adjustment

In order to observe the impact of various setpoint adjustment on peak reduction potential, a daily savings analysis is conducted for both DR periods. For building 1, setpoint is set to 72°F for building's operational time and 80°F for non-operational time and on the weekends. HVAC setpoint is raised by 1°F - 5°F during the summer week for the two DR periods. For building 2, the baseline setpoint is 70°F.

Table I and Table II illustrate the power consumption (KW) when setpoint increases by 1°F - 5°F from the base case on

Date	DR Window 1, DR Window 2									
	+1F (%)	+1F (KW)	+2F (%)	+2F (KW)	+3F (%)	+3F (KW)	+4F (%)	+4F (KW)	+5F (%)	+5F (KW)
7/8	0.45%	1.33	0.77%	2.29	1.03%	3.05	1.24%	3.68	1.43%	4.23
Mon	0.41%	1.21	0.73%	2.16	0.98%	2.91	1.18%	3.52	1.35%	4.03
7/9	0.70%	2.09	1.18%	3.53	1.46%	4.37	1.67%	5.02	1.86%	5.57
Tue	0.53%	1.6	0.88%	2.65	1.14%	3.41	1.33%	4	1.50%	4.51
7/10	0.75%	2.15	1.34%	3.87	1.84%	5.32	2.12%	6.1	2.23%	6.42
Wed	0.54%	1.57	1.00%	2.88	1.39%	4	1.72%	4.96	2.02%	5.81
7/11	0.70%	2.1	1.25%	3.75	1.57%	4.67	1.78%	5.32	1.96%	5.86
Thu	0.54%	1.61	0.99%	2.95	1.38%	4.11	1.65%	4.92	1.82%	5.43
7/12	0.45%	1.31	0.78%	2.26	1.04%	3.01	1.23%	3.58	1.41%	4.09
Fri	0.38%	1.13	0.69%	2.03	0.94%	2.75	1.14%	3.34	1.30%	3.81

TABLE I: Building 1 - Peak Reduction Potential (KW) from Setpoint Change for Summer Week

	DR Window 1, DR Window 2									
	+1F (%)	+1F (KW)	+2F (%)	+2F (KW)	+3F (%)	+3F (KW)	+4F (%)	+4F (KW)	+5F (%)	+5F (KW)
7/8	1.27%	2.10	3.35%	5.55	3.56%	5.89	3.74%	6.19	3.90%	6.46
Mon	1.53%	2.53	2.79%	4.62	3.52%	5.84	3.65%	6.05	3.77%	6.25
7/9	0.75%	1.72	4.35%	9.92	5.76%	13.14	6.07%	13.85	6.33%	14.44
Tue	1.77%	4.05	3.18%	7.26	4.33%	9.89	5.29%	12.07	5.71%	13.05
7/10	1.05%	2.84	3.75%	10.10	6.65%	17.92	9.01%	24.26	11.05%	29.74
Wed	1.20%	3.24	3.46%	9.33	6.28%	16.92	8.55%	23.02	10.46%	28.16
7/11	0.90%	2.12	5.45%	12.87	7.50%	17.73	7.91%	18.69	8.30%	19.62
Thu	2.20%	5.20	4.00%	9.45	5.43%	12.84	6.64%	15.70	7.56%	17.86
7/12	0.88%	1.58	2.84%	5.12	3.61%	6.51	3.75%	6.78	3.88%	7.01
Fri	1.43%	2.58	2.51%	4.53	3.34%	6.04	3.68%	6.64	3.78%	6.83

TABLE II: Building 2 - Peak Reduction Potential (KW) from Setpoint Change for Summer Week

a summer week for DR window 1 and DR window 2 for both buildings. Following are the observations for the peak reduction potential using setpoint adjustment in the summer week:

- Peak savings are increased by increasing the setpoint for both buildings.
- Peak savings are greater for building 2 in comparison to building 1. This is because building 2 energy consumption in the month of July is highest compared to rest of the year. On the contrary, building 1 energy consumption varies throughout the year.
- Peak reduction decreases for DR window 2 for both the buildings. This is because when the DR window is extended, the period before the peak hour has a higher indoor temperature, resulting in a higher AC consumption to cool down the building at the peak hour.

B. Analysis of Daily Savings by Brightness Adjustment

In order to observe the impact of brightness adjustment on peak reduction potentials, a daily savings analysis is conducted for both DR periods. Lighting brightness is reduced by 10% to 50% with a 10% increment during the winter and summer week for both DR periods.

1) Brightness Adjustment for Winter Week: Table III and Table IV, Fig. 3 and Fig. 4 illustrate the daily power consumption (kW) from dimming on a winter week for both DR periods when brightness is decreased by 10% to 50% from the base case. Following are the observations from the peak savings potential from Table III and Table IV by brightness adjustment:

- Peak reduction for building 1 is almost similar for both DR windows because peak occurs at the same time. For example: On Tuesday, Jan 8, the traditional window peak is 322W and new window peak is 321.5W (as shown in Fig 3), which is almost same, resulting in the same peak reduction.
- For building 2, the increase in peak reduction with dimming is almost same for both DR windows for first four days but this is not true for the next three days. This is because the week days have relatively constant power consumption pattern, except for Friday. People leaving work early or working from home on Fridays can result in such a difference.

Date	DR Window 1, DR Window 2									
	-10%	-10% (KW)	-20%	-20% (KW)	-30%	-30% (KW)	-40%	-40% (KW)	-50%	-50% (KW)
1/8	4.00%	13.02	7.99%	26.03	11.99%	39.05	15.98%	52.06	19.98%	65.08
Tue	4.00%	13.02	7.97%	25.98	11.95%	38.92	15.92%	51.87	19.89%	64.81
1/9	4.22%	14.23	8.44%	28.47	12.66%	42.7	16.88%	56.93	21.10%	71.16
Wed	4.30%	14.75	8.61%	29.5	12.91%	44.25	17.22%	58.99	21.52%	73.74
1/10	4.13%	13.84	8.27%	27.67	12.40%	41.51	16.53%	55.34	20.67%	69.18
Thu	4.52%	15.51	9.05%	31.02	13.57%	46.54	18.10%	62.05	22.56%	77.34
1/11	3.75%	11.77	7.51%	23.53	11.26%	35.3	15.02%	47.06	18.77%	58.83
Fri	3.75%	11.77	7.51%	23.53	11.26%	35.3	15.02%	47.06	18.77%	58.83
1/12	4.90%	10.27	9.80%	20.53	14.70%	30.8	19.60%	41.07	24.47%	51.26
Sat	4.90%	10.27	9.80%	20.53	14.70%	30.8	19.60%	41.07	24.47%	51.26
1/13	5.47%	10.81	10.95%	21.63	16.42%	32.44	21.89%	43.25	27.36%	54.06
Sun	5.68%	11.63	11.35%	23.27	17.03%	34.9	22.70%	46.54	28.38%	58.17
1/14	4.07%	12.71	8.13%	25.41	12.20%	38.12	16.26%	50.82	20.33%	63.53
Mon	4.07%	12.71	8.13%	25.41	12.20%	38.12	16.26%	50.82	20.33%	63.53

TABLE III: Building 1 - Peak Reduction Potential (KW) from Dimming for Winter Week

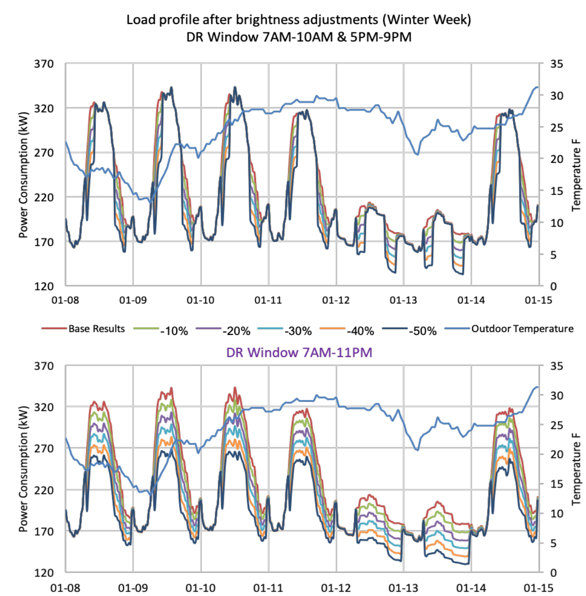

Fig. 3: Building 1 - Daily Power Consumption (KW) from Dimming on a Winter Week

2) Brightness Adjustment for Summer Week: Table V and Table VI illustrate the daily peak reduction from dimming for both buildings on a summer week for both DR windows. From the tables, it is observed that peak savings are increased by dimming.

- For building 1, both DR windows contain the same peak for all week days except Tuesday, which has two peaks and DR window 1 captures only one peak. Therefore, peak savings are slightly less for Tuesday for DR window 1 compared to DR window 2.

Date	DR Window 1, DR Window 2									
	-10%	-10% (KW)	-20%	-20% (KW)	-30%	-30% (KW)	-40%	-40% KW	-50%	-50% (KW)
1/8	5.17%	6.56	10.33%	13.11	15.50%	19.67	20.66%	26.22	25.83%	32.78
Tue	5.05%	6.64	10.11%	13.28	15.16%	19.91	20.22%	26.55	25.27%	33.19
1/9	5.23%	6.64	10.46%	13.28	15.69%	19.91	20.92%	26.55	26.16%	33.19
Wed	5.05%	6.64	10.11%	13.28	15.16%	19.91	20.22%	26.55	25.27%	33.19
1/10	5.15%	6.53	10.29%	13.06	15.44%	19.59	20.59%	26.12	25.73%	32.65
Thu	5.05%	6.64	10.11%	13.28	15.16%	19.91	20.22%	26.55	25.27%	33.19
1/11	5.21%	6.62	10.43%	13.23	15.64%	19.85	20.85%	26.46	26.07%	33.08
Fri	5.05%	6.64	10.11%	13.28	15.16%	19.91	20.22%	26.55	25.27%	33.19
1/12	3.39%	3.32	6.78%	6.64	10.17%	9.96	13.56%	13.28	16.95%	16.6
Sat	4.13%	4.63	8.25%	9.26	12.38%	13.89	16.51%	18.52	20.63%	23.16
1/13	4.40%	3.62	8.80%	7.25	13.20%	10.87	17.54%	14.44	21.57%	17.76
Sun	5.12%	4.63	10.25%	9.26	15.37%	13.89	20.13%	18.2	24.35%	22.01
1/14	4.60%	5.71	9.205	11.43	13.805	17.14	18.41%	22.86	23.01%	28.57
Mon	4.72%	6.01	9.45%	12.02	14.17%	18.03	18.90%	24.04	23.62%	30.04

TABLE IV: Building 2 - Peak Reduction Potential (KW) from Dimming for Winter Week

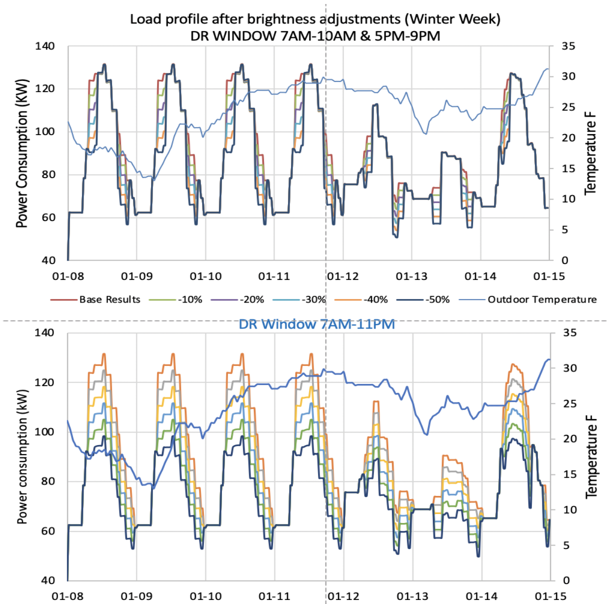

Fig. 4: Building 2 - Daily Power Consumption (KW) from Dimming on a Winter Week

- For building 1, on the weekend, peak savings are more for DR window 2 compared to DR window 1 because both DR windows are not capturing the same peak.
- For building 2, the peak reduction is same for both DR windows because both DR windows captures the buildings peak.
- For building 2 on 7/12, the peak reduction result changes, because extending the DR window creates a new peak.
- Some savings are observed on Saturday. Although the building is not open for normal operation during the weekends it may still be running in a set back mode if there are only a few occupants.
- Building consumes a great deal of lighting loads therefore significant amount of peak power can be saved by decreasing brightness.

When analyzing the results from both setpoint and brightness adjustment for the buildings, it is observed that peak savings are greater from lighting than HVAC. Also, comparing the results from winter and summer week for brightness adjustment, it is observed that more peak savings are observed in the winter week than summer week for both buildings. This is due to the reason that lighting load consumes more energy in winter than in summer for these buildings.

Date	DR Window 1, DR Window 2									
	-10%	-10% (KW)	-20%	-20% (KW)	-30%	-30% (KW)	-40%	-40% (KW)	-50%	-50% (KW)
7/8	4.17%	12.38	8.35%	24.77	12.52%	37.15	16.69%	49.54	20.87%	61.92
Mon	4.17%	12.38	8.35%	24.77	12.52%	37.15	16.69%	49.54	20.87%	61.92
7/9	4.18%	12.52	8.35%	25.04	12.53%	37.56	16.70%	50.08	20.88%	62.6
Tue	4.25%	12.75	8.42%	25.28	12.60%	37.81	16.77%	50.33	20.95%	62.86
7/10	3.97%	11.44	7.94%	22.89	11.91%	34.33	15.89%	45.77	19.82%	57.12
Wed	3.97%	11.44	7.94%	22.89	11.91%	34.33	15.89%	45.77	19.82%	57.12
7/11	4.16%	12.42	8.32%	24.83	12.47%	37.25	16.63%	49.67	20.79%	62.09
Thu	4.16%	12.42	8.32%	24.83	12.47%	37.25	16.63%	49.67	20.79%	62.09
7/12	3.94%	11.45	7.88%	22.89	11.83%	34.34	15.77%	45.79	19.71%	57.24
Fri	3.94%	11.45	7.88%	22.89	11.83%	34.34	15.77%	45.79	19.71%	57.24
7/13	3.91%	8.18	7.83%	16.36	11.74%	24.54	15.66%	32.72	16.58%	34.64
Sat	4.15%	8.87	8.30%	17.75	12.45%	26.6	16.59%	35.46	20.73%	44.31
7/14	3.92%	8.16	7.83%	16.32	11.75%	24.47	15.67%	32.63	19.59%	40.79
Sun	4.07%	8.7	8.13%	17.39	12.20%	26.09	16.26%	34.79	20.33%	43.48

TABLE V: Building 1 - Peak Reduction Potential (KW) from Dimming for Summer Week

	DR Window 1, DR Window 2									
	-10%	-10% (KW)	-20%	-20% (KW)	-30%	-30% (KW)	-40%	-40% (KW)	-50%	-50% (KW)
7/8	5.21%	8.64	10.43%	17.28	15.64%	25.92	20.86%	34.56	26.07%	43.19
Mon	5.21%	8.64	10.43%	17.28	15.64%	25.92	20.86%	34.56	26.07%	43.19
7/9	4.78%	10.90	9.55%	21.81	14.33%	32.71	19.11%	43.62	23.88%	54.52
Tue	4.78%	10.90	9.55%	21.81	14.33%	32.71	19.11%	43.62	23.88%	54.52
7/10	4.00%	10.78	8.01%	21.56	12.01%	32.33	16.01%	43.11	20.01%	53.89
Wed	4.00%	10.78	8.01%	21.56	12.01%	32.33	16.01%	43.11	20.01%	53.89
7/11	4.66%	11.01	9.32%	22.02	13.97%	33.02	18.63%	44.03	23.29%	55.04
Thu	4.66%	11.01	9.32%	22.02	13.97%	33.02	18.63%	44.03	23.29%	55.04
7/12	5.37%	9.71	10.75%	19.42	16.12%	29.13	21.50%	38.84	26.87%	48.55
Fri	4.94%	10.23	9.88%	20.46	14.81%	30.69	19.75%	40.91	24.58%	50.92
7/13	4.02%	4.55	8.04%	9.10	12.06%	13.66	16.08%	18.21	20.11%	22.76
Sat	4.02%	4.55	8.04%	9.10	12.06%	13.66	16.08%	18.21	20.11%	22.76
7/14	0.00%	0.00	0.00%	0.00	0.00%	0.00	0.00%	0.00	0.00%	0.00
Sun	0.00%	0.00	0.00%	0.00	0.00%	0.00	0.00%	0.00	0.00%	0.00

TABLE VI: Building 2 - Peak Reduction Potential (KW) from Dimming for Summer Week

Brightness control is achieved by studying daylight availability and occupancy distribution. Each building is divided into several occupant zones and based on the building structure and availability of the daylight, brightness is controlled considering occupant comfort as a priority. This casual effect can be observed by comparing the savings between winter and summer week, where it is observed that during summer week because of longer daylight period more ambient light is available therefore less light load is required.

Peak demand reduction potential changes with varying operating conditions because power consumption of a building depends on the operating conditions such as HVAC set points, brightness level, plug load status, etc. However, the set of conditions in a commercial building can be broadly classified into two major categories: operational (weekdays) and non-operational (weekends). Therefore, having individual models for those conditions can optimize the modeling efforts required under varying scenarios. Additionally, the heat/cool content in a building changes over minutes, therefore the modeling activity does not have to be very granular. Because of these slow changes in thermal conditions in a building, the model runs every thirty minutes which limits the number of cases being modeled.

Customer comfort was a priority while performing the studies. For HVAC operation, each thermal zone setpoint was considered based on the thermal mass and occupant distribution of the particular thermal zone. The occupancy level impacts the space condition requirements, the condition requirement of a storage area is less than an office area. Open studio provides an easy graphical tool to adjust the thermal zone. Similarly, for brightness control, occupant distribution and daylight availability are considered while reducing the brightness.

IV. Conclusion

This paper presents a detailed study on the quantification of peak reduction potential for commercial buildings using setpoint and brightness adjustment during different DR periods over different seasons. The building modeling is performed in EnergyPlus using OpenStudio modeling platform. Model validation is conducted by comparing the simulated monthly, daily and 30-minute building electrical consumption with the actual consumption from the smart meter data. The acceptable models called digital twins are those in which the difference between daily electrical consumption from smart meter data and simulated data falls within +/-10%.

After obtaining the digital twin, HVAC setpoint and brightness adjustment is implemented to estimate the peak reduction potential of the buildings. In general, peak savings are increased by increasing the setpoint from the base case in the summer. Similarly, by reducing the setpoint in the winter results in more peak savings. However, in our case, it is assumed that the source for space heating in the winter is natural gas, therefore, no peak savings are observed. By brightness adjustment, significant peak demand reduction is observed in the summer and winter week. It is also observed that when a building consumes more equipment and lighting load compared to HVAC load, peak savings due to HVAC setpoint adjustment are less. Additionally, the peak reduction depends on the buildings occupancy schedule. If the building occupancy changes frequently, it can produce more peak switching probabilities. In that case, a longer DR period may not be able to reduce more peak.

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