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Measurements and simulations for peak electrical load reduction in cooling dominated climate

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ABSTRACT

Peak electric demand due to cooling load in the Desert Southwest region of the US has been an issue for the electrical energy suppliers. To address this issue, a consortium has been formed between the University of Nevada Las Vegas, Pulte Homes (home builder) and NV Energy (local utility) in order to reduce the peak load by more than 65%. The implemented strategies that were used to accomplish that goal consist of energy efficiency in homes, onsite electricity generation through roof integrated PV, direct load control, and battery storage at the substation level. The simulation models developed using building energy analysis software were validated against measured data. The electrical energy demand for the upgraded home during peak period (1:00–7:00 PM) decreased by approximately 37% and 9% compared to a code standard home of the same size, due to energy efficiency and PV generation, respectively. The total decrease in electrical demand due to energy efficiency and PV generation during the peak period is 46%. Additionally, a 2.2 °C increase in thermostat temperature from 23.9 °C to 26.1 °C between 4:00 PM and 7:00 PM has further decreased the average demand during the peak period by 69% of demand from a standard home.

1. Introduction

The increase in electricity demand for short periods of time (a few hours in a day) is referred as peak load. Electricity can't be stored cost effectively with the current technologies and thus must be generated as it is being used. It is expensive for both the utilities (and hence the customers) to add more power generation capacity that will be used for only short periods of time. According to International Energy Agency (IEA) report [1], the wholesale price of electricity could be reduced by as much as 50% with a mere 5% reduction of the peak electrical demand in some cases. For U.S. market, it is also estimated that an annual savings of $10–$15 billion is possible through demand side load management [1]. The peak loads can also cause grid failures due to severe voltage or frequency fluctuations. Hence, the peak load reduction and/or load shifting are critical to improve the grid reliability and reduce the electricity costs.

A significant portion of world's electrical energy is consumed by residential and commercial buildings (according to IEA, more than 50% in 2008 [2]). In the developed countries, a substantial portion of the total electricity consumed in buildings is used for space conditioning. For example, in the U.S. the electricity usage percentage break down (in 2010) is: air conditioning - 22, water heating - 9, refrigeration - 7, space heating - 6, all other appliances and lighting - 56 [3]. It is generally agreed that air conditioning loads from both residential and commercial buildings during extreme weather conditions are responsible for sharp electrical peak demands in many regions of the world. It is implied that reducing peak loads from building sector is critical in shaving the overall peak demand.

Several studies have been reported on the peak load reduction strategies suitable for different climatic regions of the world [4–8]. Thermally activated building systems with water circulating pipes were suggested to reduce the peaks during cooling and heating periods [4]. The proposed systems were found to reduce the chiller size by 50% for a building in Netherlands. In a different method, plug-in electric vehicles are proposed for vehicle-to-grid service [5,6]. In this method, vehicle batteries are used to reduce the peak electric demand and frequency regulation in addition to powering the vehicle. A study performed for Japan has estimated that if vehicle-to-grid electric vehicle are used in the country, approximately 25% of the peak demand (in the year 1998) can be reduced [6]. Renewable energy resources are also proposed to reduce the peak electrical demand. Based on the resource assessment for different regions of India, it is found that there exists a significant

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Nomenclature

AC	Air Conditioning
ACH	Air Changes per Hour
CFM	Cubic Feet per Minute
CFL	Compact Fluorescent Light
EE	Energy Efficient
EIA	Energy Information Administration
HERS	Home Energy Rating System
HVAC	Heating Ventilation and Air Conditioning
LED	Light Emitting Diode
PCM	Phase Change Material
PV	Photovoltaic
R	Thermal Resistance, K-m^2/W
TOU	Time of Use
U	Thermal Conductance, W/m^2 K

renewable energy potential to overcome the current peak loads in the country [7]. Demand side management is another method to reduce the peak load. There are different approaches used in this method such as time of use (TOU) pricing, direct load control through customer incentive programs and off-peak storage techniques such as ice-storage air conditioners and heat storing electric boilers. There have been significant efforts made by China in implementing all the demand side management strategies in recent years to address the peak electricity demand [8]. It is found through a study in California, US that residential sector can provide substantial contribution to peak shaving when critical peak pricing is applied [9]. Several studies have been performed to study the applicability of different phase change materials (PCM) in buildings for cooling and heating load reduction and peak shifting [10–14]. A new type of wall panel integrating the structural insulated panels (SIP) with PCM is proposed [12]. The panels are reported to reduce the average heat flux by 33% and 38% for PCM concentrations of 10% and 20% (by weight) respectively. In a different study wall boards impregnated with PCM are being developed [13]. The impact of daylighting on the peak load has also been studied [15,16]. Other methods of peak shifting are by electrical energy storage in batteries and cool storage if the peak demand is primarily driven by cooling loads [17]. One of the important peak reduction strategies is the implementation of energy efficiency strategies in the buildings. The building energy efficiency not only reduces the peak demand but also reduces the overall energy use reducing the environmental impact of the buildings. There are several energy saving technologies for buildings. A review of various energy efficiency strategies for building envelopes is reported [18]. However, some of those techniques (e.g., straw-bale walls) are too time consuming and labor-intensive for production home building. Economic feasibility of various energy saving methods in buildings has been presented by different research groups [19–21]. Several studies have been performed on building energy use to reduce their grid dependence. The studies have explored the possibility of net zero energy homes [22–24]. A life cycle cost study of residential net zero energy buildings in Denmark has suggested that the energy use should be reduced to a minimum through energy efficiency measures before

Table 1
Comparison of energy efficient features in the new development compared to the home energy rating system (HERS 06) standard homes.

Type of component	HERS Ref06	Villa Trieste
Floors:		
Slab-On-Grade Edge Insulation	No	No
Floor Over Garage R-Value	2.9 K-m^2/W	3.3 K-m^2/W
Raised Floor R-Value	3 K-m^2/W	3.3 K-m^2/W
Roof:		
Deck Insulation (R-Value)	0	3.9 K-m^2/W
Solar Absorptance	0.75	0.75
Ceilings: (Under Attic)		
R-Value	4.2 K-m^2/W	0.18 K-m^2/W
Walls:		
Exterior Walls:		
R-Value	1.7 K-m^2/W	3.3 K-m^2/W
Solar Absorptance	0.75	0.75
Garage Walls:		
R-Value	1.7 K-m^2/W	3.3 K-m^2/W
Solar Absorptance	0.75	0.75
Doors:		
U-Value	3.7 W/m^2 K	0.7 W/m^2 K
Windows:		
U-Factor	3.7 W/m^2 K	2.3 W/m^2 K
Coefficient Value	0.40	0.35
Overall SHGC Winter/Summer	0.34/0.28	0.31/0.24
Infiltration:		
Effective leakage area	1882.6 cm^2	354.2 cm^2
Air conditioning:		
SEER	13.71 kJ/W-h	15.82 kJ/W-h
Heating: (Natural Gas Furnace)		
Efficiency HSPF	78	92
Ducts: (interior)		
R-Value	1.1 K-m^2/W	0.7 K-m^2/W
Hot Water: (Natural Gas)		
Energy Factor	0.67	0.82

Fig. 1. Model homes built as a part of the proposed energy efficient residential community.