Energy and Buildings 88 (2015) 15–24

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

An analysis of load reduction and load shifting techniques in commercial and industrial buildings under dynamic electricity pricing schedules

Melek Yalcintas*, William T. Hagen, Abidin Kaya

AMEL Technologies, Inc., 2800 Woodlawn Dr. Suite 251, Honolulu, HI 96822, United States

ARTICLE INFO

Article history:
Received 15 October 2014
Received in revised form 5 November 2014
Accepted 25 November 2014
Available online 4 December 2014

Keywords:
Energy conservation
Dynamic utility pricing
Electricity demand shift
Alternative scheduling
Thermal energy storage

ABSTRACT

Due to fluctuations in the supply and demand for electricity throughout the day, the wholesale cost to an electric utility to produce and provide electricity to customers varies continuously throughout the day. Presently, certain utilities are devising alternative electricity pricing structures that vary cost based upon the time in which electricity is used. Energy efficiency retrofits are typically conducted with consideration to static pricing plans for electricity and are indifferent to dynamic pricing policies. To be most effective, energy efficiency measures should be considered with regard to the time energy is used. This study investigates potential cost conservation measures that focus on reducing energy at times of higher energy costs to maximize energy savings. It is shown that shifting work schedules of office buildings with one shift 1 h early can slightly reduce monthly electricity rates by 1–3% and that thermal energy storage systems can be cost effective for retrofits with dynamic pricing schedules and areas that need full replacement of air conditioning.

1. Introduction

Due to the continuous variability of supply and demand of electricity and the fact that there are no economically viable options for the storage of electricity, the cost to an electric utility to provide electricity to customers fluctuates continuously [1]. Despite the variability in cost to provide electricity, utilities have historically charged a flat rate for electricity without regards to the time in which energy is consumed. In this scenario, since the consumer of electricity is not charged for the real time cost of production of electricity, they have no economic incentive to reduce their energy usage during times of high production cost. This can cause long run inefficiencies to the utility by having to build additional generation capacity to meet times of peak demand.

The reason that utilities historically charged a flat rate for electricity despite the variable cost of production of electricity was due to the technological constraints of measuring the real time power usage of customers. However, this has now begun to change as advanced metering infrastructure, also known as smart meters, have become technologically feasible [2]. Advanced metering infrastructure allows both the electric utility and the end consumer of electricity to know the amount of electricity that is being consumed by the end user on a continuous basis. As penetration of advanced metering infrastructure has increased to 22.9% of electric customers in 2012, the number of customers on dynamic electricity pricing structures has also increased, albeit at a much smaller rate [3].

When both the consumer and producer can measure how much electricity a consumer is utilizing at a specific moment, two events can happen. The first is that the utility can charge consumers for electricity based on their cost of producing electricity. These cost structures are called dynamic pricing schedules. While some electric utilities, such as the Hawaiian Electric Company (HECO), which serves the Island of Oahu in the State of Hawaii have initiated optional, opt-in dynamic electricity pricing schedules for commercial and industrial customers, other electric utilities, such as Pacific Gas and Electric (PGE), which serves the San Francisco Bay Area, and Southern California Edison (SCE), which serves the Los Angeles metropolitan area, each have mandated forms of dynamic pricing schedules for commercial and industrial customers. The second event that can happen is that when a customer is aware of the time in which they use electricity and the time in which electricity is more expensive, they can react to times of high pricing by reducing their electricity usage at those times. Dynamic pricing of electricity for residential customers has been shown to their reduce electricity usage and peak demands [4]. However, under certain mandated

* Corresponding author. Tel.: +1 8089880200.
E-mail address: melek@ameltech.com (M. Yalcintas).

http://dx.doi.org/10.1016/j.enbuild.2014.11.069
0378-7788/

dynamic electricity cost structures for commercial and industrial buildings, the reduction in electricity usage and peak demands was less pronounced [5,6].

Due to the rising costs of electricity and growing concern about the long run effects of pollution caused by electricity generation, energy efficiency solution providers have been working on finding measures to reduce electricity usage in buildings. However, since utilities have been typically charging flat rates for electricity, these energy efficiency solution providers focused solely on reducing energy usage within a building while indifferent to the time in which energy usage was reduced. When energy efficiency solution providers make energy conservation recommendations indifferent to dynamic pricing, it has been noted that monthly bill reductions due to these energy conservation recommendations are lower when a building transitions to a dynamic pricing structure.

To compensate for this deficiency, energy efficiency solution providers should expand their focus to also suggest measures to commercial and industrial consumers of electricity to shift their demands to times when electricity prices are lower and to reduce overall peak demands. This study suggests several measures to shift electricity usage to off peak times for commercial and industrial customers when electricity prices are lower. Subsequently, the anticipated daily energy usage and daily electricity cost under dynamic pricing schedules after these measures are enacted is measured for multiple case studies. These case studies are from buildings that have undergone energy efficiency studies and represent a variety of commercial and industrial building types, including office buildings and condominium residences. From this information, the viability of these measures is discussed for each building type.

2. Methods

In this study, specific cost saving measures that account for dynamic pricing structures are suggested. These cost savings are designed not specifically to reduce energy, but to either shift energy usage to times when electricity is less expensive or to reduce the overall peak demand of electricity usage. The suggested cost savings measures are then analyzed for their cost savings in various dynamic pricing structures of various utilities. In the following sections, specific dynamic pricing structures used by utilities and suggested cost conservation measures are described.

2.1. Dynamic pricing structures

As opposed to flat rate electricity pricing schedules in which consumers are charged a flat rate for electricity regardless of the time in which it is consumed, there are alternative dynamic pricing policies utilized by electric utilities which charge a variable price for when the energy is produced. Types of dynamic pricing structures include Time-of-Use (TOU) pricing, which has two or three tariffs for energy consumption, critical peak pricing (CPP), which has an additional critical peak price tariff on certain high demand days, and real time pricing (RTP), where the price of electricity continuously varies based upon supply and demand conditions. These are explained further in detail by reports by the Electric Power Research Institute (EPRI) [8] and the Electricity Innovation Lab of the Rocky Mountain Institute [9].

2.2. Proposed cost conservation measures

In this study, several potential cost conservation measures that can both reduce peak demand of commercial and industrial buildings and shift their energy usage to off-peak times when electricity is not as expensive are evaluated. The considered cost conservation measures include alternative scheduling, and installation of thermal energy storage systems. This list is not exhaustive and other methods of further reducing costs under dynamic pricing schedules could be devised.

2.2.1. Alternative scheduling

One manner in which electricity loads could be shifted from on peak times to off peak times in all dynamic pricing schedules could be by shifting the time when occupants are present in a building. For commercial and industrial environments, this could be accomplished by shifting the schedule of employees. Schedules could be shifted 1 h earlier than usual so that commercial and industrial buildings would not use as much electricity in the late afternoon as usual. This could partially shift their electricity usage to off peak periods. Besides having workers come in 1 h early and leave 1 h earlier, there are numerous permutations of schedules that could be enacted in order to reduce electricity costs.

One clear advantage to schedule shifting is that it represents an action that can be utilized to save money without any upfront investment. One disadvantage to shifting schedules in any form is the fact that it requires behavioral changes that could be disruptive to businesses that operate in a traditional office environment.

2.2.2. Thermal energy storage

Presently, in an air conditioned building, air conditioning is provided at the moment that it is needed. Alternatively, with a thermal energy storage system, air conditioning systems could be run to produce chilled water or ice at unoccupied times of the day. During these times, electricity prices would be lower. The chilled water or ice, which is then left in storage tanks, can be called during occupied times when it is needed.

Thermal energy storage systems can be used on large scale chilled water systems. There are two strategies to installation of a chilled water thermal energy storage system. One strategy would be to retrofit a thermal energy storage system onto an existing chilled water system in order to transfer all of the needed energy into cooling of a building from daytime to the nighttime. The other strategy would be to install a smaller chilled water system with thermal energy storage that would run continuously. Then air conditioning could be provided from both the chilled water system and the thermal storage system. Thermal energy storage systems can be installed onto chilled water systems at a cost of approximately $250 per ton h of cooling storage (this is equivalent to approximately $71 per kWh of cooling storage) [10].

In addition to thermal energy storage systems for chilled water systems, thermal energy storage systems designed for use with direct expansion split air conditioning systems and rooftop packaged air conditioning systems that are in use small and medium sized commercial and industrial buildings have been recently developed. Specifically, this type of thermal energy storage system is designed to store 30 ton h of cooling storage (∼105.5 kWh cooling storage) cooling at a rate of 5 tons cooling (∼17.58 kW cooling) for 6 h at a cost of approximately $833 per ton h (this is equivalent to approximately $237 per kWh of cooling storage). While this is more expensive than thermal energy storage for chilled water systems, it could be installed on smaller capacity air conditioning systems, and therefore not require as high of an upfront investment [11].

The main advantage to a thermal energy storage system is that it can shift the use of air conditioning equipment to off-peak periods of electricity pricing while still providing air conditioning at needed times. In this way, thermal energy storage does not require behavioral change to a building's occupants. The main disadvantages of thermal energy storage systems are that they require an upfront investment of equipment and their use and maintenance may not be readily familiar with building management staff. However, this makes installation of thermal energy storage systems equivalent to