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The impact of increased cooling setpoint temperature during demand response events on occupant thermal comfort in commercial buildings: A review

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ABSTRACT

This paper provides a review of the literature concerning the impact of temporarily increased cooling setpoint temperature on occupant thermal comfort during demand response (DR) events in commercial, air-conditioned buildings. We address concerns regarding thermal comfort as it relates to zone temperature modifications that may be implemented as a part of DR measures. Increased zone setpoint temperatures during the cooling season can adversely affect building occupants physically and psychologically, and impair their perceived indoor air quality and self-estimated performance. In some cases, however, improved occupant thermal comfort due to warmer zone setpoint temperatures during DR events has also been reported. In order to reduce the negative impacts on building occupants, DR must be implemented with careful control and monitoring.

There are significant differences in assumptions made about the way people would respond to a thermal environment between the static heat balance model and the adaptive approach, with the adaptive approach offering a wider range of acceptable indoor temperatures. Therefore, application of the adaptive approach could be one option to improve building energy performance by taking advantage of occupant adaptive behaviors during DR events. Depending on the building services and systems available, expectations of the occupants, and the control options they are given to adjust to their thermal environment, occupants could potentially adapt to temperatures higher than what are currently being practiced in buildings. However, an upper limit threshold for temperature modifications, even if temporary ones, must be recognized to minimize adverse impacts on building occupants prior to DR implementation. Therefore, the ideal goal would be to develop menthods that would identify an optimum balance between energy consumption and the building occupant thermal comfort before applying DR strategies.

Prior review papers relevant to DR have generally concentrated on the energy saving potential alone, or where energy savings have been prioritized over occupant thermal comfort. This paper reviews implementation of DR from the perspective of occupant thermal comfort and presents a summary of the most relevant experimental and field studies regarding occupant thermal comfort during DR events in commercial, air-conditioned buildings.

1. Introduction

Mechanically conditioned buildings are significant contributors to overall global energy consumption and the corresponding impact on electricity demand and greenhouse gas emissions. Building heating, ventilating, and air conditioning (HVAC) systems are responsible for roughly 20% of total energy consumption in developed countries and many developing economies as well ([22], [46]). Providing occupant thermal comfort alongside a supply of fresh air, maintaining their health and well-being, is the main purpose of HVAC system operation in buildings but also results in the consumption of a considerable amount of energy and money expenditures. Therefore, in an effort to more effectively manage energy consumption and peak energy demand, it is important to appropriately define thermal comfort and its relation with indoor temperature and other influential factors, such as relative humidity, air speed, radiant temperature, time of exposure at a given temperature, etc. Ultimately, we would like to achieve an optimized balance between thermal comfort and energy consumption.

Electrical energy production differs from other types of energy (such as liquid fuels) in that the production and consumption occur essentially simultaneously. This feature critically affects power

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Nomenclature

AC	Air-Conditioned
AMV	Actual Mean Vote
APD	Actual Percentage Dissatisfied
CLO	Clothing Insulation Value; 1 CLO equals 0.155 m^2K/W (0.88 $ft^2 \cdot °F \cdot hr/Btu$)
DR	Demand Response
HVAC	Heating, Ventilation, and Air Conditioning
IEQ	Indoor Environmental Quality
MM	Mixed Mode
NV	Naturally Ventilated
PAQ	Perceived Air Quality
PMV	Predicted Mean Vote
PPD	Predicted Percentage Dissatisfied
SSP	Summer Set Point

grids reliability. To increase grid reliability and to address power capacity shortages, buildings could be integrated with a smart grid to participate in demand-side management to reduce peak demand, total energy consumption, and utility cost [36] and participation in DR programs or temporary HVAC systems adjustment is one tool to achieve this [47]. DR is defined as “a set of time-dependent program activities and tariffs that seek to reduce electricity use or shift usage to another time period. DR provides control systems that encourage load shedding or load shifting during times when the electric grid is near its capacity or electricity prices are high” [39]. Smart buildings and their associated controls and equipment are capable of responding to DR requests from the utility or system operator to manage peak demand. The benefits to building operations are a minimized demand charge or minimizing total utility cost based on the real-time price of electricity, or taking advantage of other financial incentives that might be offered. Some response measures may involve adjustments in HVAC operational setpoints (such as zone temperatures or supply airflow temperatures and flow rates) or lighting, thus opening up potential occupant comfort perception problems. When done right, a smart building can also provide a preferred or at least adequate indoor environmental quality (IEQ) for the building occupants. In this context, the important areas of IEQ affected include temperature, humidity, ventilation rates, and lighting levels [36].

Demand Response programs are becoming increasingly important globally as a powerful tool to manage peak demand and increase electrical power network reliability and sustainability. However, the potential for zone temperature changes used in DR to adversely impact occupants, even if they are temporary, points to a need for research to study and identify the impact of these measures on building occupants. The focus of these studies should be on the occupant thermal comfort, health, and overall productivity. It is essential to identify an optimum trade-off between energy consumption and the building occupant thermal comfort before extensively applying DR strategies in buildings [39]. Based on a large body of evidence in the literature, it is apparent that in many cases the current cooling temperature setpoints in buildings are lower than absolutely necessary, and thus there is a energy saving potential in even minimally increasing the cooling setpoint temperature [15,47].

The measure of the overall performance of a building depends heavily on the occupant thermal perception. Considering the subjective nature of thermal comfort and the complexity of interactions between occupants, buildings, and environment, it is important to accurately understand, define, and predict thermal comfort [17]. There are various definitions of thermal comfort used by different researchers, but these are all generally associated with a thermal balance of the body with respect to the local ambient conditions [22]. One well-known definition states this as “the condition of mind which expresses satisfaction with the thermal environment” [5]. Thermal comfort from this viewpoint is very subjective and it is hard to deal with in practical terms. Occupant health and performance that is affected by their thermal comfort is of a paramount importance in commercial buildings, particularly in building use types such as offices or classrooms where people have less control options and freedom to adjust the thermal environment. Thus, it is particularly important to maintain occupant thermal comfort and wellbeing with maximum care in commercial buildings.

Prior review papers relevant to DR have generally concentrated on the energy saving potential alone, or where energy savings have been prioritized over occupant thermal comfort. The main goal of this article is to review prior work that describe the impact of zone temperature adjustments on building occupants in public spaces, such as might be experienced during a DR event. This is important since a better understanding of these correlations could result in fulfillment of the maximum potential for DR to save peak demand on the grid and money for the building owners while maintaining sufficient health, comfort, and wellbeing for the occupants. To set the stage for this review, we first provide a background on the various approaches to achieve thermal comfort from the perspective of the two most well known thermal comfort models; (1) the heat balance model or rational approach and (2) the adaptive model. Further background is given with a brief outline of the energy saving potential that DR can provide. This paper is not intended to review all topics associated with thermal comfort perception in buildings, as they have been the subject of various other prior reviews and publications. Rather, we are focusing here on our primary objective to provide a review of the impact of DR on occupant thermal comfort in mechanically conditioned, commercial buildings based on results reported in previous experimental studies.

2. An overview of the most well-known thermal comfort models

This following two sections provides a brief background introduction for the larger objectives of this review study, with this section covered thermal comfort models and the next the energy savings potential for DR events. This particular section is not intended to be a full review of all relevant literature associated with these thermal comfort models, but rather just as an introduction to the concepts associated with thermal comfort and DR.

2.1. Heat balance model

In the 1960′s, Fanger proposed a heat balance model to enable HVAC engineers to predict the overall acceptability of a given thermal environment for a large group of occupants. The input data for this model was generally developed from college-age students exposed to steady-state situation in climate-controlled chambers. The comfort equation with this heat balance model is based on conditions for achieving thermal neutrality. Fanger proposed the Predicted Mean Vote (PMV) index to be a representative of a “mean thermal sensation vote for a large group of building occupants for any given combination of thermal environmental variables, activity and clothing levels” [53]. This index incorporates the seven points scale which ranges from −3 for cold to +3 for hot. The PMV equation is a function of air temperature, mean radiant temperature, air velocity, relative air humidity or water vapor pressure of air at the local conditions, metabolism or type of activity, and clothing level [45,53].