Incorrect Business Assumptions and Misappropriation of Cooling Resources, or Why Do We Bring Sweaters to Movie Theaters in the Summer?

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ABSTRACT

The invention and dispersion of air conditioning has allowed society to greatly increase comfort levels in our residences, businesses, and various modes of transport. However, parts of modern American society have also developed a culture of over-cooling, wasting energy and financial resources, and actually, reducing our comfort level. Of particular concern are the country's retail businesses: our restaurants, movie theaters, malls and conference centers that regularly over-use space cooling resources.

Thermal comfort among customers of retail establishments appears to be very low as nearly all (88%) individuals responding to a survey perceive at least some retail establishments as over-cooled, and most (76%) bring extra layers of clothing into retail establishments to maintain thermal comfort. Perhaps, most tellingly, exactly half of all survey participants described half or more of all retail establishments to be over-cooled.

Behavioral modification among business managers in their use of cooling resources can lead to significant energy reductions. A 3º F setback among all commercial enterprises could reduce commercial space cooling loads by .0918 Quads. That value is equivalent to 26,903 GWh, or the energy output of more than 12 mid-sized (500 MW) gas-fired generating plants operating at 50% capacity factor.

Introduction

The patent referred to as "Apparatus for Treating Air," granted in 1906, was the first of several patents awarded to Willis Haviland Carrier, generally recognized the "Father of Air Conditioning." In 1921, Carrier patented the centrifugal "chiller" representing the first practical method of air conditioning large spaces. Previous refrigeration machines used reciprocating-compressors (piston-driven) to pump refrigerant (often toxic and flammable ammonia) throughout the system. The result was a safer and more efficient chiller.

Industries flourished with the new ability to control the temperature and humidity levels during and after production. Cooling for human comfort, rather than industrial need, began in 1924, noted by the three Carrier centrifugal chillers installed in the J.L. Hudson Department Store in Detroit, Michigan. Shoppers flocked to the 'air conditioned' store. The boom in human cooling spread from the department stores to the movie theaters, most notably the Rivoli theater in New York, whose summer film business skyrocketed when it heavily advertised the cool comfort.

Commercial Air Conditioning Loads

Air conditioning has continually increased penetration in the commercial, industrial, and residential sectors. Market saturation in new commercial space is nearly 100%. Efficiency improvements though the retrofit market has been and remains a consistent utility energy efficiency program opportunity. While that effort is an important component of total energy savings potential, the behavioral component in the use of air conditioning is likely to be just as large, if not larger.

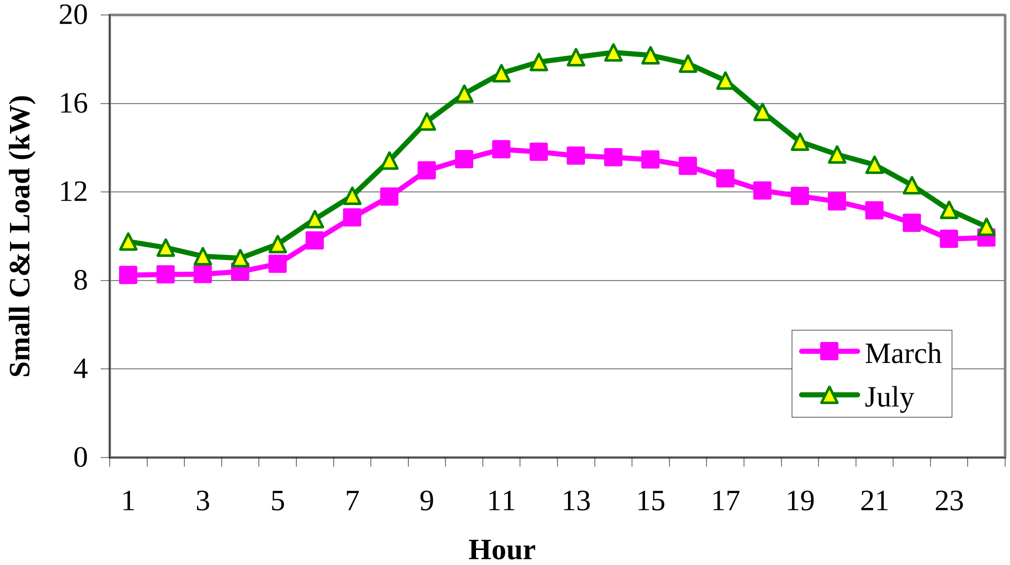
Electricity delivered to commercial loads in 2006, as reported by the Energy Information Association (EIA), was 4.44 quadrillion Btus (quads), representing 35.5% of total electricity consumption.[1] Total energy consumption in the form of electricity, after accounting for an average conversion efficiency of 31.5%, was equal to 14.1 quads. Of the 4.44 quads in direct commercial sector electricity consumption, 0.51 quads, or 11.5%, was for space cooling requirements.[2] An additional .19 quads (4.3%) was required for air handling, which is arguably partly avoidable through lower air conditioning requirements, but I've conservatively left that savings component out of my calculations.

Total 2006 CO2 emissions for commercial sector electricity requirements were calculated by the EIA at 832 million metric tons.[3] Assuming an equivalent emission rate for all energy consumption, commercial sector air conditioning consumption is responsible for approximately 96 million metric tons of annual CO2 emissions.[4]

On a capacity basis, it is well understood that air conditioning loads are highly seasonal and contribute significantly to summer peak loads. Figure 1 shows the average hourly customer loads during March and July for commercial and industrial customers taking service at secondary voltage levels served by Public Service Company of Colorado (PSCo). The difference between March and July loads is primarily represented by air conditioning and related air handling requirements.[5] Load during peak hours spike during the summer months due to extensive use of air conditioning. As such, summer peak loads for small commercial customers can be 35% higher than the off-season base loads.[6] Accordingly, a considerable amount of electric generating capacity is designed primarily to meet this load requirement, and voluntary thermostat setback by regional businesses could have a significant impact on reducing peak load requirements.

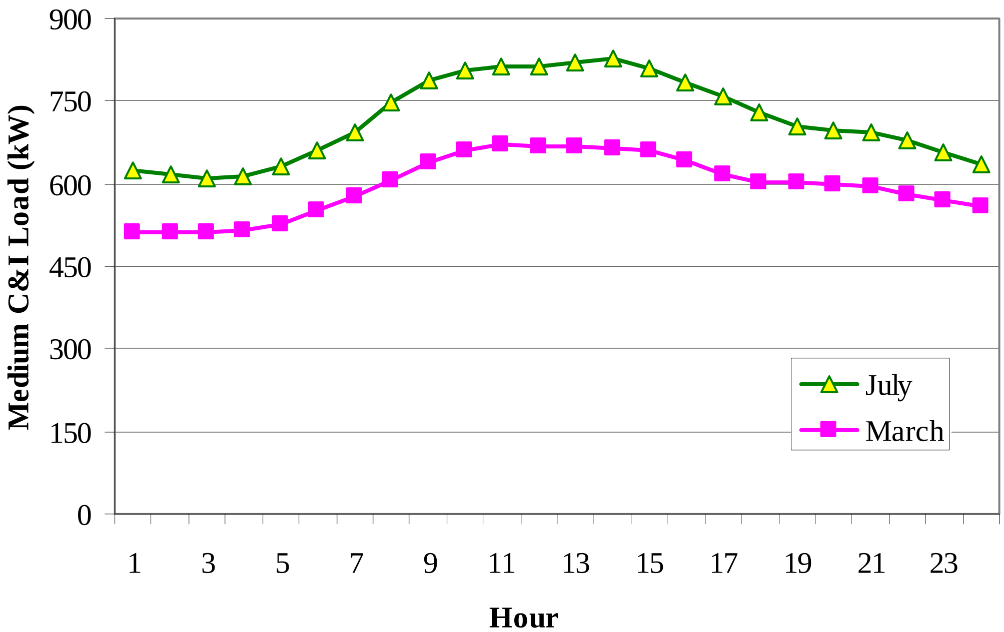
[1] 2008 Annual Energy Outlook, Table A2
[2] Ibid, at Table A5
[3] Ibid, at Table A18
[4] The actual value is likely to be lower as air conditioning and other peak load requirements are more regularly met with natural gas-fired units than the overall electric production fuel mix.
[5] Refrigeration loads will also increase due to higher summer-time temperatures.
[6] Assuming the PSCo load shapes are reasonably representative across a considerable portion of the country. Application of regional data is necessary to further assess the air conditioning load impact.

Figure 1: Hourly Small Commercial Loads: Off-Season and Peak Months



As shown by the chart below, larger commercial customers are generally less affected by summer air conditioning requirements. Figure 2 depicts hourly base loads in March against peak loads in July for medium commercial and industrial customers. The largest hourly differences are 25% between base and peak, as compared to 35% among the small commercial class.

Figure 2. Hourly Medium Commercial Loads – Off-Season and Peak Months



Total 2006 commercial sector electricity expenditures were tallied at $168.8 billion. Assuming average rates across season and usage, $19.4 billion was expended for cooling purposes. When seasonal rate structures and fuel charges are properly incorporated, the dollar expenditure value for commercial sector cooling requirements may actually be higher.

Over-Use of Cooling Resources

ASHRAE Standard 55 - 2004 "Thermal Environmental Conditions for Human Occupancy" recommends temperature ranges have been found to meet the needs of at least 80% of individuals. National Research Council of Canada has adopted identical standards.[7] The standards are separated into low and high humidity levels. Low humidity regions (approximately 30% humidity) have a broad recommended temperature range of 76-82F, with a mid-point of 79F. Recommended temperature settings for relatively humid regions of the country range from 74-78F, with a mid-point of 76F. These standards are outlined in the following table:

Table 1. ASHRAE Thermostat Setting Guidelines

Temperature / Humidity Ranges for Comfort			
Conditions	**Relative Humidity**	**Acceptable Operating Temperatures**	
		°C	°F
Summer (light clothing)	If 30%, then If 60%, then	24.5 – 28 23 – 25.5	76 - 82 74 - 78
Winter (warm clothing)	If 30%, then If 60%, then	20.5 - 25.5 20 – 24	69 - 78 68 – 75

Source: Canadian Centre for Occupational Health and Safety - Adapted from ASHRAE 55-2004.

The primary question is: do businesses use ASHRAE standards for setting thermostats levels? If not, why not? And, if so, where in the recommended range do businesses set the thermostats?

The EIA states that businesses typically set summer thermostats between 68º and 74ºF.[8] This suggests a mid-point of 71ºF, a temperature setting 5º – 8ºF lower than ASHRAE-recommended thermostat settings. If accurate, and if ASHRAE standards are set appropriately, this would suggest that many businesses are over-using their cooling resources and, in turn, many people are not thermally comfortable during the summer air conditioning season.

Fanger's PMV model was developed in the 1970's from laboratory and climate chamber studies. The PMV model combines four physical variables (air temperature, air velocity, mean radiant temperature, and relative humidity) and two personal variables (clothing insulation and activity level) into an index that can be used to predict thermal comfort. The index provides a score that corresponds to the ASHRAE thermal sensation scale which ranges from -3 (cold) to +3 (hot).

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[7] The Nebraska Public Power District recommends temperature setting, 80 °F with 55% relative humidity. See http://www.nppd.com/My_Business/Commercial_Services/Additional_Files/retail.asp

[8] http://www.energystar.gov/index.cfm?c=business.bus_summer

Many follow-on studies to Fanger's climate chamber analyses have been conducted, but most of this literature is centered around office environments and worker productivity including that by de Dear, Cena, and others. A review of the available literature showed there has been minimal analysis completed on customer comfort levels within *retail* establishments such as restaurants, movie theaters, and malls; whether businesses are setting thermostats consistent with ASHRAE standards (55-2004); the causes – if any – for over-use of cooling resources; and the associated financial and environmental costs of air conditioning practices in retail establishments.

In the Small Commercial HVAC O&M Project, 125 business establishments (units) in 4 Northwest states were assessed for energy savings opportunities in air conditioning usage. 68% of all units in the study were recommended to adjust thermostat settings based on assessment of occupant comfort levels. Of those units recommended for adjusted thermostat setting, less than half (46%) of those participants actually adjusted their thermostat settings. (Jennings, Hewitt, Banks, 2003)

Research done by Western Resource Advocates supports these findings. In a simple survey, we asked individuals if they occasionally experienced thermal discomfort due to air conditioning in retail businesses, whether they brought additional layers of clothing inside retail businesses to maintain comfort, and the general frequency of thermal discomfort due to air conditioning. In the survey questions, we specifically referenced restaurants, malls, and movie theaters. The survey was conducted in April and May of 2008. Surveys were conducted in person, by phone, and by email. Participants included individuals who work for or in close proximity to Western Resource Advocates, and acquantainces of the author and an assistant at WRA. Response rate to the survey was over 90%.

An overwhelming majority (88%) of the participants in the survey reported thermal discomfort due to air conditioning in at least some retail businesses. 76% of survey participants indicated they brought an additional layer of clothing to maintain thermal comfort in retail businesses. Exactly half of all survey participants indicated they felt thermal discomfort in half or more of the retail establishments they visited.

Because the survey was conducted outside of the summer peak air conditioning season, we did not ask for actual comfort levels. Also, as survey participants had to recall comfort levels from prior air conditioning seasons, poor recall or exaggeration are relevant concerns. Accordingly, follow-on research is necessary and is currently being planned for the summer air conditioning season. Also, most study participants (approx. 90%) were residents of Colorado, and more analysis should be conducted in other regions of the country.

Nonetheless, based on the data available, air conditioning resources appear to be overused in a significant percentage of retail establishments. Further, based on the survey results, a majority of individuals are thermally uncomfortable in at least some of the retail establishments, and most of these individuals have made behavioral modifications accordingly, such as carrying an extra layer. Specific results to the survey are in the following table:

Table 2. Commercial Retail Air Conditioning Survey Results

Total Participants:	68	
Age:		
0-30	6	9%
31-50	42	62%
51+	20	29%
Gender:		
Female	33	49%
Male	35	51%
Finds AC Occasionally Too Cold:		
No	8	12%
Yes	60	88%
Has Brought Additional Layer to Maintain Comfort:		
No	16	24%
Yes	52	76%
Frequency of Retail Establishments Too Cold:		
None	8	12%
Some	26	38%
Half	12	18%
Most	17	25%
All	5	7%

Within the survey population, certain sub-groups were more prone to thermal discomfort from over-cooling. Women comprised only 25% of respondents who indicated no thermal discomfort from air conditioning even though they made up roughly half of the survey participants.

WRA plans to more thoroughly research customer comfort and air conditioning during the summer air conditioning season. This research will focus on customer comfort based on actual temperature, outdoor temperature, and other inputs to the PMV model. Planned research will include surveys of retail establishment patrons and business managers, indoor and temperature and humidity readings, and assessment of customer and employee activity. Quantitative savings verification in response to program initiatives will also be conducted but unfortunately must also be delayed for seasonal roll-out of such initiatives, discussed below.

In addition to possibly detracting from thermal comfort, air conditioning can have negative health impacts. Seppanen and Fisk (2002) found strong correlations between air conditioning, as opposed to natural ventilation, and sick building syndrome (SBS), stating "[r]elative to natural ventilation, air conditioning with or without humidification was consistently (16 of 17 assessments) associated with a statistically significant increase in the prevalence of one or more SBS symptoms."

Socio-Economic Reasons for AC Over-Use

As part of ongoing research, I plan to assess, along with customer comfort in retail establishments, management objective and oversight in its use cooling resources. In initial conversations with restaurant and hotel managers, I believe business overuse of air conditioning may be due to a wide array of reasons, such as:

- Business assumption of customer desire
- Air Conditioning employed as sales draw
- Thermostat settings set by work force, not customers
- Employees are acclimated to temperature setting
- Lack of time-of-use rates and smart metering

A primary reason for over-use of cooling resources in the retail commercial sector may be that businesses incorrectly assume their customers desire more cooling. Operators and owners of service industry establishments – restaurants, movie theaters, hotels and other retail outlets – are primarily focused on the "customer experience", and that higher temperature settings will lead to a reduced customer experience. Accordingly, making business managers aware of customer comfort levels, and empowering patrons to express discomfort, is a critical component to altering this business behavior.

Retail businesses often use air conditioning as a form of marketing – frequently leaving their doors open as cool air billows out of the store front – to entice customers into the air conditioned on a hot summer day. Closing their front doors would obviously reduce air conditioning energy use. However, in addition to the enticing effects of billowing cool air, businesses frequently cite that open doors attract more customer visits than maintaining a closed doorway.[9]

Business over-use of cooling resources may be due to the fact that the temperature is set by the work force that is far more likely to be moving and raising body temperatures as part of their job duties. One obvious example is restaurant employees. Kitchen staff are exposed to high temperatures via the cooking process. But even the wait staff must often conduct kitchen duties, carry hot plates of food, and raise body temperatures as they walk to and from customer tables. Restaurant clientele, on the other hand, are at rest. The differences in thermal comfort between restaurant employees and patrons is consistent with two critical inputs to Fanger's PMV model: mean radiant temperature (*i.e.*, exposure to hot surfaces), and activity level.

Employee dress codes including suit jackets and ties can lead to greater cooling requirements than otherwise necessary. The social norms embedded in dress codes are widespread in commercial professional services (*e.g.*, offices) and retail establishments. A primary focus of Japan's Cool Biz program, discussed in greater detail below, is to overcome the social norms embedded in white collar business dress codes. In retail establishments, employee dress codes can cause over-cooling for optimal customer comfort levels as customers often wear lighter clothing such as shorts and T-shirts on very hot days. Clothing insulation is a critical input to Fanger's PMV model of thermal comfort.

Along similar lines of comprehending the workforce / customer relationship, employees are in the air conditioned space for extensive periods, and thus acclimated to the temperature setting. Alternatively, customers to outdoor strip malls and shopping areas often experience significant temperature fluctuations going from outside to indoor settings, potentially stressing a person's immune system.[10] The Canadian Centre for Occupation Health and Safety notes that

[9] Ontario recently started a program – Doors Closed Ontario – to have all retail establishments close their doorways to negate any competitive disadvantages of unilateral compliance

[10] See, for example, http://www.ingentaconnect.com/content/klu/bebm/2005/00000140/00000006/00000065

indoor temperature should be set in relation to the outdoor temperature. "In summertime when outdoor temperatures are higher it is advisable to keep air-conditioned offices slightly warmer to minimize the temperature discrepancy between indoors and outdoors."[11]

Finally, and perhaps, most importantly, businesses rarely experience the actual costs to generate and deliver the electricity at summer peak periods. Relative to the total cost of operation of a restaurant or other commercial business, energy expenditures for air conditioning are relatively modest. Presently, time-of-use rates and smart metering technologies are only minimally deployed. Expansion of time-of-use rates (or at least marginal cost-based seasonal and time-of-day rates) and smart metering technologies will greatly increase information available and incentives to minimize commercial sector over-use of cooling.

Modification of business perceptions of customer's thermal comfort, thermostat-setting factors such as employee dress codes, and utility pricing mechanisms are likely necessary to adjust usage patterns of cooling resources among retail businesses. Better comprehension of various socio-economic factors driving cooling loads among retail businesses is necessary to optimize cooling expenditures and thermal comfort among retail patrons.

Energy Savings and Emission Reductions Due to Adjusted AC Settings

Utility and government-based demand-side management programs almost universally attempt to alter the technology employed either in new construction or retrofit. Utility DSM programs provide significant discounts to the purchase of compact fluorescent lightbulbs and high efficiency air conditioners and other technological improvements, but rarely – other than residential education pamphlet bill stuffers – do utilities attempt to alter customer behavior. Admittedly, altering customer behavior is difficult to achieve and arguably not the job of electric utilities. But in order to achieve significant energy savings, we must proactively address the behavioral component of energy use.

The ENERGY STAR savings calculator for residential thermostats assumes 6% savings per degree of setback during the cooling season. Certain entities claim cooling load energy savings up to 8% (above 78) per degree F of thermostat setback.[12] The following figure assumes a 6ºF set-back and 6% cooling load savings per degree of set-back among small commercial customers. Behavioral modification among business managers in their use of cooling resources can lead to significant energy reductions. Relying on the PSCo data we applied before, small commercial customers could reduce peak loads by approximately 2 kW.

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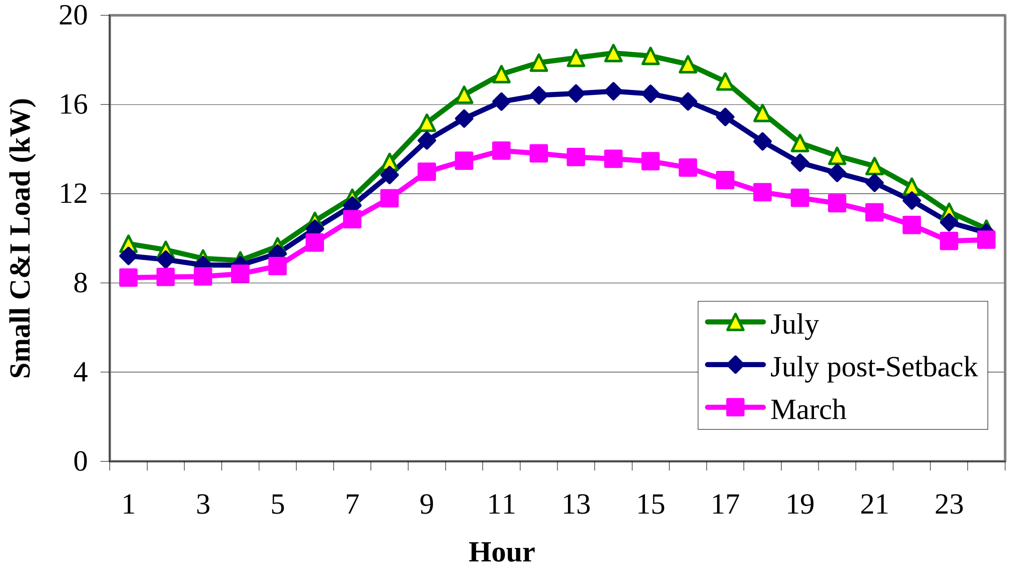
[11] http://www.ccohs.ca/oshanswers/phys_agents/thermal_comfort.html
[12] See http://www.kenergycorp.com/enmgt.aspx

Figure 3. Potential Load Reduction from a 6ºF A/C Thermostat Set-Back



As described above, small commercial loads are more subject to peak air conditioning requirements, and thus, higher percentage savings are available from thermostat setback in the small commercial sector than the medium and large commercial sectors. If we assume a more conservative 3º setback among all commercial enterprises and a 6% savings estimate per ºF thermostat adjustment, commercial space cooling loads could be reduced by .0918 Quads. That value is equivalent to 26,903 GWh, or the energy output of more than 12 mid-sized (500 MW) gas-fired generating plants operating at 50% capacity factor.

Perhaps more important is the reduced need for generating capacity from the assumed thermostat setbacks. If we assume the energy is met through simple-cycle peakers running at a 10% capacity factor, the proposed 3ºF thermostat setback could avoid the need for roughly 123 peaking plants at 250 MW each.[13]

Given the average conversion efficiency of electric power production of 31.5%,[14] a savings of .0918 Quads due to a 3ºF thermostat setback actually reduces total energy consumption by 0.29 Quads, and total CO2 emissions by 17.2 million metric tons. The reduction in direct electricity expenditures, also based on broad commercial sector values, would be $3.5 billion, roughly 2.1% of total commercial sector electricity expenditure.[15]

Air Conditioning Reduction Programs

There are several international efforts to invoke behavioral modification in the use of air conditioning by businesses. Most notably is the Cool Biz program in Japan. Starting in the summer of 2005, the Japanese Ministry of the Environment initiated the Cool Biz program to

[13] Simple cycle plants are generally developed in the 250 MW range while combined cycle units are generally developed in the 500 MW range.
[14] Source: EIA
[15] As air conditioning loads are on-peak and generally met with gas-fired power plants throughout most of the country, the energy savings, CO2 emissions avoided and rate impacts are not easily explained through average annual EIA data.

reduce greenhouse gas emissions by setting the thermostat among the nation's offices at 28º C (82.4º F, or approximately 7º F warmer than the average U.S. office building). To counter deep social fashion norms, top government officials including the heads of ministries, came to work without jackets and ties. The 82 degree setting is mandatory in government buildings. In the first year of implementation, Japan estimates roughly 500,000 tons of CO2 emissions were avoided. In 2006, the second of year of program implementation, participation in the program were up at least 100%., cutting CO2 emissions by one million tons. Japan's business association, which represents roughly 1,300 major companies, says 70% of its companies complied with the Cool Biz program as of October 2007.

Critical to comprehending the success of the Cool Biz program, and possibly replicating the program here in the United States, is understanding the Japanese social structure. Japan is often perceived to be a more structured society than the U.S., where government officials and key business leaders have greater influence over social norms and expectations. Accordingly, the Cool Biz program may be difficult to replicate here in the U.S. However, local, state, and federal government officials, as well as business leaders can and should make a concerted effort to endorse behavior modification as well as efficient technology utilization in order to lower energy usage.

The most applicable program design among energy efficiency programs in the U.S. appears to be the 20/20 conservation programs run by the three California investor-owned utilities: South California Edison, Pacific Gas and Electric and San Diego Gas and Electric whereby customers receive an extra 20% bill reduction for a 20% or more energy savings during peak summer months. As a review of the program described, "[t]he program delivered energy savings at a relatively low cost of $0.11 per first year kWh saved. However, we estimate that the effective lifetime of 20/20's 2001 impact will only extend up to three years in the future, resulting in a $0.04 cost per lifetime kWh saved. In the absence of a continuing rebate program like 20/20 and without the unique backdrop of the 2001 energy crisis and the constant threat of rolling blackouts, the behavioral changes induced by the 20/20 Rebate program in 2001 are not sustainable, and would likely dissipate within a few years."[16] A 2005 savings analysis found that most of the program savings cannot be attributed to the program, and thus, the program was largely not cost-effective.[17] The program was later discontinued.

Nonetheless, the concept of peak load energy and capacity reduction due to behavior modification, including AC thermostat setback, remains a critical component to solving the energy – environmental dilemma before us. But rather than utility-run programs that pay commercial (and non-commercial) entities incentives to set back thermostats higher than otherwise set, we propose the development and implementation of a media program established to raise business awareness of the over-use of cooling among commercial establishments and that allows businesses to communicate their participation in a voluntary reduced cooling program. This media program would also be designed to raise consumer empowerment so that consumers are more willing and able to communicate their desire for a less-cool retail environment.

[16] http://www.calmac.org/publications/CALMAC_final_03-13-03ES.pdf

[17] See Evaluation of the California Statewide 20/20 Demand Reduction Programs, Wirtshafter Associates, Inc., 2005

Conclusions

Retail businesses including restaurants, movie theaters, and shopping malls appear to significantly over-use cooling resources. Thermal comfort among customers of retail establishments appears to be very low as nearly all (88%) survey participants perceive some retail establishments as over-cooled and most (76%) bring extra layers to maintain thermal comfort. Perhaps, most tellingly, half of all survey participants described half or more of all retail establishments to be over-cooled.

However, more analysis needs to be conducted at the time of summer peak cooling as survey results may be subject to poor recall or exaggeration. Additional analysis must be done on actual thermostat settings and other inputs relevant to Fanger's PMV model, as well as the perception and practices of retail managers and employees in setting thermostats in their establishments. Western Resource Advocates will be working with local academic resources to evaluate thermal comfort and cooling resource management through customer and business operator surveys to take place during the summer heating season, as customer perception of space cooling impacts on comfort and other factors will be most accurate.

An array of reasons may be behind the over-use of cooling resources including employee activity levels and exposure to objects of relatively high mean radiant temperature. Other economic aspects, such as inaccurate pricing mechanisms may be to blame. Accordingly, along with thermal comfort analysis, we recommend better application of marginal-cost pricing via implementation of time-of-use rates and smart-metering technologies.

References

American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE). (2004). Thermal Environmental Conditions for Human Occupancy (ASHRAE Standard 55-2004). Atlanta, GA: ASHRAE.

Baille, A. P., Griffiths, I. D. & Huber, J. W. (1987). Thermal Comfort Assessment: A New Approach to Comfort Criteria in Buildings. (Report to ETSU S-1177). Guildford, UK: University of Surrey.

Busch, J. F. (1992). A tale of two populations: Thermal comfort in air-conditioned and naturally ventilated offices in Thailand. Energy and Buildings, 18, 235-249.

Cena, K. M. (1994). Thermal and non-thermal aspects of comfort surveys in homes and offices. In N. A. Oseland & M. A. Humphreys (Eds.), Thermal Comfort: Past, Present and Future (pp. 73-87). Garston, UK: Building Research Establishment.

Charles, K.E. (2003). Fanger's Thermal Comfort and Draught Models, IRC-RR-162

de_Dear, R. J., & Brager, G. S. (1998). Developing an adaptive model of thermal comfort and preference. ASHRAE Transactions, 104(1), 1-18.

Fanger, P. O. (1994). How to apply models predicting thermal sensation and discomfort in practice. In N. A. Oseland & M. A. Humphreys (Eds.), Thermal Comfort: Past, Present and Future (pp. 11-17). Garston, UK: Building Research Establishment.

Jennings, J., Hewitt, D., Banks, D., (2003). Small Commercial HVAC O&M Pilot Project, ACEEE

Seppanen, O., Fisk, W.J. (2002). Relationship of SBS Symptoms and Ventilation Type in Office Buildings, LBNL – 50046

Wirtshafter, R., (2005), Evaluation of the California Statewide 20/20 Demand Reduction Programs