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Determining Appropriate Heating and Cooling Thermostat Set Points for Building Energy Simulations for Residential Buildings in North America

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Determining Appropriate Heating and Cooling Thermostat Set Points for Building Energy Simulations for Residential Buildings in North America

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Abstract

Existing building energy simulation tools have a purported tendency to over-predict heating use and, in some cases, to under-predict cooling use, an outcome often attributed to inappropriate assumptions about thermostat management. As a result, a systematic review was conducted for the purposes of determining typical heating and cooling set points for single-family houses in North America. The preliminary consensus results provide an empirical basis for establishing typical inputs for building energy simulation models, increasing prediction accuracy of heating and cooling loads. The results of this review have been applied as default values in the Lawrence Berkeley National Laboratory's Home Energy Saver and Home Energy Scoring Tools, significantly improving on values previously in use.

The review evaluated various data sources showing measured data on heating and cooling temperatures in buildings. Measured data from eighteen studies spanning more than three decades were examined. Our evaluation also considered recent 2009 survey data on heating and cooling set points from the Residential Energy Consumption Survey (RECS) as well as a very detailed recent series of measurements in eighty homes geographically distributed around the United States.

The evaluation found that there is diurnal variation in the temperature maintained in homes in all studies and that accounting for this variation will slightly reduce simulated heating and cooling loads (compared to an assumption of constant temperatures) since the interior temperatures largely vary in phase with the outdoor temperature. For central systems, typical evening heating thermostat set points averaged 67°F with setbacks to 64°F during nighttime hours. Similarly, for cooling thermostat set points averaged 75°F with daytime setups to 78°F and 77°F during the occupied evening hours. These recommendations account for evidence of unequal room temperature distributions of at least 1-2°F, even with central space conditioning equipment. If a constant value is used, a thermostat setback of 3°F is recommended as a measure for heating; for cooling, the daytime set up should be assumed should be 2°F. A realistic assumption for conditioned basement temperatures is 7°F below the main zone.

Further, the data clearly demonstrated that zoned heating and cooling systems exhibit relaxed thermostat set points of a least 1°F beyond those recommended for central systems (eg. the occupied evening thermostat setting would be 66°F for a zoned heating system). It should be mentioned, that there was clearly shown to be geographic differences in cooling and heating temperature preference, but the data sources were not of sufficient quality to include the effect.

Finally, the report evaluated shortcomings in the various methodologies for surveying and measuring interior air temperature and extending this to determination of effective thermostat set points. Given that thermostat setting in a building energy simulation is the largest single factor controlling the prediction of heating and cooling energy we recommend systematic temperature/thermostat status research. Properly done, and in diverse locations around the U.S., such research could help further refine recommendations.

Introduction

The thermostat setting in a building energy simulation is arguably the largest and most sensitive single factor controlling the prediction of heating and cooling energy. Interaction of the interior thermal conditions with the house insulation integrity and outdoor weather is of key influence on the loads passed on to energy using furnaces and air conditioners. Early research by Ternes and Stovall (1988) showed the predictive error of simulation for envelope energy savings measures was reduced by 20-60% by appropriate selection of the measured interior temperature for individual homes. More recently, Parker et al. (2012) showed that cooling energy use varied by a factor of 5:1 in otherwise identical homes with proper specification of thermostat settings critical for accurate prediction. Moreover, the same is true for defaults and/or rating system software where the thermostat setting specified will likely be critical to reliable results for aggregate asset-assessment *averages* (Bourassa et al., 2012). Assumed thermostat settings will also strongly influence savings from efficiency measures.

Thus, where actual measurements for a given home are lacking, it is important to specify the thermostat setting parameter in as consistent and unbiased a manner as possible. This report seeks to examine relevant data, based on occupant-reported settings, thermostat observations, and direct temperature measurement. The primary objective is to provide a rational and studied examination of data sources and to use these to provide best preliminary recommendations for the set points used in building energy simulations.

Background

In practice, thermostat set points depend on homeowner comfort, clothing, occupancy, habits, schedules, energy prices, and climatic adaptation – all interacting in a potentially complex fashion. Comfort alone is a very large research area, but this is not adequate alone to determine set points. For many building energy simulation models (applied to operational and asset assessments alike), the objective is to choose the most appropriate set points for an average home as the defaults. This is meant to represent a societal average incorporating relative degree of occupancy and usage patterns. This reality necessitates an empirical evaluation of available data.

This issue continues to be important to the building simulation community. Each building energy simulation protocol currently in use has come up with differing estimates of these values as shown in Table 1 which is adapted from the recent work of Roberts and Lay (2013). HSP is the NREL House Simulation Protocol (Hendron and Engebrecht, 2010) used in DOE's Building America. Other references: IECC (ICC, 2009), RESNET/HERS (RESNET, 2006) and Home Energy Scoring Tool from internal documentation (Home Energy Scoring Tool Documentation, 2013).

Table 1. Assumed Thermostat Settings in Major Energy Simulation Software Protocols.

Standard	Cooling Set Point (°F)	Cooling Setup (°F)	Heating Set Point (°F)	Heating Setback (°F)
HSP/Building America	76	--	71	--
IECC	75	--	72	--
RESNET/HERS	78	80 (9AM - 3PM)*	68	66 (11PM- 6 AM)*
Home Energy Scoring Tool**	78	84 (8AM- 5 PM)	68	60 (8 AM- 5 PM)

* Optional, not used for the standard building; (i.e. a measure)

** It should be noted that these assumptions are historic; based on the data in this report, the assumptions for Home Energy Scoring Tool and HES have been modified.

In particular, this report examines the recent NREL work of Roberts and Lay (2013) as well as the most current Residential Energy Consumption Survey (RECS 2009) data to see what these two important sources suggest as appropriate heating and cooling set points. We also conducted an extensive survey of previous research to see how available sources might inform the decision process.

Possible Bias in Occupant Reported vs Monitored Temperature Data

There are clearly more occupant surveys of reported thermostat setting for heating and cooling than there are measurements of interior temperature. However, it is vital to keep in mind that measured interior temperatures are not the same thing as the thermostat set point and while they are more reliable they also have potential bias that is important to take into account. This disparity was first pointed out in an early study by Kempton and Krabacher (1988) which recorded occupant-reported thermostat settings, the thermostat settings directly observed at the thermostat itself, as well as the recorded air temperature near the thermostat.

Potential Source of Bias with Occupant Surveys

- Ignorance: users may have an unclear idea of the typical temperature to which they set the thermostat. Thermostats may have unclear markings or inaccurate indicators
- Awareness: occupants may have particularly poor ideas of temperatures maintained during periods when the household is sleeping
- Optimism: households may report thermostat settings which are more conservative than those they actually use
- Spatial: Occupants may also have an unclear idea about the average temperature across the house's rooms, particularly for basements or less occupied outlying zones.

Potential Source of Bias with Temperature Measurement

- Household internal gains and solar gains may bias the interior temperature high during the heating season – e.g. the temperature may float above the thermostat set point for extended periods of time, biasing upwards the measured temperature to be above the actual heating thermostat point. The opposite is true for the cooling set point. Measured temperatures will more often reflect the actual thermostat setting since internal gains will cause the temperature to float up to the control point.

- Nighttime thermostat setback may not be fully observed in the measured temperature data since the interior temperature will fall back towards the thermostat setback, but often not reach that point, particularly with deep setbacks, milder weather conditions, and/or with well-insulated buildings.
- The measured temperature is typically taken in the main living zone and may not reflect temperatures in bedrooms and outlying zones, particularly basements. Measurements taken directly above the thermostat may be biased by low-level heat generation from the thermostat itself.
- Sensor height /thermal stratification . Clearly it is best to measure temperature at a height similar to control thermostats due to the possibility of thermal stratification. However, in many cases where the measurement is wired, this location may be difficult to arrange.

Potential Bias with Actual Thermostat Measurement

- As made clear by Kempton and Krabacher (1990), as well as the study of Gladhardt et al. (1988), measuring the actual thermostat setting can potentially introduce bias. This comes about because households that use the thermostat as an on/off switch for the heating system can artifically set the thermostat high or low to produce "continuous on." In reality, however, the thermostat is set in such a fashion for a short time and with no intention that the home reaches the setpoint, which may bias the resulting averages, which in energy simulation are applied to long-term control.
- The above bias is most appropriately resolved by taking the temperature immediately below the thermostat and recording the temperature only while the heating or cooling system is operating. This was done in a single project by Lutz and Wilcox (1990).

Earlier Research

Heating Set points

In California, Lutz and Wilcox (1990) measured temperatures by the thermostat in approximately thirty California homes, with measurements taken only while the system was activated. A measured daytime temperature when the heating system was on was approximately 70.0°F with an indicated setback of only about 1.5°F[1].

Another unique small sample study of ten homes in Lansing, Michigan in 1986-1987 recorded the actual heating thermostat device setting, that reported by occupants, and the interior temperature (Gladhardt, et.al., 1988). That study showed the observed thermostat setting was 1.9°F warmer than that reported, with the recorded interior temperature being the better indicator of the thermostat setting.

[1] One caveat on this study is that the measured temperature while the heating system is on may bias the results high as the low point at which the thermostat is triggered is of greater interest for the simulation. This could be resolved by including the temperature during the period immediately *before* the heating/cooling systems were activated.

An early study of 187 homes in Oregon in the Hood River Conservation Project (1983-1985 showed a measured indoor temperature in the main living zone of 70.3°F but with a minor observed setback such that the 5AM temperature was about 0.4 lower (Ternes and Stovall, 1988). Other research on the same data verified that the occupants claimed much larger setbacks than were observed (Dinan, 1987), but with no evidence of consumer temperature "take-back" after retrofits were implemented.

One significant past study for our purposes was that by Conner and Lucas (1990) of 206 electrically heated homes in the Pacific Northwest as well as 400 additional homes located in the same regionevaluated by Vine and Barnes (1988). The average temperature measured during the winter season in the 206 ELCAP homes was 68.4°F. There was some variation by time of day. The highest temperature was at 9 PM (69.6°F) with a shallow setback beginning at 10 PM which eventually dropped to 66.0°F at 6 AM. *It should be noted, however, that a sub-sample of the homes found that average temperatures maintained in bedrooms was three degrees lower– only 66.4°F with even more variation for basements* (see section below for more discussion).

The evaluation of Conner and Lucas found almost no difference in the degree of thermostat setback from the use of clock or programmable thermostats vs. manual ones. The authors suggested that programmable thermostats were unlikely to produce savings due to this fact. The authors also categorized each site in terms of thermostat behavior. They found that 40% of the sites had a relatively constant thermostat setting (negligible setbacks) in the winter – the most common pattern. The next most common patterns in decreasing order of prevalence were: nighttime setback (25%), daytime setup (10%) and erratic control where the thermostat may be changed several times a day and not consistently across days. For those sites practicing a consistent nighttime setback, the day and evening settings averaged at 68.5°F, with a nighttime setback allowing the temperature to drop to a low of 64°F at 6 AM. A corresponding set-up was seen at 7 AM which likely relates to occupant daily schedules and habits.

Occupants in these homes were surveyed as to their believed thermostat settings in the main living zone. These were compared to the measured data. Analysis revealed that while occupants poorly reported their interior temperatures in individual homes, on average, they were very close. For instance, the average reported temperature in the main zone was 69.6°F during the occupied period vs. a measured value of 69.3 °F. However, the occupants reported a nighttime thermostat setback of 63°F, while the average measured low morning temperature was 64°F.

This disparity between reported and realized setback for individual cases has been observed in repeated studies: Kempton and Krabacher (1987) and Gladhart et al. (1988), although with small samples (n=7 and n=10, respectively). Ternes and Stovall (1988) also had similar findings in other studies of claimed versus realized degree of thermostat setback. Part of this disparity may be lack of homeowner awareness of temperature while sleeping, but an equally likely explanation has to do with the lagged rate at which the building loses heat as temperature coasts downward towards the setback. Still, even those studies did find the occupant reported temperatures during waking hours agreed on average.
Ternes and Stovall uggested t recommended simulation assumptions based on their study of a thermostat setting of 69°F with a setback to 66°F from 10 PM to 6 AM. However, in interpreting the study, the

proviso must be applied that these suggestions only applied to the main living zone. The bedroom areas and particularly basements were colder as pointed out by the authors.

The other important study of a large sample of 400 electrically heated homes in the Pacific Northwest by Vine and Barnes (1988) revealed an average interior monitored temperature of 67.5°F against an averaged observed thermostat setting of 65.2°F. One important conclusion from this work was that a part of the difference (2.3°F) between the reported thermostat setting and that measured in the main zone was likely due to the likelihood that indoor temperatures float above thermostat settings as a result of effects of solar, internal gains from appliances and occupants, and high insulation levels.. Most importantly, a follow-up study (Vine and Barnes, 1989) conducted a statistical discriminant analysis which clearly showed that measured temperatures higher than reported thermostat settings were correlated with factors that would cause the interior temperature to float above the set point: added wall and floor insulation, numbers of appliances, occupants. The importance of zoning was also demonstrated once more in that the presence electric space heaters and lack of a central thermostat (baseboard electric systems) correlated with greater disparities.

Finally, a more recent study of 478 low-income homes by Tonn et al., (2011) measured the temperature immediately underneath the thermostats (to avoid bias due to heat from thermostat circuitry and anticipators). The 24-hour average temperature at the thermostat during the heating season was 70.3°F with only 25% of the households exhibiting a temperature profile suggesting that thermostat setback was practiced. The study also found that the temperature was 69.2°F in homes with programmable thermostats and that after weatherization no statistically valid indication of occupant take-back relative to comfort could be discerned. While useful, and well executed, there are two issues with using these data directly:

1) The data are exclusively from low-income households which tend to be more heavily occupied and thus have less setback and higher winter temperatures due to greater occupancy, and

2) The investigators intentionally removed periods where the homes appeared to be unoccupied. However, these periods are important within the characterization of real homes which experience vacant periods for holidays, vacations etc. that is implicit in the use of simulation tools.

Cooling Set points

Information on cooling thermostat settings is scarce. The California Residential Appliance Saturation Survey (KEMA, 2010) recorded an average user-reported cooling thermostat setting of 78.7°F among 24,464 homes , albeit without temperature measurement. Henderson et al., (1991) recorded the cooling-season temperature by the thermostat in 23 homes in Central Florida. The average measured temperature at the thermostat was 78.4°F. Also, the previously cited study in California (Lutz and Wilcox, 1990) found the typical cooling thermostat setting was about 76.0°F, albeit in only about half a dozen measured sites where cooling was used.

Most relevant is a large scale study of 171 homes in Central Florida, Parker (2002), which found that while the user-reported thermostat settings for individual homes varied substantially from measured temperatures, the averages were quite close. Average reported daytime cooling thermostat setting was 77.6°F. When split during the day, the temperatures were 77.3°F during evening hours and 77.2°F during nights, weekends and holidays.

In the sample of Central Florida homes, the interior temperatures were measured from June 1 - September 30th 1999 every 15-minutes in all the homes. The average measured temperature over this period in all of the homes with valid data was 78.0°F. When classifying them by time-of-day, the cooling temperatures were 78.8°F day (8 AM - 5 PM) and 77.5°F night-- just over a degree apart on average.

Setback Behavior

A common practice in U.S. homes is to set the thermostat temperature back during nightime hours to provide energy savings and perhaps better thermal conditions for sleeping. To a lesser extent, the same practice is used during daytime periods (assuming no one is at home), both with heating and cooling (a thermostat setup in the latter case) as a way of producing further savings. That this technique has potential for energy savings has been demonstrated in measurements. For instance, experimental work by Levins at ORNL (1988) showed 20% measured savings from thermostat setback in the highly instrumented and unoccupied Karns homes versus the use of a constant thermostat setting.

However, knowing the extent to which this is practiced is important for simulating *typical* thermostat behavior in homes – and therefore to estimating energy savings from various envelope and HVAC measures. How prevalent is the practice of setting back thermostats? The available data suggests a disparity in the claims of occupants for the frequency and depth of thermostat setback versus that actually performed.

For instance, a survey of 212 homes in North Carolina (Turner and Gruber, 1990) attempted to categorize household thermostat control behavior. They reported that 35% of households practice a relatively constant set temperature while 13% used a nighttime setback and 8% a daytime setback. However, the largest proportion – 43% used a combination of nighttime setback and daytime setback. The average claimed interior set temperature was 68.1°F; the claimed degree of setback was 5.3°F. Programmable thermostats were found to confer no increased likelihood of a setback or its depth.

Similarly, in Iowa, a survey of occupants in 135 homes claimed heating thermostat setbacks of 5.9°F (Neme et al., 1996). However, a survey of 281 households in Wisconsin (Nevius and Pigg, 2000) showed much lower claimed setbacks: thermostat settings of 68.7°F when someone was home vs. 66.9°F during the nighttime setback period or during the daytime setback period if no one was home (only 29% of households claimed occupancy during weekday, daytime hours.

One of the largest and most relevant studies was that of Conner and Lucas (1990) on 400 electrically heated homes in the Pacific Northwest. That study showed that nighttime thermostat setback during the long heating season was approximately 7 degrees F, but that measured data on interior temperatures showed a much lower degree of temperature change during that period (3.0°F). The difference was explained by the fact that the homes only slowly cooled after the thermostat setback due to building capacitance and insulation (time constant). Moreover, that same study showed the likelihood that a household would practice thermostat setback was not influenced by the ownership of a programmable thermostat; those with a manual thermostat were equally likely to setback the house temperature. Another older study by Kempton and Krabacher (1987) of seven homes measured in detail showed the same phenomenon: occupant reported heating thermostat setbacks (67.7°F) were about 2.0°F lower than those observed through measurement of the actual thermostat device setting (69.6°F). Moreover, that study also measured the interior temperature which generally averaged higher than the actual thermostat setting.

Finally, the study in California (Lutz and Wilcox, 1990) showed some bias of slightly underestimating the winter thermostat setting and over estimating the cooling thermostat setting. Occupant predictions for the degree of the nighttime setback were the most exaggerated estimate, with occupants optimistic about the depth of the setback. This is in general agreement with previous studies where occupants, on average, are reasonably cognizant of their thermostat settings during waking hours, but much less so when asleep or otherwise away from home.

Variation of Room to Room Temperatures

The variation in room to room temperatures is important to consider since many building energy simulations assume a single interior temperature to compute thermal losses and gains. Unfortunately, these data are seldom available, but an early case study of superinsulated homes in Montana showed that room to room temperatures in a cold climate could vary by 5-10°F (Palmiter and Hanford, 1986). More recently, in a cooling dominated climate, a single household showed that there can be a 3°F variation from room to room even with central systems operating (Parker, 2012).

Within the important PNL study of measured homes in the Pacific Northwest (Conner and Lucas, 1990), a sub-sample of the homes had temperatures measured in the main living zone by the thermostat as well as bedrooms and basements. This evaluation found substantial variation across rooms. *The living zone averaged 69.6°F in winter, but the bedrooms averaged only 66.4°F. Basements, however, were often less heated, even when claimed as conditioned. The measured systems were fairly evenly distributed between central (n=49) and baseboard electric systems (n-42) although the evaluation did not find large differences in central room temperatures between the types. They did find greater difference, however, in bedrooms as expected. The average measured temperature in basements was only 58.5 °F. These findings may have substantial implications for simulations which assume isothermal conditions across rooms.*

In contrast, the new data summarized by Roberts and Lay (2013) found only about a 1°F variation in the temperature of the main living room versus the master bedroom. Intentional zoning can obviously influence the variation in room-to- room temperatures. Hunt and Gidman (1982) documented the variation in room to room temperatures in 1,000 homes in Great Britain, predominantly heated with hydronic systems and portable electric heaters. They found that the average differences between the coldest (bedrooms) and the warmest rooms (living room) in a typical home was 7.0°F. Zoning may also reduce energy use. Detailed experiments done in Knoxville in centrally heated, unoccupied, heavily instrumented homes by Levins (1988) showed a 15-17% reduction in space heating energy from closing off two bedrooms.

Examination of the RECS Data on Temperatures

The DOE/EIA 2009 RECS data is a valuable source as it is statistically selected from allhomes across the U.S. and includes questions about the heating and cooling temperatures maintained. The survey data represents the 70 million single-family U.S. households. For this report, the data was analyzed for single-family detached homesLooking at responses to the heating and cooling temperatures being maintained during daytime when “someone is home” and “no one is at home” as well as the temperature at night..

As can be seen, we evaluated the question response weights as objectively as possible, using midpoints, and used these data to estimate the averages. The resulting calculation is show below in Table 2 and 3 for heating and cooling respectively.

Table 2. RECS 2009 Heating Temperature Analysis (occupant-reported values)

Space Heating	Total U.S. (millions)	Single-Family Units	
		Detached	Weighted Value
Daytime Temperature When Someone is Home			
63 Degrees or Less.................................	6.1	3.5	3.0
64 to 66 Degrees....................................	11.8	7.6	7.0
67 to 69 Degrees....................................	29.6	21.5	20.8
70 Degrees...	26.2	15.4	15.3
71 to 73 Degrees....................................	17.8	12.1	12.4
74 Degrees or More.................................	18.5	10.3	11.0
		70.4	**Average 69.5**
Daytime Temperature When No One is Home			
63 Degrees or Less.................................	26.7	16.7	14.5
64 to 66 Degrees....................................	21.8	15.0	13.8
67 to 69 Degrees....................................	23.2	16.9	16.3
70 Degrees...	17.2	9.2	9.1
71 to 73 Degrees....................................	10.4	6.7	6.9
74 Degrees or More.................................	10.9	5.9	6.3
		70.4	**Average 66.9**
Temperature at Night			
63 Degrees or Less.................................	19.0	12.7	11.0
64 to 66 Degrees....................................	20.0	13.7	12.5
67 to 69 Degrees....................................	25.3	18.0	17.4
70 Degrees...	19.5	10.7	10.6
71 to 73 Degrees....................................	12.0	7.8	8.0
74 Degrees or More.................................	14.3	7.5	8.0
		70.4	**Average 67.5**

Table 3. RECS 2009 Cooling Thermostat Analysis (occupant-reported values)

Air Conditioning	Total U.S. (millions)	Single-Family Units	
		Detached	Weighted
Daytime Temperature When Someone is Home			
63 Degrees or Less.................................	6.6	3.8	7.3
64 to 66 Degrees....................................	8.5	5.9	11.4
67 to 69 Degrees....................................	11.2	8.5	17.0
70 Degrees...	13.2	9.8	20.4
71 to 73 Degrees....................................	8.4	6.6	14.3
74 Degrees or More.................................	2.2	1.5	3.4
	63.5	35.6	
			Average 73.7
Daytime Temperature When No One is Home			
63 Degrees or Less.................................	4.8	2.9	5.5
64 to 66 Degrees....................................	6.3	4.1	7.9
67 to 69 Degrees....................................	7.8	5.9	11.7
70 Degrees...	12.4	9.2	19.1
71 to 73 Degrees....................................	9.4	7.3	15.7
74 Degrees or More.................................	9.4	6.8	15.4
	63.5	35.6	
			Average 75.4
Temperature at Night			
63 Degrees or Less.................................	7.9	4.9	9.3
64 to 66 Degrees....................................	8.7	6.1	11.8
67 to 69 Degrees....................................	10.7	8.0	15.9
70 Degrees...	12.6	9.4	19.5
71 to 73 Degrees....................................	7.4	5.8	12.5
74 Degrees or More.................................	2.7	2.0	4.5
	63.5	35.6	
			Average 73.5

Results of RECS Data Analysis

Average Heating Temperatures

Daytime Heating when Someone is Home: 69.5°F
Daytime Temperature when No one is Home: 66.9°F
Nighttime Temperature: 67.5°F.

Average Cooling Temperatures when Air Conditioning

Daytime Temperature when Someone is Home: 73.7°F
Daytime Temperature when No one is Home: 75.4°F
Nighttime Temperature: 73.5°F.

It is noteworthy that while the RECS data does show some natural variation in the maintained interior temperature with time of day, the magnitude is not large.

NREL Study on Temperatures in 60 U.S. Homes

A new and important source on appropriate thermostat settings in our review comes from a recent NREL study of the previously-collected temperatures in eighty U.S. homes performed by Roberts and Lay (2013). The homes– twenty in each location – were instrumented in Florida, New York, Oregon and Washington State. Temperatures were collected on a 15-minute basis for an entire year as part of a U.S. HUD study aimed at determining interior moisture levels in homes (Arena et al., 2010). Temperatures were obtained in several spaces, but a key parameter taken was the temperatures in the main zone in the living room.

Within the evaluation, the authors established that the average main zone temperature during the cooling season in both Florida and New York homes was 76.8°F. Similarly, the average living room zone temperature in the combined New York, Oregon and Washington samples was 64.5°F when heating. However, NREL also found that there was systematic variation by climate: the average living room temperature in Florida homes was 78.5°F compared to a preference for cooler temperatures in New York, where they averaged 74.0°F. The variation in heating temperatures was less pronounced: 65.0°F in New York vs. 63.9°F in the Oregon and Washington samples.

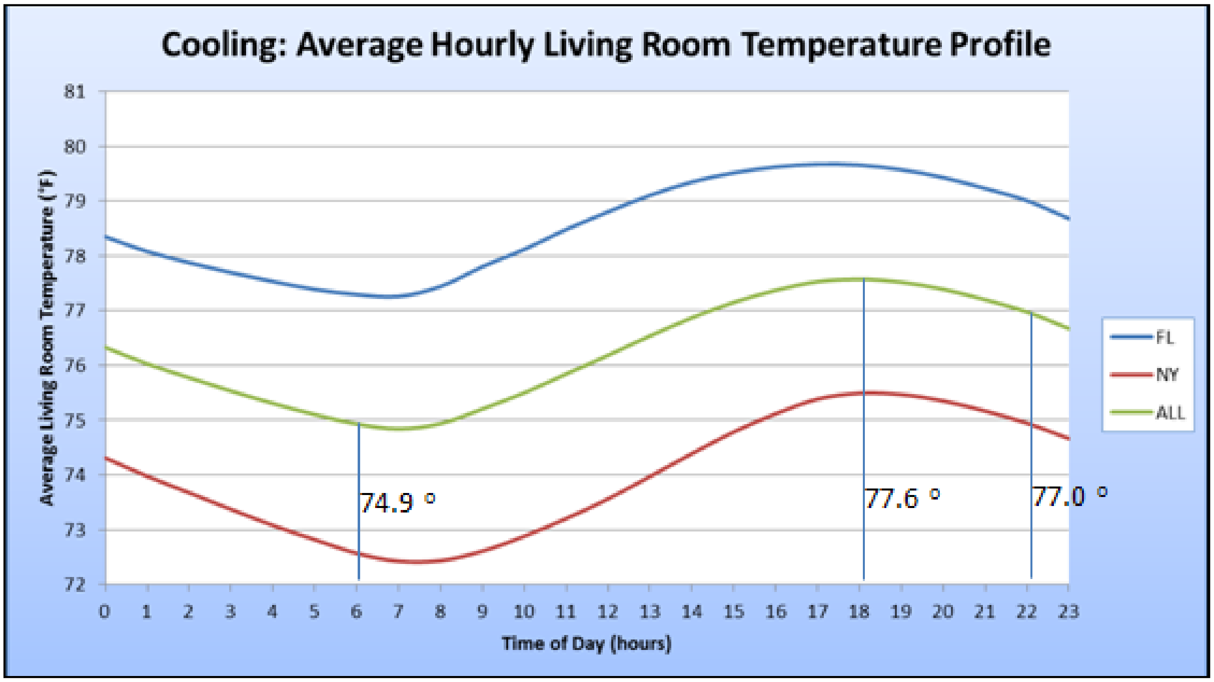
The source report (Arena et al., 2010) included useful data on temperature variation from one home to the next, information on room-to-room temperature variations and speculation on some of the differences noted. For instance, part of the difference in the New York and Oregon/Washington samples is attributed to increased incidence of fireplace use.

The evaluation also established patterns of daily variations in the samples, in the interior temperatures maintained – an important facet within building energy simulations where night and daytime setback or setups are often assumed. *Approximating such control behavior within simulations may be important to computing savings as all the temperature measurements showed a variation in the interior temperature with the natural outdoor daily temperature cycle. To the extent that this is incorporated within the modeling, computed loads will be lower even with the same average temperature maintained inside over the 24 hour period*.

Within the report, authors composed helpful aggregate profiles of the heating and cooling temperatures over the diurnal cycle. As shown below, these can be used to develop some idea of typical thermostat settings for heating and cooling over the daily cycle. We reproduce two graphs from that report with annotations to suggest what they may indicate for cooling and heating thermostat settings.

Cooling

Figure 1. Comparison of hourly living room temperature profiles from Roberts & Lay (2013).



We segmented these data into periods from *Daytime* (6 AM to 6 PM), *Occupied Evening* (6 PM - 10 PM) and *Nighttime* (10 PM - 6 AM) which captures a period of occupant setback. The segmentation was done based on the recommendations made by Conner and Lucas (1990) that these as the natural occupancy rhythms within U.S. households based on their detailed assessment. Once this was done, we can approximate the control points over these periods by examining the temperature terminating at the beginning the following segment. It is important to use the starting and termination points at the end of each segment, rather than the temperatures averaged during that period, to capture the changing conditions of the direction of thermal control.

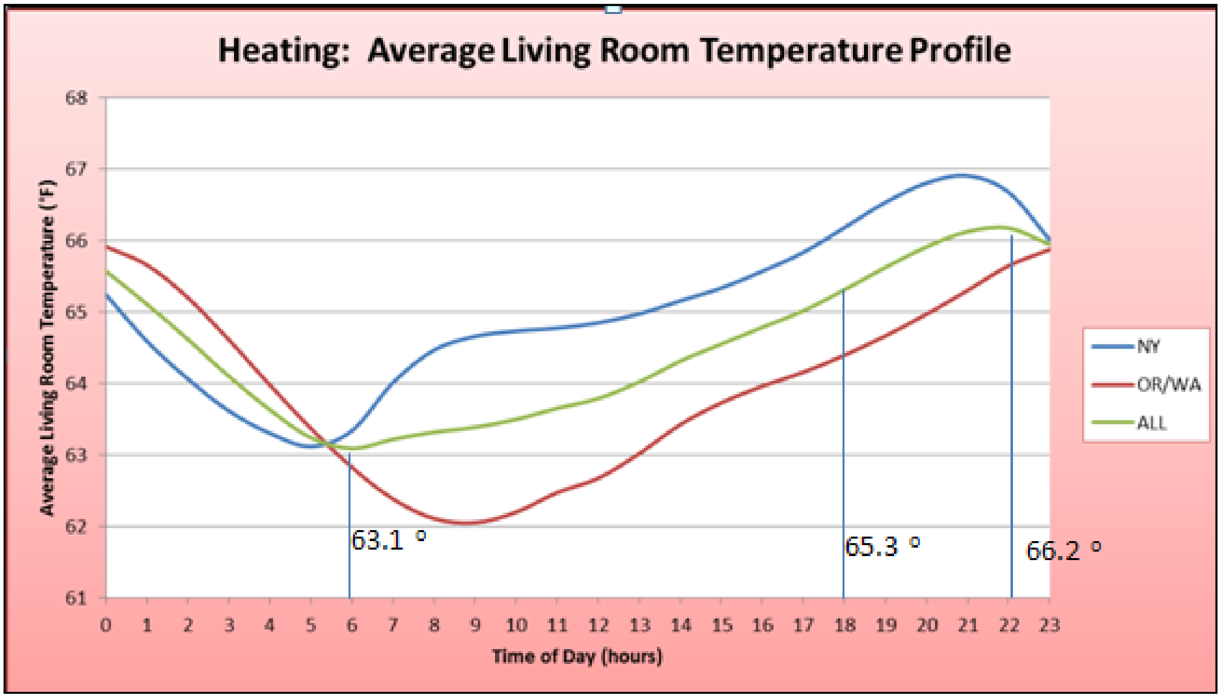
Following the curve for the combined Florida and New York segment (ALL), the temperature at 6 AM is approximately 74.9°F which is allowed to rise in the daytime hours to 77.6°F at 6 PM when the home is occupied. The temperature during the occupied evening segment ends at 10 PM with a temperature of 77.0°F and then drops to 74.9°F at 6 AM. Thus, the control points are:

Daytime (6 AM - 6 PM): 77.6°F
Occupied Evening (6 PM - 10 PM): 77.0°F
Nighttime (10 PM - 6 AM): 74.9°F

Heating

The same type of analysis for heating is done in Figure 2.

Figure 2. Comparison of hourly living room temperature profiles during heating from



Roberts & Lay (2013)

Following the curve for the combined New York, Oregon and Washington segments (ALL), the heating temperature at 6 AM is approximately 63.1°F which is allowed to rise in the daytime hours to 65.3°F at 6PM when the home is occupied. The temperature during the occupied evening segment ends at 10 PM with a temperature of 66.2°F and then drops to 63.1°F at 6 AM. Thus, the implied control points are:

Daytime (6 AM - 6 PM): 65.3°F
Occupied Evening: 66.2°F
Nighttime (10 PM - 6 AM): 63.1°F

Summary of the Various Studies

Tables 4 and 5 provide a convenient summary for the previously described studies. These are separated into those relevant to heating and cooling with sample size and indication of those that exclusively relied on occupant-reported temperatures rather than measurements. Evaluation of set-back temperatures is shown for the heating values. It should be noted, that even though the measurements and survey spanned over 25 years, there was no evidence of trend in the data, even with varying energy prices and changing vintage of heating and cooling equipment.

Table 4. Summary of Studies of Residential Heating Temperatures

Source	Sample Size (n)	Temperature (°F)	Set-back (°F)
Lutz & Wilcox (1990)	30	70.0	1.5
Ternes & Stovall (1988)	187	70.3	0.4
Conner & Lucas (1990)	206	68.4	3.4
Vine & Barnes (1988)	400	67.5	3.0
Vine & Barnes (1989) (survey)	400	65.2	7.0
Tonn et al. (2011)	478	70.3	1.1
Turner & Gruber (1990) (survey)	212	68.1	5.3
Nevius & Pigg (1996) (survey)	281	68.7	1.8
Kempton & Krabacher (1987)	7	69.6	2.1
Roberts & Lay (2013)	60	64.5	3.1
RECS (2009) (survey)	7,337*	67.9†	2.0
Average		**68.2**	**2.8**

Table 5. Summary of Studies of Residential Cooling Temperatures

Source	Sample Size (n)	Temperature (°F)
Henderson, et al. (1991)	23	78.4
Lutz & Wilcox (1990)	6	76.0
Parker (2002)	171	78.0
Roberts & Lay (2013)	40	76.8
KEMA (2009) (survey)	24,464	78.7
RECS (2009)* (survey)	7,337	74.0†
Average		**77.0**

*Single family detached homes only

† Weighted RECS values assuming half of household are occupied during the day and the other half is not

Note: "Survey" indicates occupant-reported temperatures as distinct from measurements or thermostat observations

Conclusions

Below we use the various data sources to attempt to specify preliminary consensus heating and cooling thermostat set points. Numerous studies, cited above, have shown that while occupant knowledge of the individual thermostat set points is quite poor, that collectively they tend to be fairly accurate. This lends credence to use of the RECS data for a first order estimate of appropriate values. Based on the RECS definitions, we assume the daytime temperature is an equal mix of occupied and unoccupied settings.

<u>Heating:</u>
Daytime Temperature: (69.5 + 66.9)/2 = 68.2°F
Nighttime Temperature: 67.5°F

<u>Cooling</u>
Daytime Temperature: (73.7+75.4)/2 = 74.5°F
Nighttime Temperature: 73.5°F

For final values, we take the mean of the RECS averages along with the Roberts and Lay (2013) temperature data. We round to the nearest integer with the following suggested as recommended settings for the main conditioned zone:

Heating:
Daytime (6 AM - 6 PM): (68.2 + 65.3)/2 = 67°F
Occupied Evening: (6 PM - 10 PM) (69.5 + 66.2)/2 = 68°F*
Nighttime (10 PM - 6 AM): (67.5 + 63.1)/2 = 65°F
* The occupied evening period value would also be used for the weekend and holiday periods.

If a constant set point is used instead of the above schedule, a value of 67°F would be recommended. It should be noted that the above values not only agree well with the RECS data and the NREL source, but also with the large monitored data sets from the PNW (Conner and Lucas, 1990 and Vine and Barnes, 1989).

Similarly derived values for cooling are:

Cooling:
Daytime (6 AM - 6 PM): (75.4 + 77.6)/2 = 77°F
Occupied Evening: (6 PM - 10 PM) (75.4 + 77.0)/2 = 76°F*
Nighttime (10 PM - 6 AM): (73.5+ 74.9)/2 = 74°F
* The occupied evening period value would also be used for the weekend and holiday periods.

If a constant value was to be used for estimating cooling with no daily schedule, these data would suggest that a value of 76°F would be best. These values are also somewhat lower than those measured in the large monitoring study in Florida – not surprising since the NREL work has found evidence of systematic differences in interior summer temperature expectations across the geographic U.S. This suggests the need to eventually make adjustments to thermostat settings depending on climate severity, perhaps using heating degree days or a similar metric. However, better quality data will be needed to allow this relationship to be established in a defensible fashion. The Roberts and Lay (2013) data are a first step.

Correction for Non-uniform Room Temperatures

An important caveat on the above estimates is that they do not account for variation in temperatures across rooms that may result in lower heating and cooling loads than estimated from these data. Each investigation cited in this report that examined this issue found evidence of differences, although of varying magnitude. For instance, the Connr and Lucas (1990) data clearly showed that basements are maintained at temperatures 10°F colder than the main zone in winter although not all were conditioned. Should simulations wish to account for the impact of unintentional zoning, without modeling of the thermal resistance of partitions etc., it is recommended that the above described thermostat settings be relaxed:

- Heating set points be relaxed by 1°F (e.g. a set of 67°F becomes a setting of 66°F).
- Heating set points be relaxed by 2°F for buildings primarily conditioned by zoned space conditioning systems (e.g. radiators, mini-split heat pumps).
- Heating set points for conditioned basements relaxed by 7°F from that of the main zone. Unchanged in summer.
- Cooling set points be relaxed by 1°F (e.g. a setting of 76°F becomes a setting of 77°F).
- Cooling set points be relaxed by 2°F for homes primarily conditioned by zoned systems such as room air conditioners or mini-split heat pumps.

Table 6 below provides the current recommendations for thermostat settings to be used in building energy simulations based on the preceding analysis:

Table 6. Final Recommendations for Heating and Cooling Thermostat Settings (°F)

Time of Day	Heating* Central	Heating* Zoned	Cooling Central	Cooling Zoned
Daytime	66	65	78	79
Occupied Evening	67	66	77	78
Nighttime	64	63	75	76
24-hourH	66	65	77	78

* Conditioned Basements should be set to a value 7°F lower than main zone for heating (e.g., 66°F, becomes 59°F).

H If a constant value is used, a thermostat setback of 3°F is recommended as a measure for heating; for cooling, the daytime set up should be assumed should be 2°F.

Future Work

We assembled data provided in the existing literature into preliminary consensus recommendations for thermostat settings. While we likely have enough information to make improvements to current assumptions, the overall process could be greatly improved by future research as outlined below:

- Establishment of consensus protocols for uniform data collection
    - Instrumentation: Collection of temperature data immediately below the thermostat (to avoid bias due to heat from thermostat circuitry and anticipators.
    - Study duration and sampling frequency – Duration: preferably over an entire year Frequency: where collecting 15-min data is not possible, measurements should be made at 1-h intervals
    - Temperature sensors should remain calibrated within 0.1degree F
    - Outdoor temperatures should be collected in tandem with indoor ones
    - Determination of the heating and cooling system status during periods of thermostatic control, as was done in the Lutz and Wilcox (1990) study. This is likely the single most important recommendation to obtain effective thermostat set points.
    - Obtain whole house power and space conditioning system power to help understand data and to flag the use of portable space heaters and similar devices.

- Simultaneous collection of temperature data in each occupied room to assess uniformity of thermal conditions. Collection of temperature data in conditioned and unconditioned basements is particularly important.
- Field studies should be conducted in a diversity of climates to determine whether simulation default assumptions should be varied by location.
- Studies of building types (e.g., mobile homes; multi-family apartments) other than those predominating in the existing research (single-family detatched).
- Further assessment of RECS data to identify additional determinants of reported thermostat settings.
- Monitored status of wood stoves and fireplaces.

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