Overheating in Multifamily Residential Buildings

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In this project data have been collected for eighteen multifamily buildings from the archives of multiple companies that provide energy management systems (EMS). Overheating was found in all eighteen buildings: the overall average temperature of all buildings was well above 70°F when the EMSs were not in operation.[1] In fifteen of the eighteen buildings, average temperatures in 100% of the apartments when EMSs were not in operation were above 70°F (ranging from 70.7°F to 87.4°F). In the remaining three buildings, average temperatures in 88% of apartments were also above 70°F (ranging from 70.3°F to 85.2°F). Likewise, when the EMSs were on, in seven of eighteen buildings, average temperatures in 100% of the apartments were above 70°F (ranging from 70.3°F to 81.1°F). In the remaining eleven buildings, average temperatures in 67% of the apartments were above 70°F (ranging from 70.0°F to 81.2°F). Based on this analysis, the estimated average increase in annual space heating energy cost for these buildings due to overheating is approximately 18.6% when the EMS is off, compared to a baseline average temperature of 70°F all the time.

Introduction

Due to a need to minimize energy consumption and associated greenhouse gas emissions, researchers in the U.S. are employing various techniques to avoid undesired energy consumption in residential and commercial buildings. This involves all aspects of energy consumption in a building. In the United States, approximately 41% of all energy utilized (approximately 40,000 trillion Btu [11.7 trillion kWhr]) is consumed in residential and commercial buildings (U.S. Energy Information Administration/Annual Energy Review 2010) and out of the energy consumed in residential and commercial buildings, approximately 50% is used for space heating.

As stated, a large portion of total energy is consumed in space heating and the energy consumption increases rapidly if the buildings are overheated. In the Northeast and Midwest regions of the US, there is a large stock of multifamily buildings with space heating provided by common systems using hot water or steam. According to the 2005 American Housing Survey, there are about 3.2 million occupied hydronically-heated, low-rise housing units in the US (U.S. Census Bureau 2005). Nearly 90% of these homes are in the Northeast or Midwest; with a large portion being rental units (40%), or occupied by the elderly (24%) (U.S. Census Bureau 2005). Most hydronically-heated residences are older, with only 1% being classified as New Construction (built within the past four years) in the 2005 AHS data (U.S. Census

[1] When the EMS is deactivated the boilers operate on outdoor reset control, the dominant boiler control type for multifamily buildings. EMS operation is intended to depress overheating. Using data from periods when the EMS is not operational is more representative of typical buildings because most buildings do not have an EMS.

2006). Typically, residents of these buildings do not pay for heat directly (i.e. heat is not sub-metered). Heating fuel use for these systems is reputed to be higher than necessary, given the thermal properties of the buildings. Anecdotally, a significant number of apartments are overheated much of the time (the window-as-a-thermostat syndrome) (Urban Green Council). Overheating results in an increase in annual energy consumption of approximately 1% per °F over the desired temperature in a dwelling for each eight hours of the day (the percentage of savings is greater in milder climates than in severe climates) (U.S. DOE). In the US, controlling of hydronic heating systems typically involves outdoor reset control algorithm, different day and night time space temperature set-points etc. The extent of overheating, and the variance of it in different parts of the building and on different days during the heating season, affects the strategy used to combat it. Generally, apartments must be heated to at least 68°F (20°C) by law during the heating season. Recently, at the 2011 expert meeting conducted by the ARIES Building America team[2] titled Multifamily Hydronic and Steam Heating Controls and Distribution Retrofits, the subject of just how significant a factor overheating is (and how large a potential exists for energy savings by eliminating it) was debated (Dentz 2011) and it was acknowledged that no rigorous analysis of the phenomenon is published.

Problem Description

Overheating is defined as heating to a temperature greater than that required by local ordinance or desired by building management. In New York City, for example, local law requires multifamily building operators to maintain the indoor air temperature at a minimum of 68°F if the outside temperature is below 55°F during the day (10:00 pm to 6:00 am) and a minimum of 55°F if the outside temperature is below 40°F during the night. However, it was found that indoor temperatures in many buildings were significantly higher than the required indoor air temperature. Overheating can cause discomfort for residents due to the heat and excessively low humidity levels, which can have negative health consequences. Overheating also results in higher fuel consumption than necessary and increases building fuel expenses. Moreover, if residents find it too hot, they may open windows, which further exacerbates the problem.

To quantify overheating, data were obtained from the archives of companies that provide EMS to multifamily buildings in the Northeast U.S. Data were collected for time periods when the EMS control system was disabled and for time periods when it was enabled. This procedure enabled us to quantify overheating in these buildings when the EMSs were not in operation as well as effectiveness of the EMSs when they were in operation. Data were analyzed for eighteen multifamily buildings for deviation from the locally required minimum heating requirements. Data have been analyzed for enough apartments (a minimum of 11%, and an average of 20% per building) so that the data are representative of the entire building. Table 1 shows characteristics of the buildings considered in this study.

[2] Building America is a U.S. Department of Energy research program focusing on residential energy efficiency.

Results and Discussion

In this study, data from at least 10% apartments in each building were analyzed for eighteen buildings located in New York City (Table 2). New York City law requires building owners to provide heat to the building only if the outdoor air temperature is below 55°F. Most of the boilers in this region of the US function based on outdoor air reset control in which the boiler supply temperature or firing cycle varies with respect to the outdoor air temperature and if the outdoor air temperature is above 55°F the boiler shuts off automatically. Ideally, the outdoor reset settings are formulated to maintain at least 68°F indoor air temperature. Figure 1 through Figure 3 show data from a typical building (building 15) in the study for the 2011-12 heating season. The figures show the variation of indoor air temperature, average indoor air temperatures, and the variation of indoor air temperature as a function of outdoor air temperature. For nearly the entire time, indoor air temperatures in all apartments were above 70°F.

Table 1. Characteristics of the multifamily residential buildings

No	Number of Floors	Total No. of Apartments	Heating System	Ownership Type
1	3	60	Steam	Rental
2	3	48	Hot water	Rental
3	4	36	1-pipe Steam	Rental
4	4	16	1-pipe Steam	Rental
5	4	12	1-pipe Steam	Rental
6	4	39	1-pipe Steam	Rental
7	5	21	Hot water, Staged boilers	Rental
8	5	77	1-pipe steam	Rental
9	5	77	1-pipe steam	Co-op
10	5	202	1-pipe Steam	Rental/Co-op
11	6	71	Hot water	Rental
12	6	74	1-pipe steam	Rental
13	6	56	Hot water	Rental/SRO
14	6	48	1-pipe steam	Rental
15	6	26	1-pipe steam	Rental
16	6	22	1-pipe steam	Rental
17	6	34	1-pipe steam	Rental
18	6	44	1-pipe steam	Rental

Table 2. Building summary data

Bldg. no.	No. floors	No. apts.	Sensor location (by floor)	No. apts. with sensors	EMS Status	Range of T (F)	Avg T in all apts. (F)	Apts. found overheated (>70°F)	Average T in overheated apts. (F)
1	3	60	1, 3	16	OFF	59.0 – 82.0	71.8	88%	72.3
					ON	53.0 – 85.0	72.3	94%	72.5
2	3	48	3	16	OFF	57.2 – 90.2	74.7	100%	74.7
					N/A				
3	4	36	4	5	OFF	63.4 – 87.6	78.7	100%	78.7
					ON	66.0 – 88.4	77.3	100%	77.3
4	4	16	3, 4	12	OFF	60.0 – 91.0	73.7	100%	73.7
					ON	46.0 – 88.0	71.3	83%	72.0
5	4	12	3, 4	3	OFF	69.1 – 87.1	75.5	100%	75.5
					ON	69.1 – 95.1	76.1	100%	76.1
6	4	39	3	9	OFF	62.0 – 84.0	72.3	89%	72.7
					ON	59.0 – 82.0	70.5	67%	71.7
7	5	21	4, 5	5	OFF	69.2 – 83.7	75.5	80%	76.5
					ON	65.7 – 90.2	74.6	100%	74.6
8	5	77	6	9	OFF	65.0 – 84.0	76.2	100%	76.2
					ON	59.0 – 83.0	73.6	89%	74.2
9	5	77	1, 4	12	OFF	54.0 – 86.0	77.7	92%	78.5
					ON	61.0 – 83.0	75.2	92%	75.8
10	5	202	5	20	N/A				
					ON	64.8 – 82.8	75.0	100%	75.2
11	6	71	6	8	OFF	65.5 – 87.5	74.3	100%	74.3
					ON	62.5 – 93.5	75.9	100%	75.9
12	6	74	6	10	N/A				
					ON	59.0 - 83.0	72.9	80%	74.1
13	6	56	6	6	OFF	62.1 – 100	77.7	100%	77.7
					ON	57.0 - 91.0	75.1	83%	76.8
14	6	48	5, 6	12	OFF	62.8 – 94.7	81.0	100%	81.0
					ON	48.8 - 95.7	74.7	92%	75.2
15	6	26	2, 3, 4, 5	10	OFF	65.0 – 88.0	76.3	100%	76.3
					ON	54.0 – 82.0	70.9	70%	72.1
16	6	22	1, 2, 3, 5	13	OFF	59.4 – 89.6	79.2	100%	79.2
					ON	62.8 – 95.4	75.0	100%	75.0
17	6	34	6	11	OFF	61.0 – 87.0	76.6	100%	76.6
					ON	55.0 – 87.0	72.0	73%	73.4
18	6	44	1, 2, 3, 5, 6	15	OFF	66.5 – 86.5	77.6	100%	77.6
					ON	63.3 – 90.5	74.1	100%	74.1

Figure 1. Building 15 indoor air temperatures and outdoor air temperature

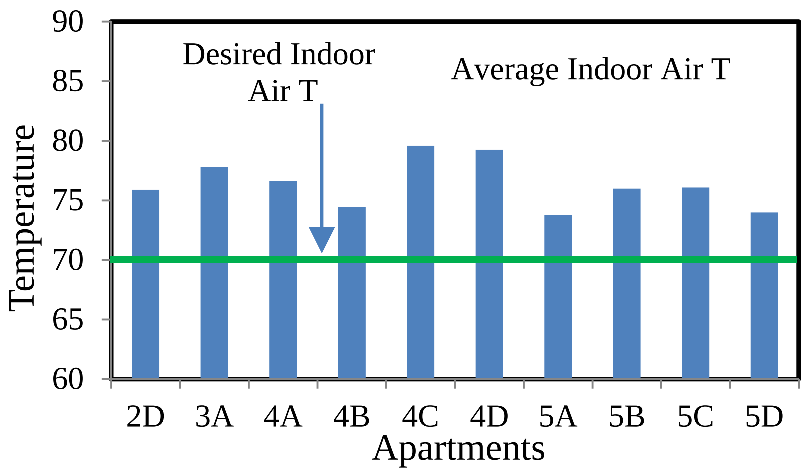


Figure 2. Building 15 average indoor air temperatures during the 2011-2012 heating season

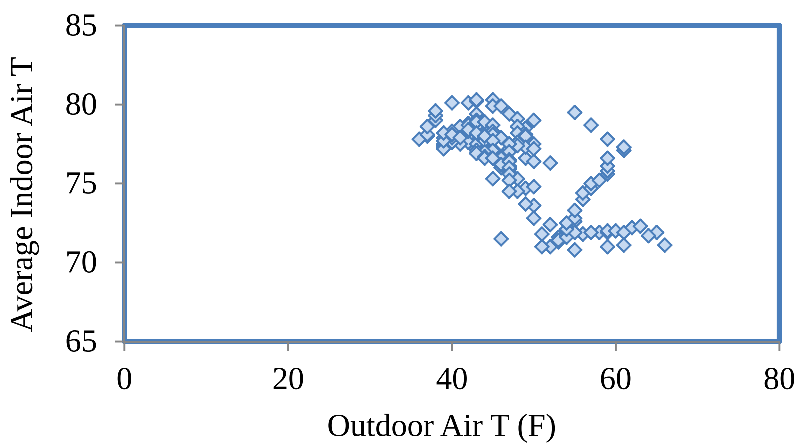


Figure 3. Building 15 indoor air temperature as a function of outdoor air temperature (2010-2011 heating season)

In this building, the sensors were located in ten different apartments on various floors. The average temperatures in all the apartments were above 70°F ranging from 73.8°F to 79.6°F (average of 76.3°F). Apartments located on the 4th floor were overheated the most (Figure 2). The average temperature of the top floor apartments was 75.0°F which was lower than the average temperature of the entire building. It can also be seen in Figure 3 that indoor temperature increases as outdoor air temperature decreases. Table 2 shows the overheating results for each building. Overheating is significant in nearly every building, even with the use of an EMS. Note that minimum temperatures in few buildings were significantly low but for a short duration, perhaps due to open windows or vacancies. The average temperature was more than 70°F in all the buildings when the EMSs were OFF. In fifteen of the eighteen buildings, average temperatures in all the apartments when EMSs were not in operation ranged from 70.7°F to 87.4°F and in three buildings, average temperature in more than 88% of apartments ranged from 70.3°F to 85.2°F. Likewise, when the EMSs were on, in seven of eighteen buildings, average temperatures in all the apartments were above 70°F, ranging 70.3°F to 81.1°F. In the remaining eleven buildings, average temperature in more than 67% of apartments were also above 70°F ranging 70.0°F to 81.2°F. The average temperature in overheated apartments was more than 75°F in 61% of the buildings when EMSs were off and more than 75°F in 33% of the building when EMS were on.

Temperature variation by floor was examined in four buildings. Figure 2, Figure 4, Figure 5 and Figure 6 show average temperature by apartment for apartments on various floors. It can be seen in these figures that average temperature is not a function of floor level. The buildings considered in this work were low-rise buildings and therefore stack effect did not play a significant role. Based on these results, it is concluded that for buildings in which sensors were located only at the top floors, the average of top floor temperature sensors closely represents the average temperature of the entire building.

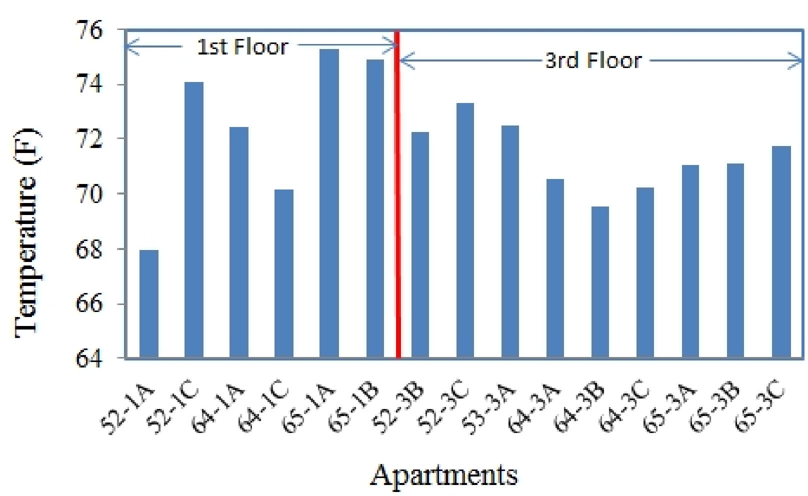


Figure 4. Building 1 average temperatures for apartments on two floor

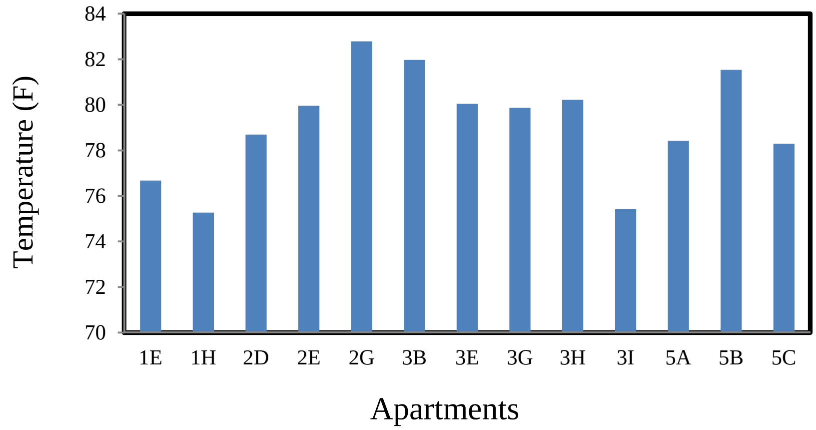


Figure 5. Building 16 average temperatures for apartments on four different floors (1st digit is floor number)

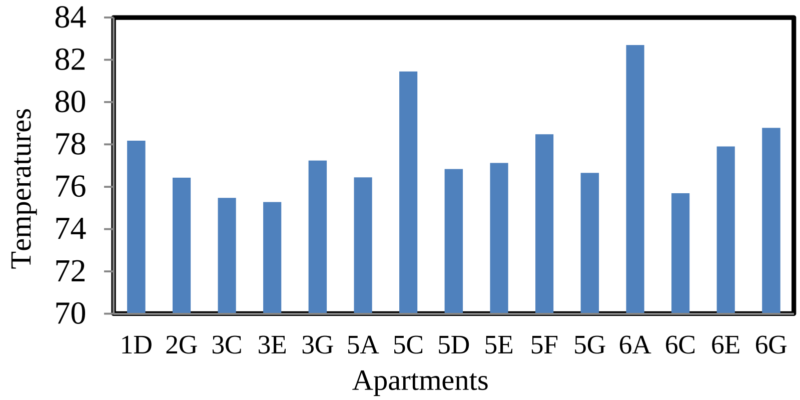
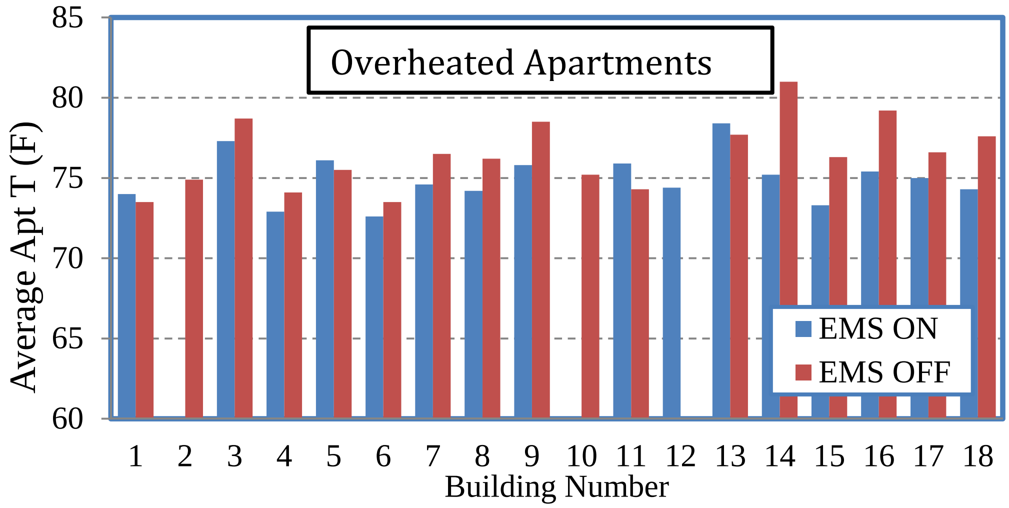
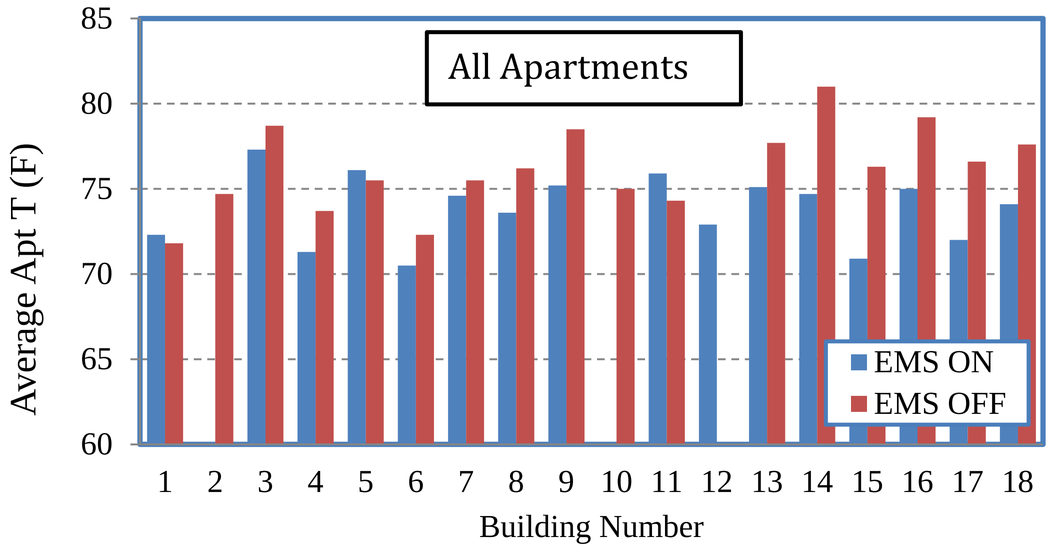


Figure 6. Building 18 average temperatures for apartments on five different floors

Figure 1 shows the variation of indoor air temperature in various apartments in building 15 and the outdoor air temperature. It can be seen that for nearly the entire time and for a wide range of outdoor air temperatures, indoor air temperatures in all apartments were above 70°F. In this building, temperature sensors were located in apartments at four different floors. In all the apartments, indoor air temperatures were above 70°F. Results show similar graphs for all remaining buildings. The pattern is similar: nearly all apartments are heated to more than 70°F for nearly the entire time when the EMS is off. However, there is a wide spread of apartment temperatures with the warmest and coolest apartments being separated by about ten degrees F on average and the coolest apartment being close to 70°F much of the time. This indicates that while there is some room to reduce heating building wide, individual zone (by apartment or by section of building) is necessary to achieve the full extent of available savings. Table 3 shows the effect of different types of heating distribution systems on overheating. Of the eighteen buildings, four were heated by hot water and the remainder by 1-pipe steam. When the EMSs were off, average temperature in the hot water heated buildings was slightly lower than the steam buildings. When the EMSs were on, the average temperature in the hot water buildings were nearly 2°F higher than that of the steam buildings. Figure 7 (a and b) compares the overall average indoor temperature of the buildings and average indoor temperatures of overheated apartments when the EMSs were off and on. As stated, the data were collected for the 2011-2012 winter season except building 9 for which data was collected from the 2010-2011 season. Note that the temperature data presented in Table 2 only represent temperatures in the buildings for a portion of the 2011-12 winter because the EMSs were installed part way through the heating season. The green line in Figure 1 and Figure 2 shows the desired indoor air temperature of 70°F. As can be seen in Table 2 average space temperatures in all the buildings were significantly higher than desired space temperatures, especially when the EMSs were disabled. Table 3 and Table 4 present a statistical analysis of the temperature data collected in the buildings. The average lowest temperature of all apartments was 72.6°F when the EMS was off.



(a)



(b)

Figure 7. Comparison between the overall average indoor temperature of the buildings and average indoor temperatures of overheated apartments when the EMSs were off and on.

Based on a U.S. Department of Energy report, (U.S. DOE), overheating results in an increase in annual energy consumption of approximately 1% per °F over the desired temperature in a dwelling for each eight hours of the day (US DOE). In all the buildings studied, the average temperatures were well above 70°F, ranging from 75.2°F to 81.0°F. It was also found that most apartments' average temperature was well above 70°F. Average temperature of all the buildings when the EMS system was off was 76.2°F whereas when the control systems were on, the average temperature of all the buildings was 74.4°F. Based on this analysis, the estimated average increase in annual space heating energy cost for these buildings (assuming no EMS) due to overheating is approximately 18.6% based on 70°F target temperature, or 24.6% based on the 68°F legal daytime temperature. In addition, night time set back can be used, reducing the legally required temperature to 55°F during night (in New York City). Under these conditions, the estimated average increase in annual energy cost for these buildings (assuming no EMS) due to overheating is as high as 37.6% based on 68°F target day time temperature and an eight-hour 55°F target night time temperature.[3] These overheating saving assumptions will vary with envelope characteristics and climate conditions.

In a year with average winter temperatures, fuel bills for a typical 80-100 unit apartment building can run $50,000-60,000. Therefore annual overheating waste for this typical building and overheating profile is approximately $11,160 based on a desired temperature of 70°F, $14,760 based on the legal limit of 68°F without nighttime setback, and $22,560 with a 55°F nighttime set back.

Table 3. Variation in overheating by heating system type

Heating Type	No. of buildings	EMS OFF		EMS ON	
		Avg T	Avg T in Overheated (>70°F avg.) Apts.	Avg T	Avg T in Overheated (>70°F avg.) Apts.
Hot water	4	75.6	75.9	75.2	76.3
Steam	14	76.3	76.6	73.5	74.7

Table 4. Statistical analysis of the temperature data

EMS Status		Mean T (F)	Standard Deviation	Minimum T (F)	Maximum T (F)	Range T (F)
ON	Overall average T in Apts	72.5	1.2	70.9	75.0	4.1
	Average T in the Overheating Apts	74.4	1.6	72.9	78.6	5.7
OFF	Overall average T in Apts	75.6	1.6	72.8	78.2	5.4
	Average T in the Overheating Apts	76.1	1.5	74.1	79.0	4.9

[3] Note that because of morning boost heat, actual savings will be lower than this theoretical maximum.

Conclusion

Eighteen sites were selected where EMS systems were already installed and the data were analyzed for several apartments in each building. The primary research question addressed by this report was: How significant is overheating in this building type? Overheating was found in all eighteen buildings. In all eighteen buildings, average temperature was well above 70°F when the EMSs were not in operation (Table 2). In fifteen of the eighteen buildings, average temperatures in all the apartments when EMSs were not in operation ranged from 70.7°F to 87.4°F and in three buildings, average temperature in more than 88% of apartments ranged from 70.3°F to 85.2°F. Likewise, when the EMSs were on, in seven of eighteen buildings, average temperatures in all the apartments were above 70°F, ranging 70.3°F to 81.1°F. In the remaining eleven buildings, average temperature in more than 67% of apartments were also above 70°F ranging 70.0°F to 81.2°F. Based on this analysis, estimated average increase in annual energy cost for these buildings due to overheating was approximately 18.6% based on a 70°F target temperature or 37.6% based on the legal temperature with night time setback to 55 °F for eight hours per day.

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