Air conditioning versus heating: climate control is more energy demanding in Minneapolis than in Miami

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Abstract

Energy demand for climate control was analyzed for Miami (the warmest large metropolitan area in the US) and Minneapolis (the coldest large metropolitan area). The following relevant parameters were included in the analysis: (1) climatological deviations from the desired indoor temperature as expressed in heating and cooling degree days, (2) efficiencies of heating and cooling appliances, and (3) efficiencies of power-generating plants. The results indicate that climate control in Minneapolis is about 3.5 times as energy demanding as in Miami. This finding suggests that, in the US, living in cold climates is more energy demanding than living in hot climates.

Keywords: energy demand, air conditioning, heating, climatology, energy efficiency

1. Introduction

A new, thought-provoking book [1] eloquently illustrates the huge energy demand from living in a hot climate such as in the southwestern US. On the other hand, the energy demand from living in a cold climate such as the Midwest or Northeast is frequently taken for granted. This letter compares the energy demands for climate control in Miami (the warmest large metropolitan area) and Minneapolis (the coldest large metropolitan area). This research builds on the ideas and material presented in two previous papers [2, 3].

This analysis will include the following relevant parameters:

- Climatological deviations from the desired indoor temperature as expressed in heating and cooling degree days. (Bottom line: Minneapolis deviates downward more from the desired temperature than does Miami upward from the desired temperature.)
- Efficiencies of heating and cooling appliances. (Bottom line: surprisingly to most, air conditioners are more energy efficient than furnaces.)
- Efficiencies of power-generating plants. (Bottom line: the resulting losses have larger effects for cooling than for heating.)

2. Climatological demand

2.1. Approach

Heating and cooling degree days were used for estimating the differences between the outdoor and desired indoor temperatures. Heating degree days is an index of the energy demand to heat buildings. This index is calculated by subtracting the mean daily temperature from 18°C, and summing up only positive values over a fixed period, such as an entire year. An analogous index for the energy demand for cooling is represented by cooling degree days. Although these temperature-based indices do not take into account secondary variables influencing the need for heating and
cooling (e.g., humidity and cloud cover), studies have shown that energy consumption is highly correlated with degree days for both heating and cooling [4–6]. (For an average outdoor temperature lower than 18 °C, most buildings require heating to maintain a 21 °C indoor temperature. Conversely, for an average outdoor temperature higher than 18 °C, most buildings require cooling to maintain a 21 °C indoor temperature. The selection of 18 °C as the base outdoor temperature is due to the additional heat generated by occupants and their activities, resulting in an average indoor temperature of 21 °C at 18 °C outdoors when no heating or cooling is used.)

2.2. Results

A recent article [2] presented the average heating and cooling degree days (as well as the combined heating and cooling degree days) for the 50 metropolitan areas in the US with the largest population, based on climatological data from 1971 through 2000 [7]. The five coldest areas are Minneapolis, MN (4376 HDDs), Milwaukee, WI (3937 HDDs), Rochester, NY (3738 HDDs), Buffalo, NY (3718 HDDs), and Chicago, IL (3610 HDDs). Analogously, the five warmest areas are Miami, FL (2423 CDDs), Phoenix, AZ (2327 CDDs), Tampa, FL (1934 CDDs), Orlando, FL (1904 CDDs), and Las Vegas, NV (1786 CDDs).

2.3. Conclusion

When considering the two extremes, the HDDs for Minneapolis (4376) are 1.8 times greater than the CDDs for Miami (2423).

3. Efficiencies of heating and cooling appliances

3.1. Approach

Typical efficiencies of heating and cooling appliances were considered.

3.2. COP, AFUE, EER, and SEER

In the US, the energy efficiencies of heating and cooling appliances are currently rated using different measures—a situation that does not encourage direct comparisons. For furnaces and boilers the measure is typically the annual fuel utilization efficiency (AFUE), for room air conditioners it is the energy efficiency ratio (EER), and for central air conditioners it is the seasonal energy efficiency ratio (SEER). In this paper, the three measures were converted into a common measure of energy output (energy generated for heating or energy transferred for cooling) divided by energy input—the coefficient of performance (COP)—using the following approximate conversions [8]:

\[ 1.0 \text{ COP} = \frac{\text{AFUE}}{100} = \text{EER} \times 0.29 = \text{SEER} \times 0.24. \]

3.3. Results

The heating sources in the US are natural gas (69% of energy generated), oil and other petroleum liquids (17%), liquid petroleum gas (7%), and electricity (7%) [9]. COPs for new furnaces and boilers powered by natural gas or heating oil are currently in the range of 0.80–0.98, while for electric resistance heating they are near 1.00 [10]. In contrast, for new central air conditioners, COPs are currently between about 3.1 and 4.3 [11]. (For new room air conditioners, COPs are typically between about 2.8 and 3.5 [12].) Note that the COP of an air conditioner can be greater than 1 because it operates much like a lever, a block-and-pulley system, or a gear ratio that provides a mechanical advantage, allowing a greater quantity of heat energy to be transferred than the electrical energy that is consumed to create the movement.

3.4. Conclusion

A typical central air conditioner is about 4 times more energy efficient than a typical furnace or boiler (3.6 divided by 0.9 equals 4).

4. Efficiencies of power plants

4.1. Approach

The source of energy for cooling appliances is almost exclusively electricity. In comparison, only about 7% of the energy consumed by heating appliances in the US is currently generated by electricity [9]. However, electricity is not a primary source of energy. Instead, electricity is generated in power plants from other sources of energy through processes that involve energy losses. Thus, energy efficiencies of power plants are of relevance.

In the US, electricity is generated mostly from burning fossil fuels such as coal (42%), natural gas (25%), and oil and other petroleum liquids (1%); additional sources are nuclear (19%), hydroelectric (8%), and other (5%) [13]. Typical efficiencies of power plants in converting the source energy into electric energy are about 0.43 for coal, 0.45 for natural gas, 0.41 for oil, 0.34 for nuclear, and 0.92 for hydroelectric [14]. Given the energy-source distribution and the typical efficiencies of power plants by energy source, the weighted efficiency of power plants is 0.43. (The energy generated by other sources (5% of the total) was disregarded in this calculation.)

4.2. Results

As indicated above, electricity is the source energy for almost 100% of all air conditioners. Consequently, the weighted average of power-plant efficiencies (0.43) should be applied to all energy used for cooling. Thus, the resulting power-plant efficiency for generating electricity for cooling is 0.43.

On the other hand, electricity constitutes only 7% of all energy consumed by heating appliances. Consequently, only 7% of the energy used for heating was multiplied by a factor of 0.43 (the weighted efficiency of power plants). The remaining
93% of the energy used for heating was left unchanged because no power-plant energy losses were assumed for this proportion of energy. Therefore, the resulting power-plant efficiency for generating electricity is 0.96 because $(0.07 \times 0.43) + 0.93 = 0.96$.

4.3. Conclusion

The effective efficiencies of power plants are 0.43 for the energy used for cooling and 0.96 for the energy used for heating.

5. Implications for Minneapolis and Miami

5.1. Heating in Minneapolis versus cooling in Miami

Table 1 derives an overall index of the energy demand for heating in Minneapolis, and compares it with an analogous index for cooling in Miami. The overall index is based on sub-indices for climatological demand, efficiency of heating and cooling appliances, and energy efficiency of power plants. The results indicate that heating in Minneapolis is about 3.6 times more energy demanding than is cooling in Miami.

5.2. Heating and cooling in Minneapolis versus heating and cooling in Miami

While in Miami cooling overshadows heating and in Minneapolis heating overshadows cooling, there is also some demand for heating in Miami and for cooling in Minneapolis. (Interestingly, the HDDs for Miami are substantially lower than the CDDs for Minneapolis (83 versus 388)—as is the case in the comparison of the CDDs for Miami and HDDs for Minneapolis (2423 versus 4376).) Therefore, table 2 includes calculations that combine both types of climate control for each city. The results indicate that, if both heating and cooling are taken into account, Minneapolis is 3.5 times as energy demanding as is Miami (9140/2589 = 3.5).

6. Discussion

6.1. Critical role of the efficiencies of cooling and heating appliances

To the surprise of many, air conditioners are more energy efficient than furnaces or boilers. Another way of stating this is that it takes less energy to cool down an interior space by one degree than to heat it up by one degree. This is the case, because (in layman’s terms) it takes less energy to transfer heat (air conditioners) than to generate heat (furnaces and boilers).

Table 1. Indices of the energy demand for heating in Minneapolis and for cooling in Miami.

| Consideration | Minneapolis, heating | Miami, cooling |
|---------------|---------------------|---------------|
| Climatological demand | 1.8 (4376/2423 = 1.8) | 1 |
| Efficiencies of cooling appliances relative to heating appliances | 4 (3.6/0.9 = 4) | 1 |
| Efficiencies of power plants for the energy used for cooling relative to heating | 0.5 (0.43/0.93 = 0.5) | 1 |
| Overall (climatology, efficiency of appliances, and efficiency of power plants combined) | 3.6 (1.8 \times 4 \times 0.5 = 3.6) | 1 (1 \times 1 \times 1 = 1) |

Table 2. Indices of the energy demand for both heating and cooling in Minneapolis and Miami.

| Measure | Minneapolis | Miami |
|---------|-------------|-------|
| HDDs | 4376 | 83 |
| CDDs | 388 | 2423 |
| Adjusted HDDs$^a$ | 8752 | 166 |
| Adjusted CDDs$^b$ | 388 | 2423 |
| Adjusted HDDs plus adjusted CDDs | 9140 | 2589 |

$^a$ Adjusted by a combined factor of 2 $(4 \times 0.5 = 2)$, where the sub-factor of 4 is based on the efficiency of cooling appliances relative to heating appliances, and the sub-factor of 0.5 is based on the efficiency of power plants for the energy used for cooling relative to heating; see table 1.

$^b$ The adjusted CDDs are identical to the non-adjusted CDDs, because the adjustment factor for CDDs is 1; see table 1.

6.2. Regional differences

The present calculations used national statistics. Although there are regional differences in some of the variables used (e.g., the distribution of energy sources for generating electricity), national data are appropriate for this study because the inferences drawn relate not only to living in Miami and Minneapolis, but to living in other US cities that are in hot or cold climates.

6.3. Tolerances for heat and cold

People are generally more tolerant of heat than of cold. Therefore, HDDs likely overestimate the need for cooling. Therefore, the present calculations likely underestimate the advantage of Miami over Minneapolis.

6.4. Factors not considered in the analysis

Not included in the analysis were extraction losses (the energy used to extract fuels from the ground), transmission loses (the energy losses during transmission or the energy used to transmit sources of energy), and energy costs (and the associated socioeconomic factors).

7. The bottom line: energy demand and living in hot versus cold climates

The traditional discussion of climatology and energy demand concentrates on the energy demands for cooling in hot climates. However, the present results indicate that the focus should be paid to the opposite end of the scale as well: In the US, living in cold climates (e.g., in Minneapolis, Milwaukee, Rochester, Buffalo, and Chicago) is more energy demanding than is living in hot climates (e.g., in Miami, Phoenix, Tampa, Orlando, or Las Vegas).
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