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Our climate conditions are already changing – Should we care?

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Abstract

The IPCC and many others predict significant changes to our climates over the rest of this century, including average temperature increases for 2–5°C. However, we can see possible indications of change already – increasing frequency of severe storms and other weather events. However, many of the major weather data sets used around the world for building energy simulation are more than 15 years old. Does it matter? This paper compares several of the major data sets used in building performance simulation against newer data derived from the past 15 years. Ten of the past 15 years are the hottest on record and this rapidly changing climate already is evident in the temperature record. We use energy simulation to demonstrate how the various data sets impact energy use. In addition, the design conditions for heating and cooling calculations are already seeing slight changes over the past 20 years. Data for 12 locations around the world is used to demonstrate the changing climate that we already see.

Practical application: This paper encourages building designers to use the most up-to-date climatic data in their design and evaluation of building performance.

Keywords

Weather data, climate change, urbanization, building simulation, climate design conditions

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Introduction

Weather and climate data are an integral part of designing our buildings today. We need a measure of how hot or cold we can expect it to be to be able to calculate the size of heating and cooling equipment. Additionally, to determine how a building design might perform, we use time-series data (usually hourly) in building simulation software. However, several climate data sets commonly in use are more than 20 years old. With the five hottest years on record occurring within this past decade, we cannot depend on data from the 1990s to represent today or tomorrow. The UN's Intergovernmental Panel on Climate Change (IPCC) in their fifth assessment report,[1] show a range of potential temperature change of 2–5°C by 2100. This paper

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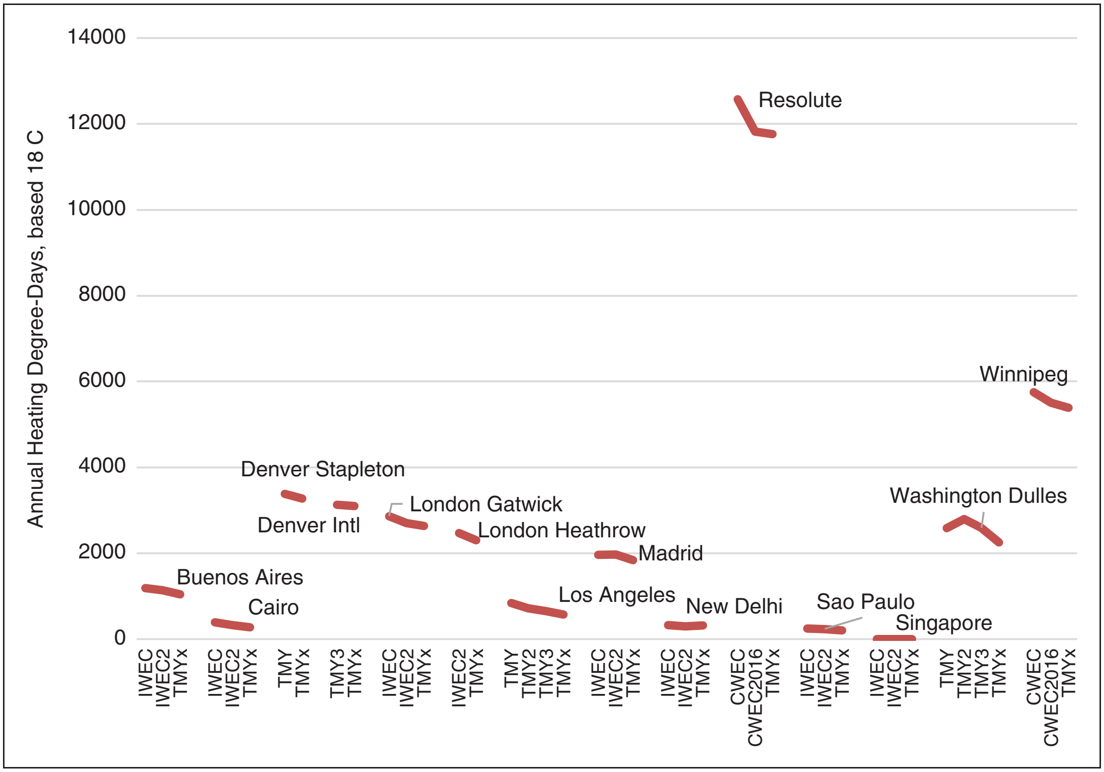

Figure 1. Heating degree-days by location and climate data set.

compares how climate data have evolved over the past 24 years – both the peak design conditions and several typical hourly data sets.

Climate data sets

Over the past 40 years, organizations throughout the world have created weather data sets specifically designed for use in building energy simulations, often usually called typical or reference years. Typical Meteorological Year (TMY) or Test Reference Year (TRY) data sets were first available in the 1970s and have been regularly updated.

Climate data for building simulation

One of the earliest weather data sets for building performance simulation is the Test Reference Year (TRY)[2] for 60 locations in the United States. The TRY contain hourly dry-bulb temperature, wet-bulb temperature, dew point, wind direction and speed, barometric pressure, relative humidity, cloud cover and type, and a placeholder for solar radiation; however, no measured or calculated solar data are included. When used for building energy simulations, the simulation program must calculate the solar radiation based on the cloud cover and cloud type information available in the TRY. TRY are a single, historic year of weather, selected using a process where years in the period of record (~1948–1975) which had months with extremely high or low mean temperatures were progressively eliminated until only one year remained. This results in a mild year that usually excludes extreme conditions. To deal with the limitations of the TRY, particularly the lack of solar data, the National Climatic Data Center (NCDC) worked together with Sandia National

Figure 2. Cooling degree-days by location and climate data set.

Laboratory (SNL) to create a new data set, Typical Meteorological Year (TMY). TMY include, in addition to the data contained in TRY, total horizontal and direct normal solar radiation data for 234 U.S. locations.[3] The method used is like that used for the TRY, but the TMY method selects individual months rather than entire years. The resulting TMY data files each contain months from several different years. These were subsequently updated as the TMY2[4] and TMY3[5] over the following 20 years. In Canada, two major TMY-type weather data sets were published: CWEC (Canadian Weather for Energy Calculations)[6] and CWEC2016.[7] ASHRAE published two versions of TMY-type data named IWEC[8] and IWEC2[9] covering hundreds of locations outside the US and Canada. Since 2002, CIBSE has compiled hourly weather data (TRY and DSY or Design Summer Year) for 14 UK locations for use in building simulation tools. These are described in several Technical Manuals.[10,11] Recently, a global data set of more than 13,500 locations, known as TMYx has become available.[12] TMYx are derived from the 15 most recent years (2004–2018) of hourly data. TMY and UK TRY use the same methodology as ISO 15927-4:2005.[13] These and other climate data sets are described in more detail by Crawley and Barnaby.[14]

Trends in climate data sets for simulation

Our first step for this paper was to see if we could see trends in the data. We selected twelve locations to represent a broad range of climates (listed alphabetically): Buenos Aires, Argentina; Cairo, Egypt; Denver (Stapleton

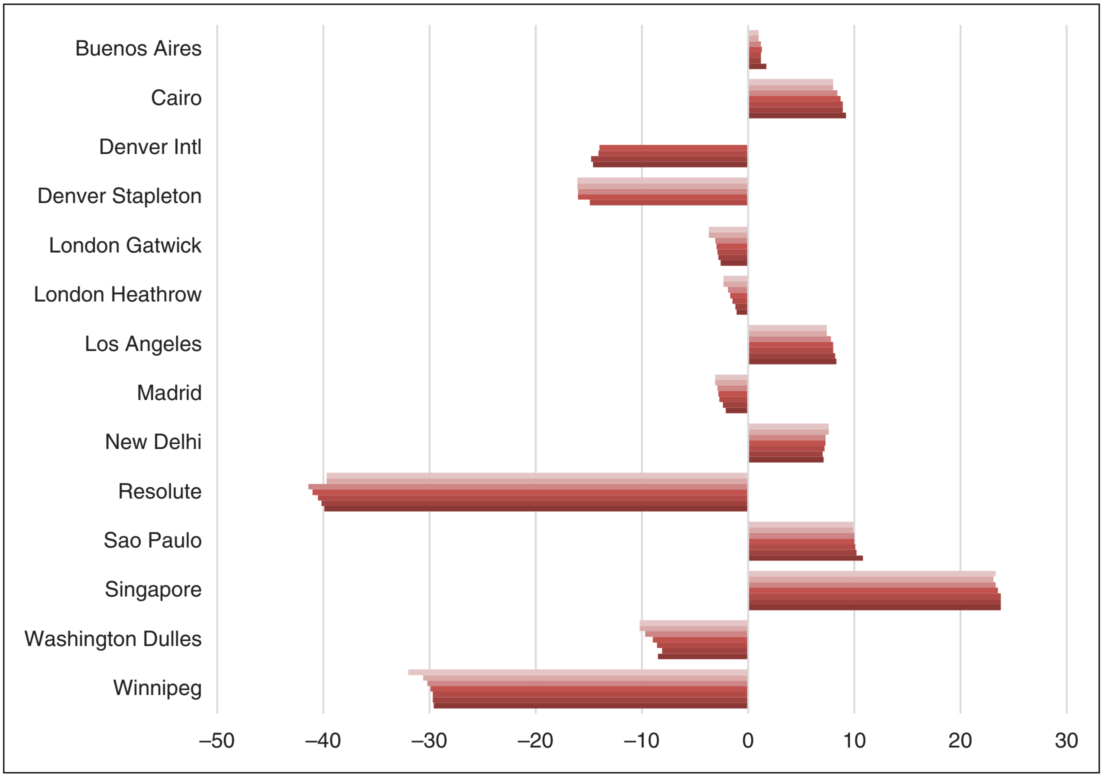

Figure 3. 99% annual heating design conditions (°C) by Fundamentals Handbook year and location.

AF and International AP), Colorado, USA; London (Gatwick and Heathrow), UK; Los Angeles, California, USA; Madrid, Spain; New Delhi, India; Resolute Bay, Nunavut, Canada; Sao Paulo, Brazil; Singapore; Washington (Dulles), Virginia, USA; and Winnipeg, Manitoba, Canada. For locations outside North America (Buenos Aires, Cairo, London, Madrid, New Delhi, Sao Paulo, and Singapore), IWEC, IWEC2 and TMYx data are available. These data sets comprise typical or representative years derived from periods of record. IWEC are derived from the years 1982–1999; IWEC2 from 1983–2008, and TMYx from 2004–2018. For the two Canadian locations (Resolute and Winnipeg), CWEC, CWEC2016, and TMYx data are available. CWEC are derived from 1953–2001; CWEC2016 from 1998–2014, and TMYx from 2004–2018. For the three US locations, TMY, TMY2, TMY3, and TMYx are available, derived from 1952–1975, 1961–1990, 1991–2005, and 2004–2018, respectively. These data sets should reasonably represent the periods shown. However, the data should not be interpreted as indicating future trends. Figures 1 and 2 show the heating and cooling degree days (10 and 18°C) for the 12 locations. Degree-days are a measure of temperature over the entire year. The 12 locations are identified by their name and the climate data set. In all cases in Figure 1, heating degree-days decrease over the data sets. The oldest data are for IWEC, TMY, progressing up to TMYx. Similarly, Figure 2 shows an increase in cooling degree-days towards the newer data sets.

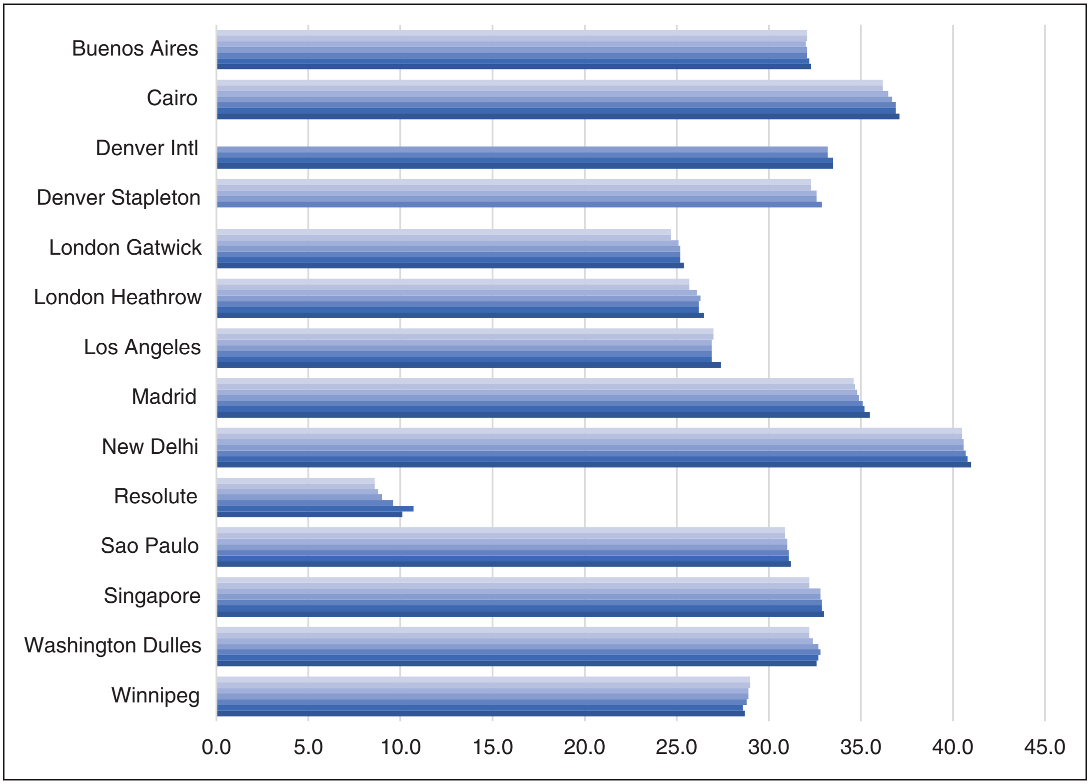

Figure 4. 1% annual cooling design conditions (°C) by Fundamentals Handbook year and location.

Trends in peak climate design conditions

CIBSE and ASHRAE have regularly published peak heating and cooling design conditions for more than 50 years. CIBSE Guide A Environmental Design[15] contains summary data for 14 UK locations including cold and warm temperature by percentile. Similarly, ASHRAE has been publishing similar world-wide peak design conditions since the 1960s in their Fundamentals Handbooks.[16]

To see if there are trends in the peak conditions, we compared the 99% (heating) and 1% (cooling) design dry-bulb temperature conditions from the 1997, 2001, 2005, 2009, 2013, 2017, and 2021 ASHRAE Fundamentals. 99% and 1% represent the number of hours that you can expect the temperatures to be exceeded – all but 88 h for 99% and 88 h for 1%. These are shown in Figures 3 and 4, respectively.

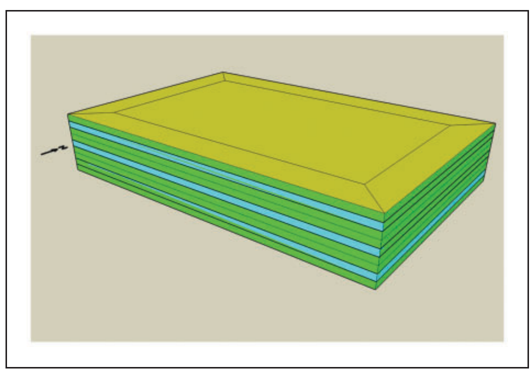

Figure 5. Prototype medium office building.

These progress from 1997 through 2021, with 1997 being on top of each stack and the lightest color (blue for heating and orange for cooling), and 2021 on the bottom for each location and

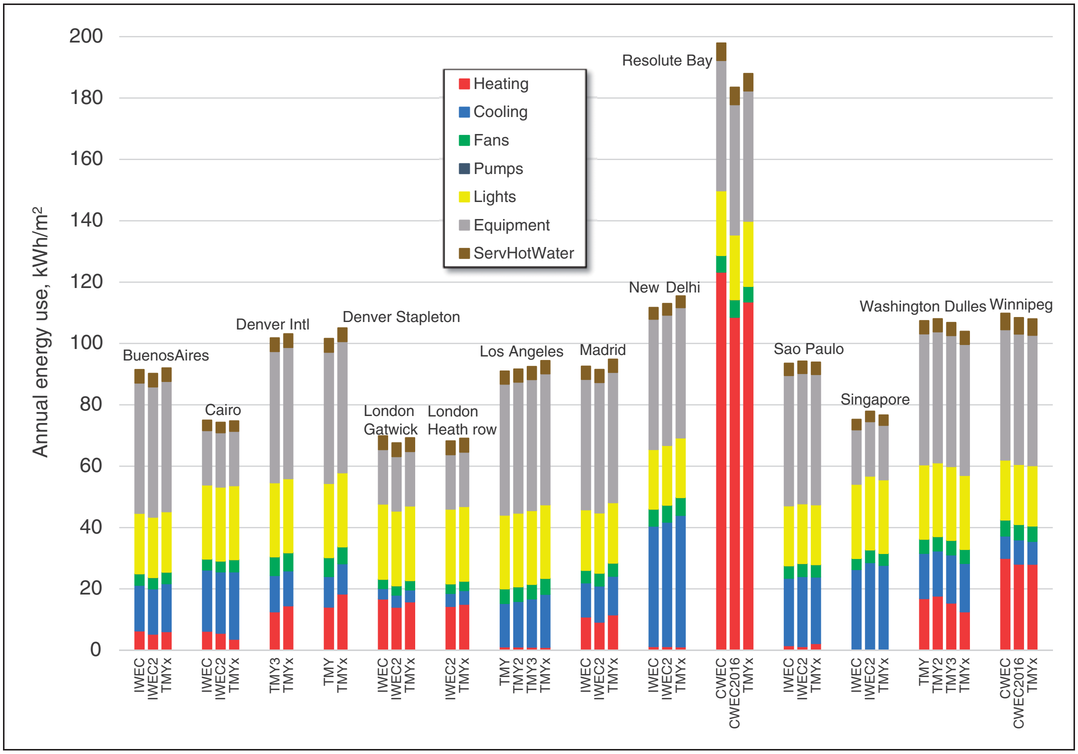

Figure 6. Annual energy use by category and location.

dark color. For the 99% heating design conditions over these 20 years, there has been a discernible increase in nine of the locations: Buenos Aires increased 0.7°C, Cairo increased 1.2, Denver Stapleton 1.2, London Gatwick 1.1, Heathrow 1.2, Los Angeles 0.9, Madrid 1.0, Sao Paulo 0.9, Singapore 0.5, Washington Dulles 1.7, and Winnipeg 2.4. But three locations decreased heating design conditions: Denver International 0.6°C (over eight years),

New Delhi –0.5, and Resolute –0.2. Interesting that these locations got colder – including the coldest (Resolute), and all three are relatively dry climates with Denver and New Delhi affected by urbanization around the airports. Similar but smaller increases in 1% cooling design conditions are also apparent in 11 locations: Buenos Aires increased 0.2°C, Cairo increased 0.7, Denver Stapleton 0.6, Denver International 0.3 (over eight years), London Gatwick 0.7, Heathrow 0.8, Los Angeles 0.4, Madrid 0.9, New Delhi 0.5, Resolute 1.5, Sao Paulo 0.3, Singapore 0.7, and Washington Dulles 0.5. Only Winnipeg experienced a small decrease in the 1% cooling design condition of 0.3°C. Likely many of the increases are due to increased urban development around these airports. However, Wickham et al.[17] found small differences (0.05°C) in temperature change between rural and developed suburban and urban locations due to heat islands.

Impact of older climate data on building performance

As shown above, newer climate data sets – both hourly and peak conditions – are showing

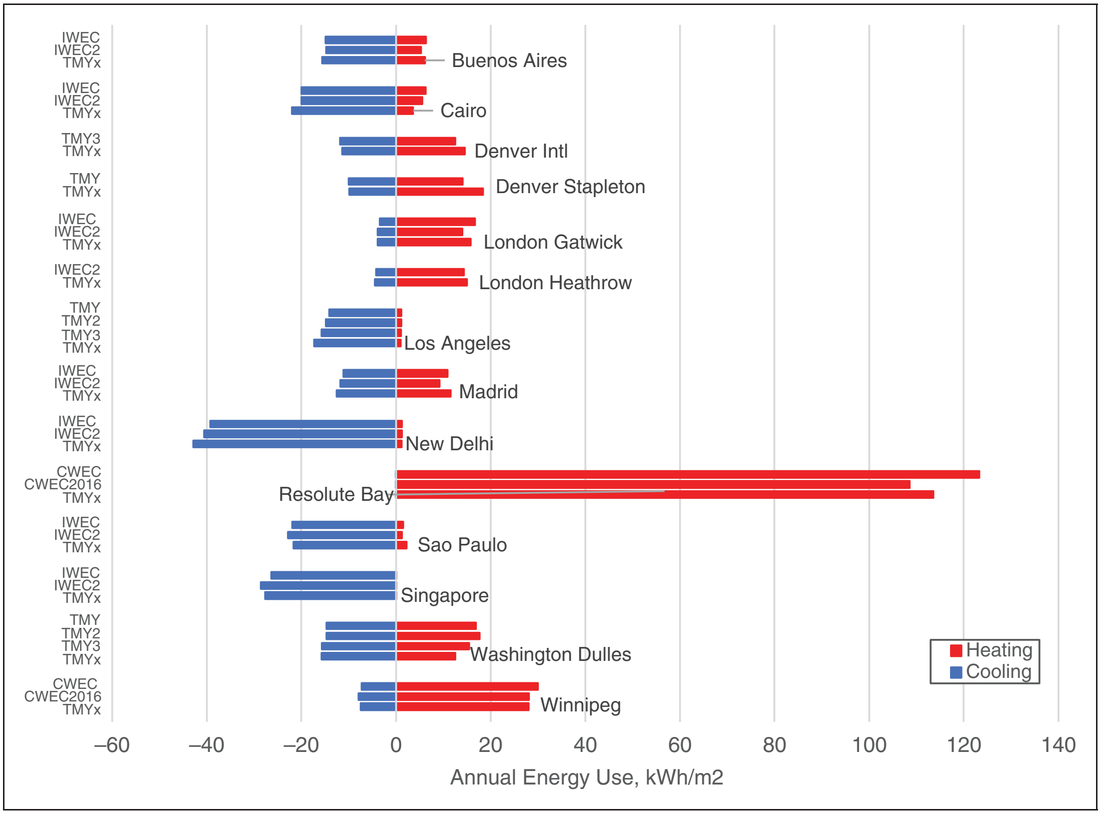

Figure 7. Annual energy use for heating and cooling by location.

Table 1. Percentage change in annual energy use from oldest to newest climate data set.

	Percent change in annual energy use				
Location	Total energy	Heating cooling and fans	Heating	Cooling	Fans
Buenos Aires, Argentina	0.6%	2.2%	–3.4%	5.0%	0.5%
Cairo Egypt	–0.3%	–0.6%	–41.9%	10.1%	11.3%
Denver Intl AP, Colorado, USA	1.3%	4.3%	15.6%	–3.5%	–3.8%
Denver, Colorado, USA (Stapleton AF)	3.4%	11.6%	30.5%	–1.3%	–10.7%
London, UK (Gatwick)	–0.9%	–1.9%	–5.4%	13.4%	0.2%
London, UK (Heathrow)	1.2%	4.1%	4.8%	5.4%	–0.7%
Los Angeles, CA, USA	3.7%	17.0%	–14.2%	22.4%	8.5%
Madrid, Spain	2.5%	9.1%	6.3%	13.2%	5.3%
New Delhi, India	3.4%	8.2%	–7.0%	9.1%	5.0%
Resolute, Nunavut, Canada	–10.7%	–7.8%	–7.9%	79.8%	–6.9%
Sao Paulo, Brazil	0.4%	1.3%	44.3%	–1.2%	–1.1%
Singapore (Changi Intl AP)	1.9%	5.4%	–72.5%	5.2%	7.0%
Washington Dulles, Virginia	–3.2%	–9.2%	–25.5%	7.1%	–1.3%
Winnipeg, Manitoba, Canada	–1.7%	–4.6%	–6.5%	2.2%	–3.3%

change, effectively getting warmer over the past 50 years (design conditions often include data from 15–30 years earlier). To test what that means in terms of building performance, we performed EnergyPlus[18] simulations using a medium office prototype,[19] 4982 m^2, 50 m × 33 m with main axis oriented East-West, 3 floors, 18 zones, with thermal characteristics based on ASHRAE Standard 90.1-2016[20] by climate zone. Window and wall U-values vary by location based on climate zone. The system is a packaged VAV unit with economizers and ERV. More details on the thermal and physical characteristics of the prototype building as well as the mechanical systems in the simulation model are available on the web page provided with reference.[19] An image of the prototype building is shown in Figure 5. These simulations used the available data sets for the same twelve locations shown in Figures 1 and 2. Figure 6 compares total annual energy use by end-use category for these six locations and the available data sets. Figure 7 shows the same locations but only for heating and cooling as they change the most (fans, lighting, equipment, and other scheduled end-uses were removed.).

Results

As seen in Figures 6 and 7, there are indeed trends in the newer data. While the overall energy use changes relatively little among the data sets and locations, the largest differences can be seen in heating and cooling energy. Buenos Aires sees a small (3.4%) decrease in heating energy while a 5% increase in cooling energy. Cairo, is experiencing increases in cooling partially offset by decreases in heating, resulting in a small decrease overall. In Denver, heating increases significant while cooling and fans decrease a bit – yielding a small increase in total energy. For London Gatwick and Heathrow, both see increases in cooling. However, Gatwick experienced an offsetting decrease in heating, resulting in a small overall decrease. Heathrow shows increases in heating, providing a small increase in total energy. For Los Angeles, there is a large decrease in heating but an even larger increase in cooling. This results in a small increase in total energy use. In Madrid, there's an increase in both heating and cooling, but total energy only increases by 2.5%. In New Delhi, the decrease in heating partially offsets the cooling energy, resulting in a 3.4% increase overall. In Resolute, while the cooling energy increases by 79.8%, it was a very small number to begin with. Heating dominates this, the coldest location, with a decrease of 7.9% in heating dominating the overall reduction in energy use. For Singapore, where there is almost no heating, the increase in cooling contributes to overall energy use increase. For Washington Dulles, heating declines by more than 25% while cooling increases 7%, resulting in an overall lower energy use. Table 1 shows the percentage changes in overall energy and by heating, cooling, and fans for the twelve locations. Note that while Cairo and Singapore had large decreases in heating and Resolute had a large increase in cooling, none of these locations had significant heating (Cairo and Singapore) or cooling (Resolute) energy to begin with as shown in Figures 6 and 7.

Conclusions

So, does it matter if you're using up-to-date climate data? Yes, the climate is changing, whether from urbanization or climate change and this can influence building performance and building equipment loads. We recommend using the most up-to-date climate data –whether for design conditions or for building simulation to assure that you are getting the most recent impacts into your simulations.

Recommendations

This study used 12 locations ranging from tropical hot to desert, temperate, warm, cold, and extreme cold locations, studying only the potential impact of changes in hourly climate data. While peak design conditions may influence equipment sizing, that was not tested here. For future work, we plan to:

- include more locations, bringing in several that are not influenced as much by urbanization, and add more extreme locations, covering at least one from each ASHRAE climate zone (this paper covers 12 of the 18 climate zones).
- evaluate how other climatic variables are changing. For example, are solar radiation and humidity changing?
- evaluate changes in monthly peak design conditions. ASHRAE Fundamentals have provided monthly design conditions since 2009.
- evaluate if changes in peak design conditions (annual and monthly) significantly change equipment sizing. Consistent peak design condition data are available back to 1977. Have the data changed significantly in that 40 years or is it a recent phenomenon
- Look at other building performance indicators such as cooling/heating equipment runtime
- Evaluate if the energy performance changes seen in the medium office are similar for other building types

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