RETHINKING THE TMY: IS THE 'TYPICAL' METEOROLOGICAL YEAR BEST FOR BUILDING PERFORMANCE SIMULATION?

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ABSTRACT

Historically, building simulation users have used a single typical year or a constructed typical meteorological year to represent climatic conditions for a location or region. With advent of increasingly powerful computers, it is no longer necessary to represent climatic conditions with a single year of data. Prior studies have shown that a single year of data often do not well represent the range of climate conditions over a period.

This paper proposes a new regime for climatic data representation in buildings—an XMY or eXtreme Meteorological Year—building on a paper from Building Simulation 1999 that called for a common format for building simulation representation. We demonstrate how several sets of international typical meteorological data sets compare to the actual period of record that they represent. Then using an example prototype building, we show that the climatic response of the building would be better served by a range of building climatic data, investigating high and low cases of temperature, humidity, solar radiation and wind conditions.

INTRODUCTION

Over the past 40 years, organizations throughout the world have created weather data sets specifically designed for use in building energy simulations, usually called typical or reference years.

One of the earliest weather data sets for building performance simulation is the Test Reference Year (TRY) (NCDC 1976) 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. The TRY are an actual 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 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 (NCDC 1981). The method used is similar to 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 a number of different years.

Crawley (1998) provides details on the developments of typical reference and meteorological years up through 2008, including European TRY, TMY2, CTZ, CTZ2, CWEC, WYEC, WYEC2, and IWEC and showed how they compare in terms of impacts on building energy performance. Crawley discourages the use of the TRY-type method and recommends the TMY or other weather data created using similar procedures, such as European test reference years (Barnaby and Crawley 2011).

FROM TMY TO XMY?

Since TMY-type weather data have been available, several authors have evaluated their effectiveness in representing the range of building performance in response to climate conditions. Several have proposed using a multi-year simulation including Donn and Amor (1993) and Hui and Cheung (1997). Crawley, Hand and Lawrie (1999) proposed a common weather data format for building simulation representation–the EPW (EnergyPlus Weather). More than 20 building simulation programs now read and use the EPW format.

More recently, Kershaw et al (2010) contrasted the design reference year (DRY) and test reference year (TRY) used in the United Kingdom with the base 23-year period of record from which they were developed. They found that DRY and TRY both had limitations with respect to overheating calculations. Bhandari et al. (2012) compared measured weather data with nearby TMY3 and satellite-based weather files and found significant variation between measured data and satellite, gridded data sources. Narowski et al (2013) recently evaluated the impact of 'untypical' weights in selecting months for weather files, concluding that untypical weights would be useful for predicting maximum energy use but for most uses, the TMY method was sufficient. Georgiou et al. (2013) examined various weights for selecting months for TMYs, finding that different weights provided better results for different applications such as solar collectors or wind turbines. Pernigotto et al (2014) proposed changes to EN ISO 15927-4 (Calculation and Presentation of Climatic Data - Part 4: Hourly Data) in order to improve the representativeness of BES results when reference years are developed.

These authors conclude that the TMY are good enough to represent typical building operation, yet we need more. We need weather that represents a reasonable range of climate conditions that a building might experience. In this paper, we propose the development of extreme meteorological year (XMY) weather files to represent the extremes of climate that the building will experience. An XMY starts from the same period of record as the TMY, but the methodology purposely selects more extreme months.

MODELING AND CONTRASTING THE IMPACTS OF WEATHER DATA

Building Models

To model the impacts of the weather data, we used EnergyPlus (Crawley et al. 2001) to simulate a range of building types–from small, climate-dependent building to large, energy-intensive buildings. We simulated five of the DOE reference buildings (Deru et al 2011):

- hospital, 22,422 m^2, 5 floors, 55 zones
- medium office, 4,982 m^2, 3 floors, 18 zones
- small office, 511 m^2, 1 floor, 6 zones
- quick service restaurant, 232 m^2, 1 floor, 3 zones
- warehouse, 4,835 m^2, 1 floor, 3 zones

The full set of 16 commercial reference buildings represent reasonably realistic building characteristics and construction practices based on a specific version of ASHRAE Standard 90.1 (ASHRAE 2004, 2010, 2013). See Figure 1 for graphic view of the five reference buildings used.

Weather Data

For this study, we wanted to look at the building performance impacts of several of the data sets in comparison with actual meteorological year (AMY) data. We assembled TMY3 (Wilcox and Marion 2008), TMY2 (Marion and Urban 1995), TMY (NCDC 1981) data for locations in the United States; CWEC (Environment Canada 2008) data for Canadian locations; and IWEC (ASHRAE 2001) and IWEC2 (2011) data for other locations. We selected six locations to represent a range of climate types from extremely hot to cold. Table 1 lists the selected locations along with their heating and cooling degree-days. To see how well these TMY-type files correspond to actual weather data, we also assembled AMY files from Weather Analytics (2015) for 1980-2014. Also available were three alternative TMYs with 15-, 10- and 7-year period of record (1999-2013, 2004-2013, and 2007-2013, respectively)–hereafter referred to as short-period TMYs.

XMY Development Methodology

Brainstorming the possibilities that we wanted to investigate, we selected an initial set of variables – dry-bulb temperature, dew-point temperature, solar insolation, precipitation, relative humidity, and wind speed–to create initial maximum/minimum extreme meteorological years (XMY).

To select months for the XMY, we first calculated the daily maximum, minimum, and average values by month for each type of XMY (dry-bulb temperature, etc.) from a 15-year period (1999-2013). Then, to select the extreme “daily” months, we looked at the daily maximum and minimum values for each day of the month and selected the month with the highest daily maximum value for the max extreme and the lowest daily minimum value for the min extreme. To select the extreme “hourly” months, we looked at the average hourly value for the month and selected the months with the highest hourly and lowest hourly average value. We smoothed the transitions between months using a 5-hour boxcar averaging of data–6 hours before to 6 hours after each month transition and then wrote the selected XMYs in EPW format. This resulted in four combinations of possible extremes: daily maximum, daily minimum, hourly maximum, and hourly minimum – except in the case of the solar insolation extremes where there is no daily minimum XMY.

Simulating TMY, AMY and XMY

With these initial XMYs, we simulated the five buildings compliant with 90.1-2013 using the Dulles weather data. Figure 2 shows the initial energy results for the three TMY (TMY3, TMY2, TMY), the short-period TMY (TMY_15, TMY_10, TMY_7), and the five initial XMY variables: dry-bulb temperature, dew-point temperature, global horizontal insolation, precipitation, relative humidity, and wind speed. The XMYs with the greatest difference in energy use between min and max are dry-bulb temperature, dew-point temperature, and precipitation. Minimum and maximum relative humidity and wind speed show very little impact on energy performance while solar insolation shows some variation. In Figure 3, we removed the “constant” loads (Interior/Exterior Lighting, Interior/Exterior Equipment, Domestic Hot Water) to focus on the energy end-uses that vary by building type and location. Figure 3 clearly shows the heating and cooling as the key drivers in the changing energy use for the XMYs. (Figure 4 is the legend of energy end-uses for all the figures. Note that the end uses vary by building type with hospital having the most energy end-uses.)

Table 1. Selected Weather Locations and Typical Weather Types

Location	Typical Weather Types Available	Latitude, Longitude	Heating Degree Days, 18 C	Cooling Degree Days, 18 C
Chicago-O'Hare Intl AP, IL, USA	TMY, TMY2, TMY3	41.98, -87.9	3449	480
Dubai Intl AP, ARE	IWEC, IWEC2	25.25, 55.33	21	3568
Phoenix-Sky Harbor Intl AP, AZ, USA	TMY, TMY2, TMY3	33.45, -111.98	513	2570
San Diego-Brown Field Muni AP, CA, USA	TMY, TMY2, TMY3	32.58, -116.98	934	363
Yellowknife AP, YT, Canada	CWEC	62.47, -114.45	8189	34
Washington-Dulles Intl AP, VA, USA	TMY, TMY2, TMY3	38.98, -77.47	2597	657

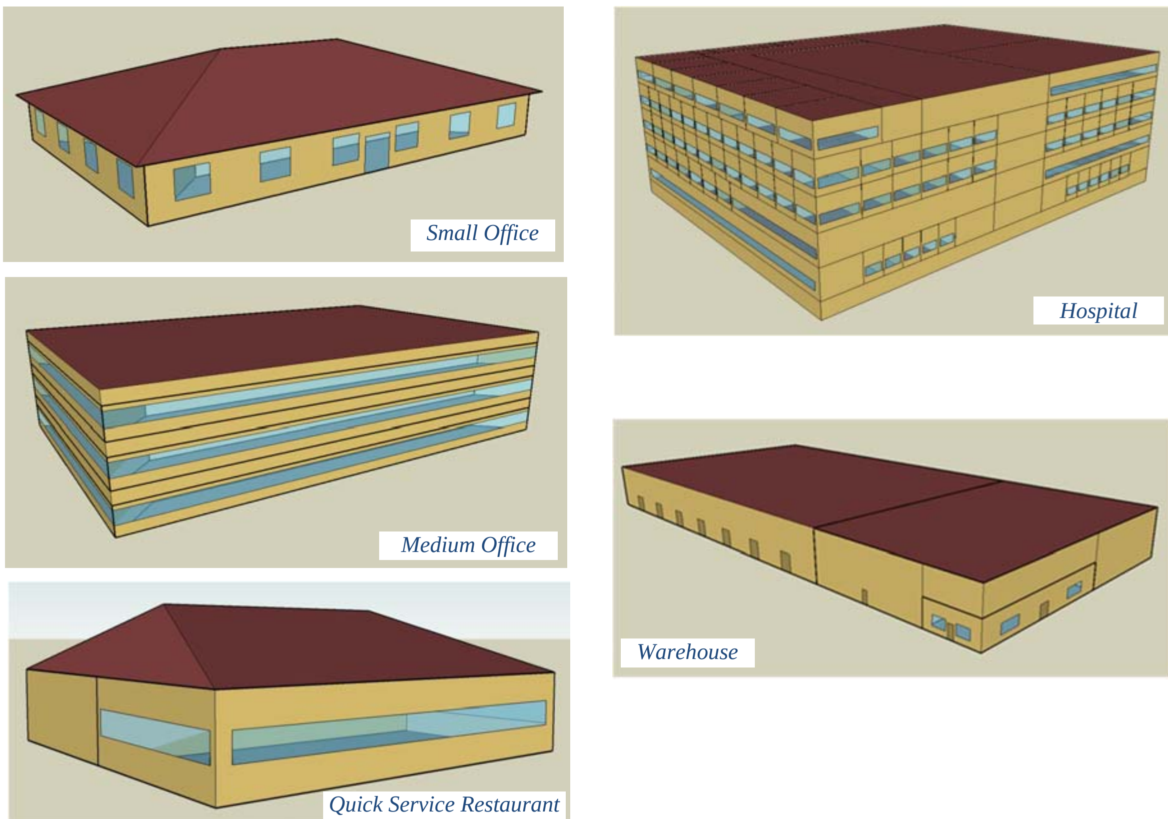

Figure 1. Reference Buildings

Dry-bulb temperature, dew-point temperature, and precipitation showed the largest range between minimum and maximum "Daily" and "Hourly" XMYs, Because relative humidity and wind speed XMYs have little impact on energy performance, we excluded those variables from further study. For a second round of XMY analysis, we added two other solar insolation variables–direct normal and diffuse horizontal insolation and created XMYs for the other five locations shown in Table 1. The next section describes the results for this second set of XMYs using the six locations and five building prototypes.

Results

Figures 5-9 show energy results for the second set of XMY using the five building types and Washington Dulles weather data. Figure 5 clearly shows the domination by equipment and other systems of energy use for the Hospital—heating, cooling and fans only contribute about 40% to the total energy use. This contributes to the relatively lower impact of the XMYs – in the range of -2.2/+0.7%. Figure 6 shows the Medium Office again but this time with the new solar insolation variables (direct normal and diffuse horizontal). Temperature and precipitation XMYs still have the largest range of results, -5.5/+3.8%. As seen in Figure 7, cooking and other food preparation equipment dominate energy use in the Quick Service Restaurant. This building type has the largest range of energy use for the XMYs–-7.2/+5.6% probably due to the relatively high ventilation rates compared to other building types. Figure 8 shows the relatively low variation in XMY results for the Small Office due to a constant volume system type, with a similar range of energy variation to that of the hospital: -2.3/+0.5%. The domination of energy use by heating and lighting in the Warehouse is shown in Figure 9, which has the largest variation in energy use for the XMYs: -13.3/+14.5%

Because the Medium Office has both heating and cooling, it provides a median snapshot of the impacts of the XMY types. Figures 10-13 show energy results for the second set of XMY again but this time for four locations in Table 1 using the Medium Office prototype. (We omitted Phoenix because of the similarity of results to Dubai.) Compare the variation shown in Figure 10 for Chicago against the Dulles results and you see the much larger heating energy use, with a range of -9.6/+7.0%. Figure 11 shows XMY results for Dubai, the hottest climate in this analysis, the energy range skewing towards increases, a range of -0.6/10.1%. The results for the relatively mild climate of San Diego is shown in Figure 12, with heating, cooling and fans only contributing 20% of energy use and a range of -3.6/+7.5%. Figure 13 shows the coldest climate in the set, Yellowknife, with almost no cooling and significant heating (approaching 50% in some cases), a range of -21.0/+16.5% in energy among the XMY.

The last four Figures (14-17), show another aspect of this study—comparing the energy results for the TMYs with those for AMYs (Actual Meteorological Year) for 1980-2014. These AMY are the source data for both the short-period TMYs (15, 10, and 7) and the XMY. These four graphs show AMY and TMY results for the hottest (Figure 14, Dubai), mixed heating/cooling (Figure 15, Dulles), mild (Figure 16, San Diego) and coldest climates (Figure 17, Yellowknife). These illustrate the inherent inter-annual variability of building performance. The black line is at the level of the TMY3 (or IWEC2 and CWEC in the case of Dubai and Yellowknife, respectively). These show that, for most cases, the TMY3 represents a median climate in terms of energy use, with significant variability both above and below the TMY3. The short-period TMYs appear to give significantly higher energy use in cooling-dominated Dubai and lower energy use in heating-dominated Yellowknife. In these cases, the short-period TMYs also do not seem to match the energy use of most of the relatively recent years from which they are drawn.

SUMMARY AND CONCLUSIONS

From this study, we believe that building simulation users should regularly use more than one weather file–a TMY-type to represent median or typical conditions and two XMYs to capture a range of building performance. This will ensure that we are presenting a range of values and that the inherent variability of climate does not influence decision-making.

Which XMY variable? The "Hourly" max and min dry-bulb temperature XMYs, almost without exception, consistently had the highest and lowest energy. Even in the internal-load dominated buildings, dry-bulb temperature best captured the range of energy use for the XMY. This paper and research focused on buildings with HVAC and heating/cooling loads. For other applications (passive solar, IAQ, naturally ventilated buildings), similar focus for the XMY choice may be appropriate or it may be that further research should be done to fine tune the XMY choices for other building types.

It appears that short-period TMYs can introduce bias but it is not clear from this study why that is the case. For example, in Figure 15 (Dulles), all the short-period TMYs had lower energy use than most of the years from which they are drawn. Similar but opposite effects for Figures 14 (Dubai) and 16 (San Diego)–the short-period TMYs results in higher energy use than many of the years. How do you know the last seven years will represent the next seven? Hubbard et al (2004) found that at least eight complete years were necessary to represent a climate accurately. In the near future, we plan to do further analysis into the issues with the short-period TMYs and more building types that include non-traditional systems such as passive solar and natural ventilation.

ACKNOWLEDGEMENTS

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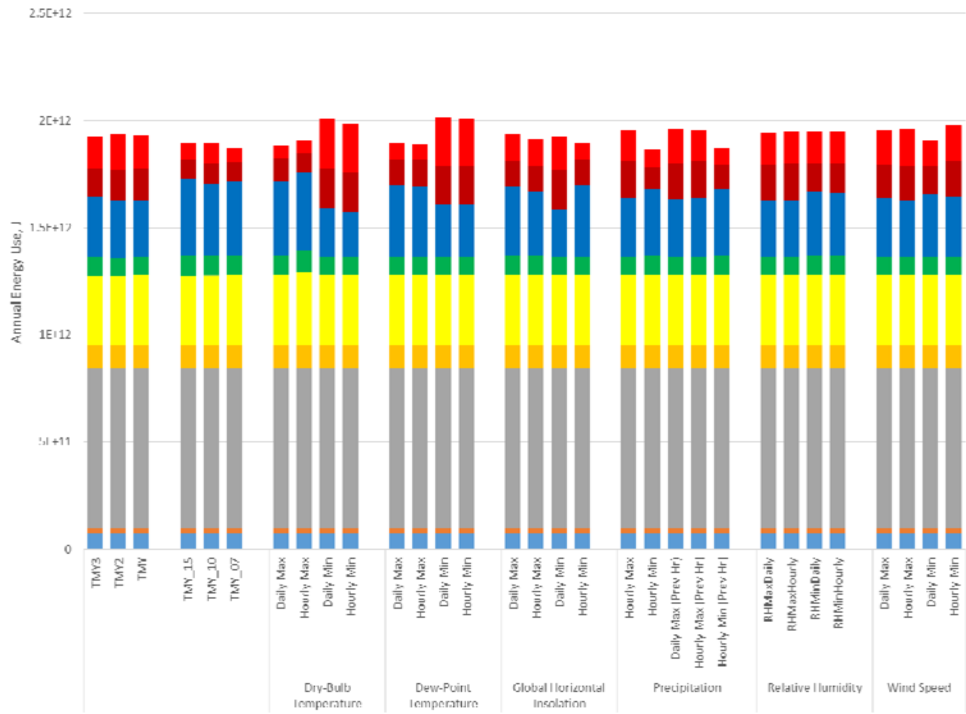

Figure 2. Initial Set of XMY vs TMY, Energy End-Uses for Medium Office, Washington Dulles

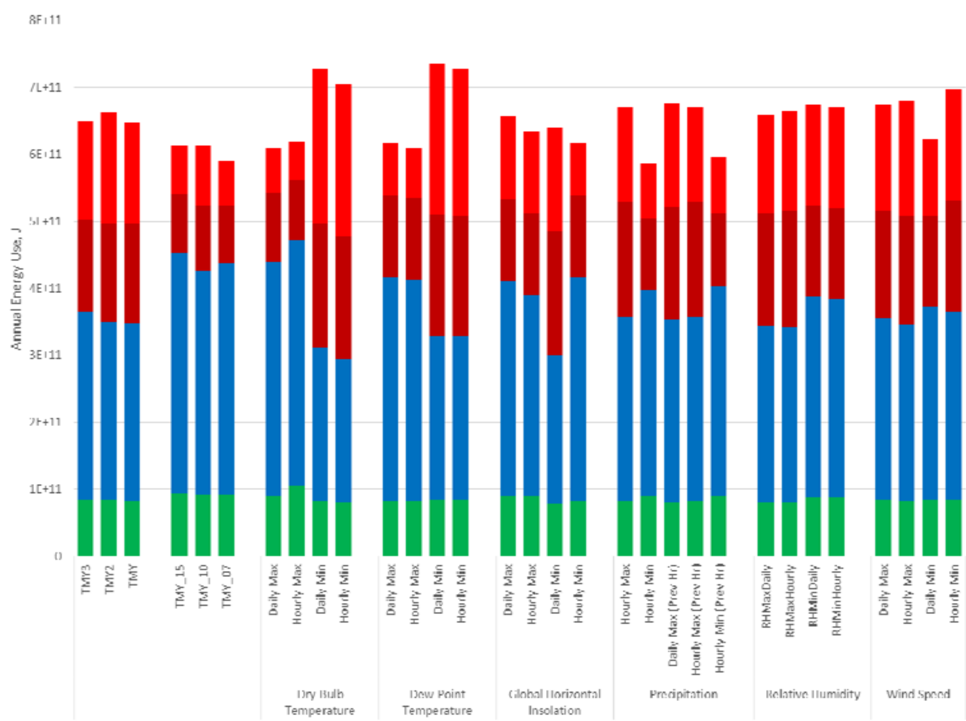

Figure 3. Heating, Cooling and Fan Energy Use for Initial Set of XMY and TMY for Medium Office, Washington Dulles

Figure 4. Common Legend for Figures 2-17

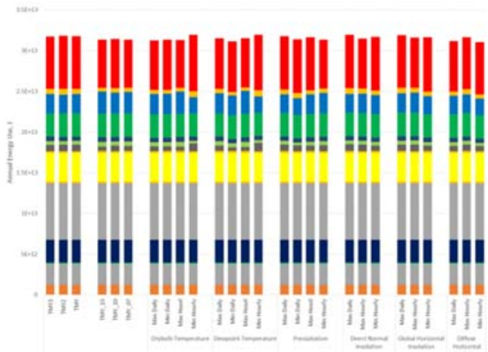

Figure 5. TMY and XMY Energy End-Uses for Hospital, Washington Dulles

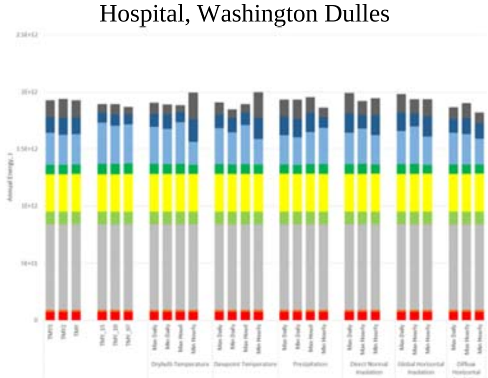

Figure 6. TMY and XMY Energy End-Uses for Medium Office, Washington Dulles

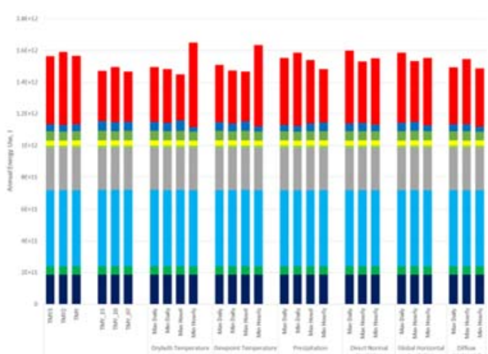

Figure 7. TMY and XMY Energy End-Uses for Quick Service Restaurant, Washington Dulles

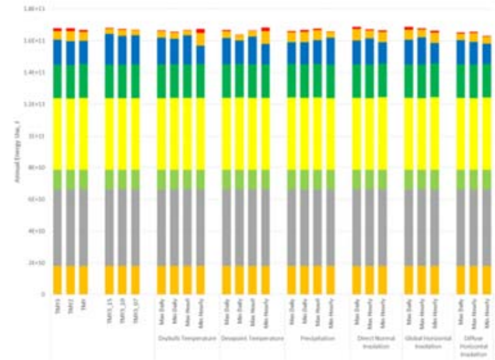

Figure 8. TMY and XMY Energy End-Uses for Small Office, Washington Dulles

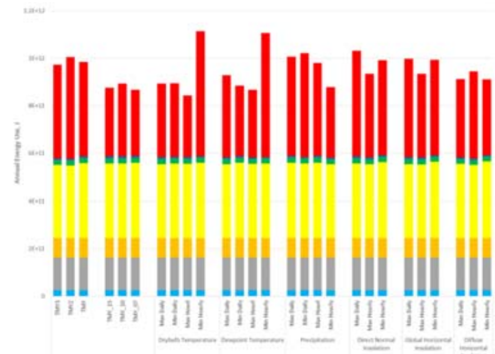

Figure 9. TMY and XMY Energy End-Uses for Warehouse, Washington Dulles

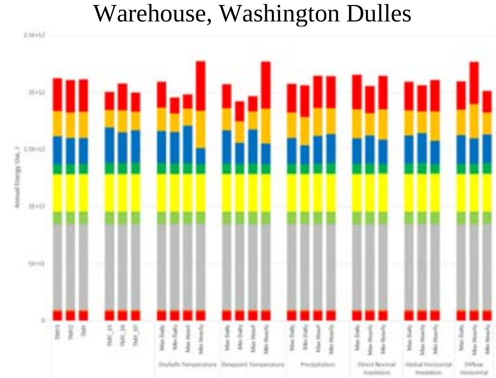

Figure 10. TMY and XMY Energy End-Uses for Medium Office, Chicago

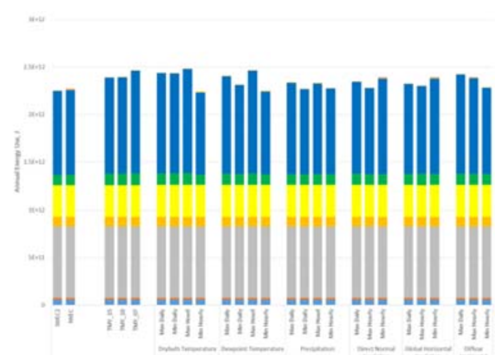

Figure 11. TMY and XMY Energy End-Uses for Medium Office, Dubai

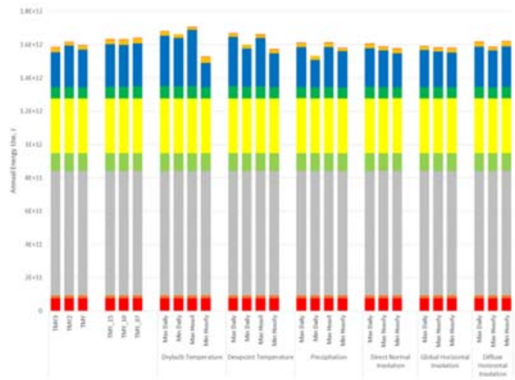

Figure 12. TMY and XMY Energy End-Uses for Medium Office, San Diego

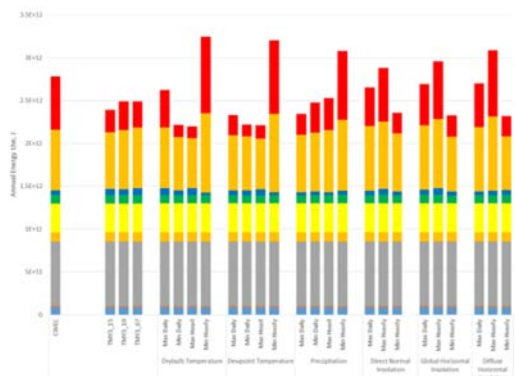

Figure 13. TMY and XMY Energy End-Uses for Medium Office, Yellowknife

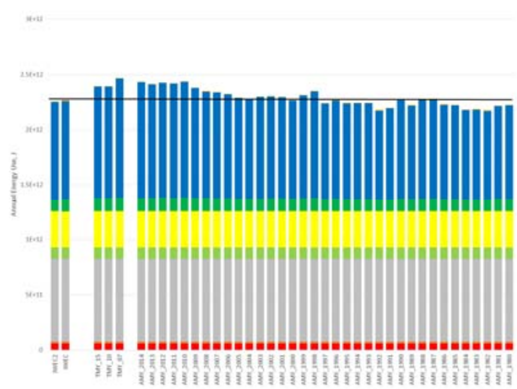

Figure 14. TMY and AMY Energy End-Uses for Medium Office, Dubai

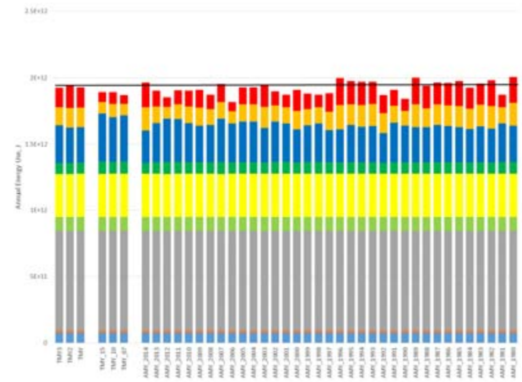

Figure 15. TMY and AMY Energy End-Uses for Medium Office, Washington Dulles

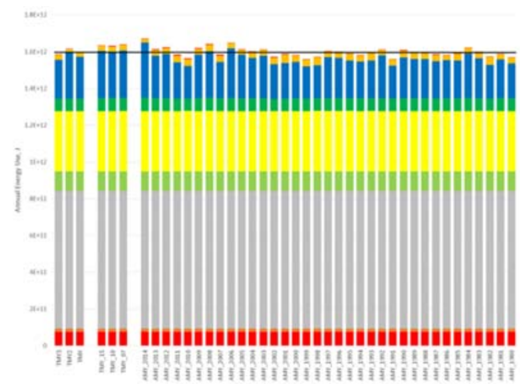

Figure 16. TMY and AMY Energy End-Uses for 90.1-2013 Compliant Medium Office, San Diego

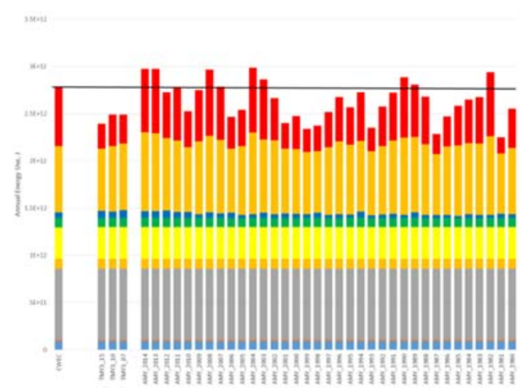

Figure 17. TMY and AMY Energy End-Uses for 90.1-2013 Compliant Medium Office, Yellowknife