ESTIMATING THE IMPACTS OF CLIMATE CHANGE AND URBANIZATION ON BUILDING PERFORMANCE

Drury B. Crawley

U. S. Department of Energy
Washington, DC 20585, USA

ABSTRACT

While the scientific literature is full of studies looking at the impact of climate change driven by human activity, there is very little research on the impact of climate change or urban heat island on building operation and performance across the world. For this study, typical and extreme meteorological weather data were created for 25 locations (20 climate regions) to represent a range of predicted climate change and heat island scenarios for building simulation. Then a set of prototypical buildings were created to represent typical, good, and low-energy practices around the world. When these prototype buildings were simulated, the results provide a snapshot view of the impact of a wide variety of building performance based on the set of climate scenarios. These include location-specific responses of the prototype buildings including impacts on equipment use and longevity, fuel swapping as heating and cooling ratios change, impacts on environmental emissions, comfort issues, and how low-energy building design incorporating renewables can significantly mitigate any potential climate variation.

KEYWORDS

Climate change, urban heat island, future simulation

INTRODUCTION

Over the past 10 years, the international scientific community [organized through the Inter-governmental Panel on Climate Change (IPCC)] has focused significant effort to characterize the potential impacts of greenhouse gas emissions from human activities (anthropogenic) on the complex interactions of our global climate. IPCC Working Group I focused on creating atmosphere-ocean general circulation models (GCM), similar to models used to predict the weather, in which the physics of atmospheric motion are translated into equations which can be solved on supercomputers. The GCM predict climate at a relatively high level of spatial resolution (5 x 5 degrees latitude and longitude or several hundred kilometers).

But climate change may not be the only change affecting our built environment. Over the past 30 years, there has been a significant trend towards increasingly larger urban areas. This concentration of transportation infrastructure and buildings often results in urban heat islands—increasing the cooling loads on buildings. For example, London Heathrow, Los Angeles, and Phoenix have all seen average temperature increases of at least 1°C over the past 30 years.

WHAT ARE THE POTENTIAL IMPACTS ON THE BUILT ENVIRONMENT?

Yet with all the scientific study, little of it has pursued the impact of climate change on buildings. The IPCC’s Third Assessment Report (IPCC 2001) summarizes the impact on the built environment simply as “increased electric cooling demand and reduced energy supply reliability.” This top-down view of the entire building sector ignores the variability in climatic response seen among buildings from the poles to the equator. Buildings have complex time-varying interactions of local weather conditions with internal loads (people, lights, equipment, and appliances) and heating and cooling systems (natural or forced). This is seen in Figure 1, comparing energy end-uses of commercial buildings in the United States and Europe, where typical European buildings use little or no cooling but it is a significant portion of commercial building energy performance in the United States.

In the Third Assessment Report, Working Group II states:

. . The basis of research evidence is very limited for human settlements, energy, and industry. Energy has been regarded mainly as an issue for Working Group III, related more to causes of climate change than to impacts … Impacts of climate change on human settlements are hard to forecast, at least partly because the ability to project climate change at an urban or smaller scale has been so limited. As a result, more research is needed on impacts and adaptations in human settlements (IPCC 2001).

So what might be the potential impacts of climate change or urbanization on buildings?

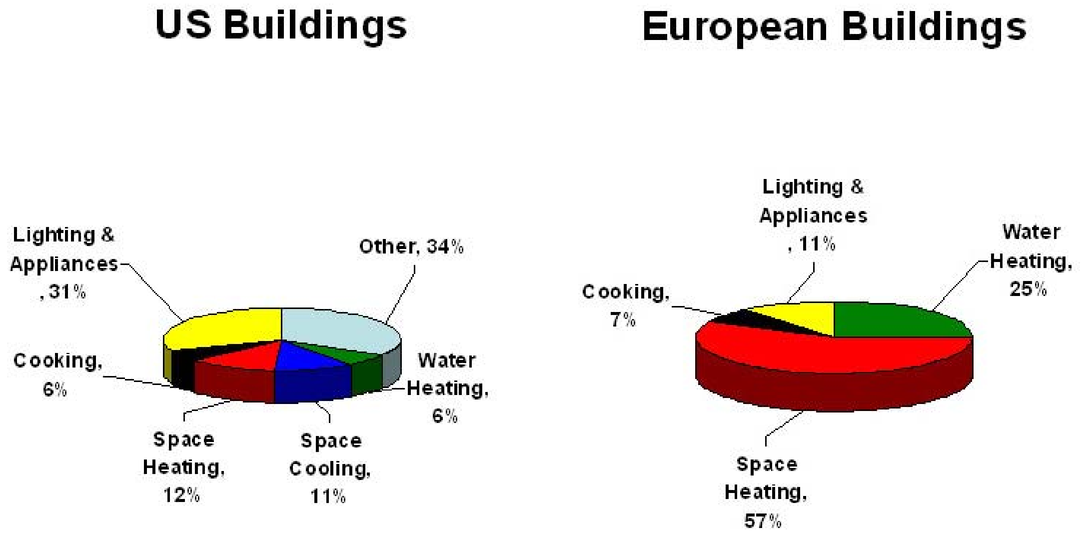

Figure 1. Commercial Building Energy End-Uses in the United States (EIA 2002) and Europe (EC 2000)

Will the changes predicted by the climate models and recent measurable temperature changes due to urbanization significantly impact buildings—changing patterns of energy use and peak demand or causing cost shocks?

Will increased demands on building heating and cooling equipment decrease life?

What are the potential impacts on comfort?

What other potential impacts might be seen?

BUILDING SIMULATION AS A TOOL FOR EVALUATING CLIMATE CHANGE

Building energy and environmental performance simulation programs have the capability to evaluate a wide range of response to external stimulus and have been in use (and development) for more than 40 years (Clarke 2001). Typically, these software tools are used by practitioners evaluating individual building design or retrofits. Other uses for building simulation includes overheating prediction; heating and cooling equipment design, evaluating alternate technologies (energy efficiency and renewable energy), regulatory compliance, or more recently, integrated performance views.

Simulation, when coupled with building models that represent a range of building types and locations, can essentially represent a portion of (existing or new, office or hospitals, large, medium or small) or the entire building stock. In this paper, building energy simulation is used to answer questions such as those above for a small office building. This work is a portion of a broader study currently under way on the value of building simulation as a policy tool—while presenting some answers to the questions above.

So how would we go about using building simulation (in this case, specifically energy and environmental performance simulation) to answer policy questions?

The following process was tested:

- Translate the policy scenarios [such as the IPCC Special Report on Emissions Scenarios (SRES) mentioned above or urban heat islands] into temporal climatic change based on a reference period.
- Define a building (or sets of building) prototypes which can be to represent a portion of the building stock.
- Define the series of simulation cases which represent the range and combinations of scenarios and building response.

This paper describes analysis of the potential impacts of climate change and heat islands on a small office prototype. For this analysis, the process included selecting a range of climates, selecting a range of scenario impacts, modifying the climate information to represent the scenario impacts, and running a series of building energy simulations, and finally analyzing the hundreds of megabytes of hourly data available.

CALCULATING THE IMPACT ON A SMALL OFFICE BUILDING

For this study, an office building was defined to represent smaller office buildings based on U.S. building surveys. This 550 m^2 building represents approximately 25% of office buildings, the smaller buildings, with the following characteristics (see the schematic in Figure 2):

- 550 m^2 (5918 ft^2)
- two stories
- 14 m^2/person

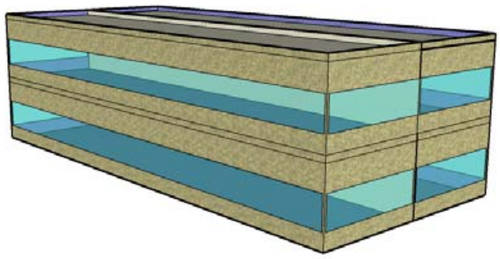

Figure 2. Schematic of Small Office Building Model

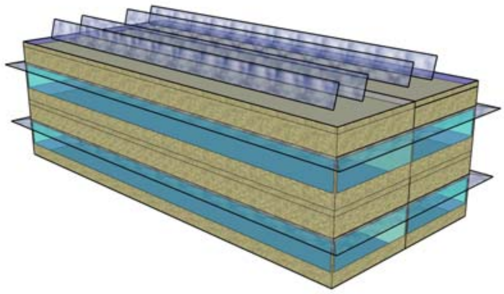

Figure 3. Schematic of Low Energy Building

- typical office schedules
- lighting power at 11 W/m^2
- office equipment at 8 W/m^2
- natural gas heating and hot water
- packaged rooftop electric DX cooling units
- opaque building envelope and windows and equipment efficiencies equivalent to current minimum regulations [Standard 90.1-2004 (ASHRAE 2004)]

Two other prototypes were also created:

- Low energy building including photovoltaic power cells on the roof as well as the shading overhangs (see Figure 3), using approximately 50% of the energy of the baseline small office building.
- Building which does not meet the minimum requirements of Standard 90.1, more typical of locations without an energy code.

To start, 25 locations were selected to represent the range of climatic conditions worldwide. The list of locations and Köppen region they represent is shown in Table 1. For each location, a combination of typical year data (TMY2, CWEC, or IWEC) and high and low energy weather years were selected. Then, for each of these (typical/high/low), weather files were created to represent four IPCC climate change scenarios (A1FI, A2, B1, and B2) and two levels of heat island (1 and 5 C). The process for modifying the weather files to represent climate change scenarios and heat islands is described by Crawley (2007). Design conditions from Chapter 28 of the Handbook of Fundamentals (ASHRAE 2005) were used in all cases—essentially using 2005 design conditions for equipment and system sizing. The EnergyPlus whole-building energy performance simulation software (USDOE 2007) was used to calculate building thermal flows given time-varying weather data. For each simulation, results available from the annual simulations include:

- surface temperature and conduction and radiation through the building envelope
- zone sensible, latent, convective, and radiant heating gains and losses
- zone air and mean radiant temperature, relative humidity, and humidity ratio
- HVAC equipment runtime fraction, heating and cooling rates, part-load ratios, and temperature and humidity

Table 1 Climate Locations

Köppen Climate	City Rank[1], D/E[2]	Location
Af	65, D	Singapore, Singapore
Am	139, D	San Juan, Puerto Rico
Aw	57, D	Miami, Florida, USA
BSh	12,E	Cairo, Egypt
BSk	145, D	Boulder, Colorado, USA
BSk	3, E	Mexico City, Mexico
BWh	6, E	New Delhi, India
Cfa	1, D	Tokyo, Japan
Cfa	7, E	Sao Paulo, Brazil
Cfb	22,D	London (Gatwick), UK
Cfb	38,E	Johannesburg, South Africa
Cfc	-, E	Punta Arenas, Chile
Csa	17, E	Buenos Aires, Argentina
Csb	9, D	Los Angeles, California, USA
Csb	48, E	Santiago, Chile
Dfa	35,D	Washington-Dulles, Virginia, USA
Dfb	60, D	Toronto, Ontario, Canada
Dfb	18, E	Moscow, Russia
Dfc	-, D	Whitehorse, Yukon Territory, Canada
Dwa	19, E	Beijing, China
Dwb	-, D	The Pas, Manitoba, Canada
Dwc	-, D	Fairbanks, Alaska, USA
Dwd	-,E	Yakutsk, Russia
ET	-, D	Resolute, Nunavut, Canada
H	224, E	La Paz, Bolivia

[1] Rank of cities with population greater than 1 million. (Brinkhoff 2007)
[2] D = Developed economy, E = Emerging economy

- energy consumption and demand by zone, system, and plant equipment
- energy end-uses, consumption and demand by energy source
- atmospheric emissions by pollutant type and equivalent carbon

A few summary energy performance results from the EnergyPlus simulation of the climate change scenarios and heat island for Washington, D.C. are described in the following figures. Figures 4 and 5 show the annual energy consumption for the small office building in Washington, DC, USA (Köppen region Dfa, wet all seasons, hot summer). These figures each have three columns for each case—low, TMY2, and high. The low and high cases are the years from the period of record (see Crawley 2007) that result in the lowest and highest energy use; TMY2 is the typical year weather file. Figure 4 compares the results for the small office building baseline with the four climate change scenarios. Figure 5 compares the results of the baseline with those of the two heat island cases. Figures 6 and 7 show similar results, but for monthly energy end use of only the typical (TMY2) weather file for Washington, DC.

Interestingly, both Figures 4 and 5 show that total site energy consumption for the small office in Washington, D.C. declines slightly over the range of scenarios and for the two heat island cases. This is due to significant decreases in less-efficient natural gas-fired heating while the more efficient electric cooling increases slightly. This fuel swapping results in roughly equivalent total site energy consumption over the range of scenarios. While not shown in this paper, locations with predominant heating or balanced heating and cooling energy usually decreased with the climate change scenarios. Warmer regions with significantly less heating such as New Delhi or Singapore showed significant overall increases in total site energy consumption. Heating consumption in these cooling-dominated regions, reductions in which might have offset the increased cooling energy, was small to begin with.

The last two figures, 8 and 9, show the monthly energy end-use consumption for the low-energy office building. These figures show data similar to Figure 6 and 7 and similar results—end-use swapping between heating and cooling for the climate change scenarios and the heat island cases. The difference for the low-energy office building is that the variation between the baseline and the climate change scenarios or heat island cases is significantly less. For the small office building built to the energy standard, the largest difference is 7%; while for the low-energy office building, the largest difference is 5%. Similar reduction in the spread of results is seen (but not included in this paper) among the high, low, and typical cases are included for the low-energy office building. This suggests that the low-energy office building while already significantly reducing energy consumption by 50% over the baseline energy standard also reduces the variation in energy performance due to variation in climatic conditions year to year.

CONCLUSIONS

The analysis of the small office building prototype shows test case showed that building performance simulation can be used to answer policy questions such as:

- Location-specific responses to potential scenarios
- Impacts on equipment use and longevity
- Fuel swapping as heating and cooling change
- Emissions impacts
- Comfort
- Means to improve building energy efficiency and incorporate renewable energy while mitigating potential changes

This paper only presented a very small portion of the building performance data available from this study. Today's building energy performance simulation tools can provide data for study from annual, monthly, weekly, daily, hourly and even down to the time-step (10 minutes for this study) for all surfaces, components, spaces, zones, equipment, spaces, and systems within the building.

Further Work

The author will be drawing additional data from the available results over the next few months. Some of the work includes:

- More results for the entire range of 25 locations.
- Adding results from a high and low energy version of the small office building.
- Evaluating the results from the high and low energy weather data years.
- Substantially greater depth of time-dependent resolution

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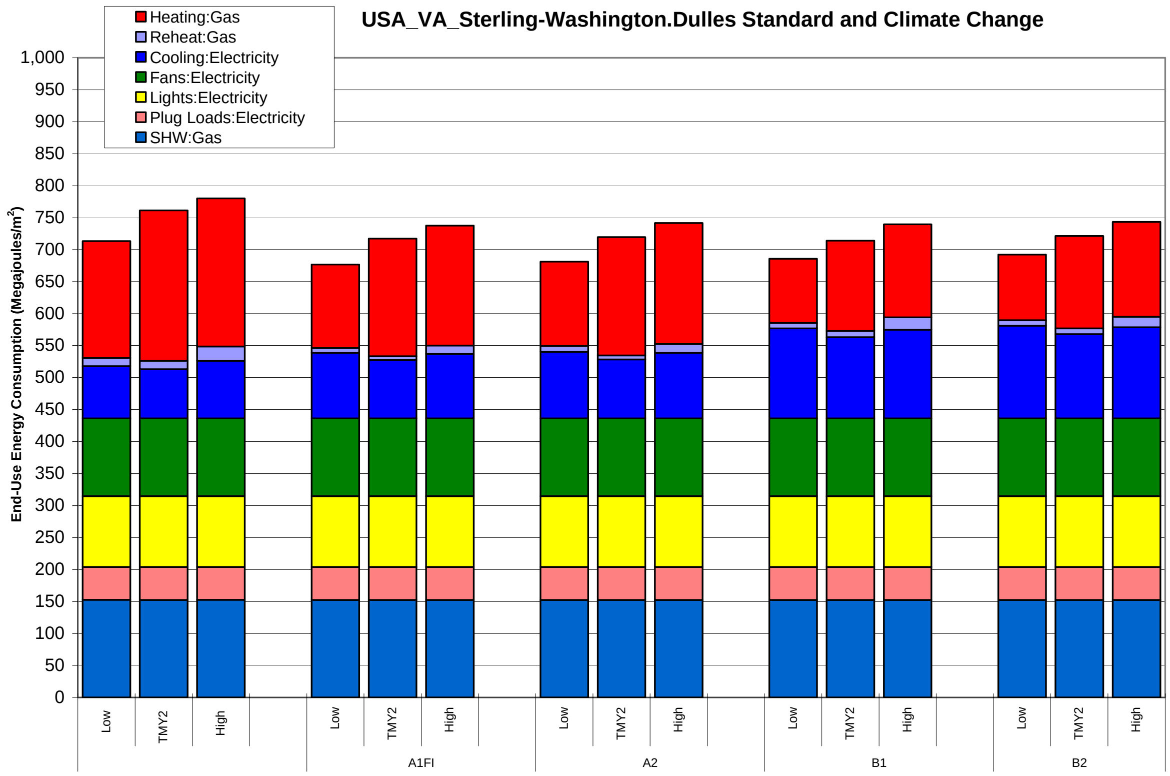

Figure 4. Predicted Annual Energy Energy-Use Consumption, in MJ/m^2, for Washington, DC, USA for Baseline and Four Climate Change Scenarios

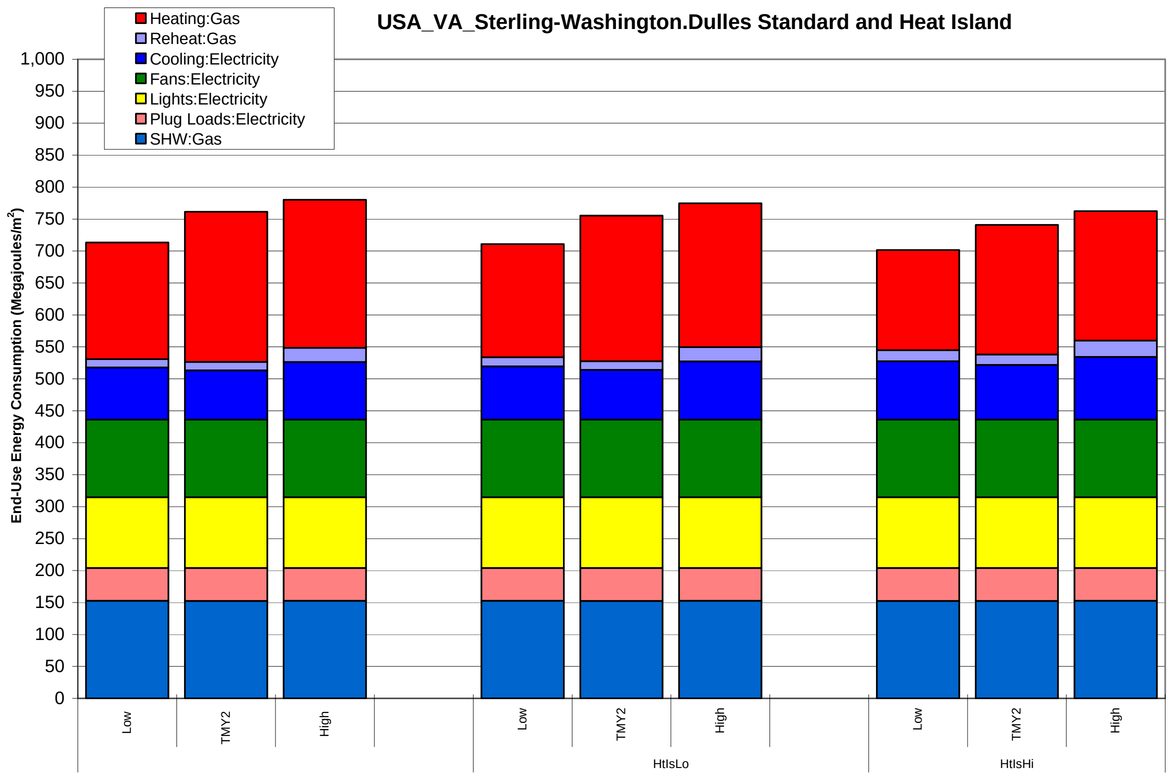

Figure 5. Predicted Annual Energy Energy-Use Consumption, in MJ/m^2, for Small Office Building in Washington, DC, USA for Baseline and High and Low Heat Island Cases

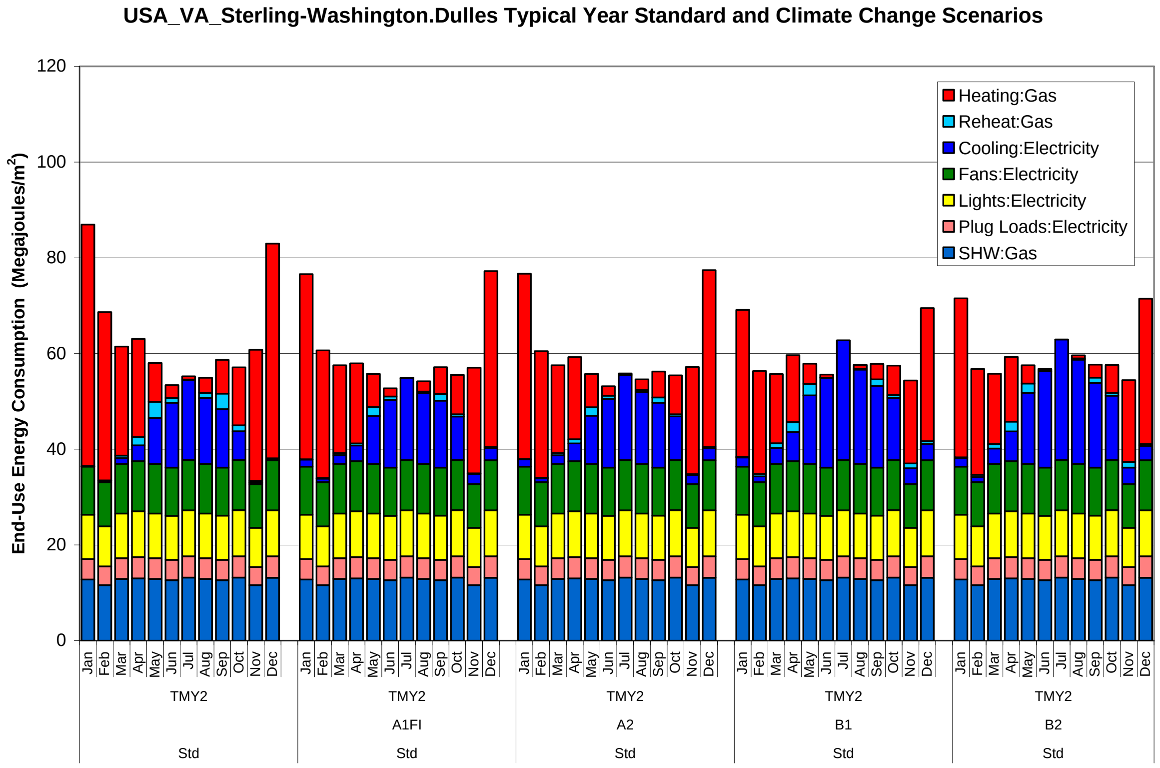

Figure 6. Predicted Monthly Energy Energy-Use Consumption, in MJ/m^2, for Small Office Building in Washington, DC, USA for Baseline and Four Climate Change Scenarios

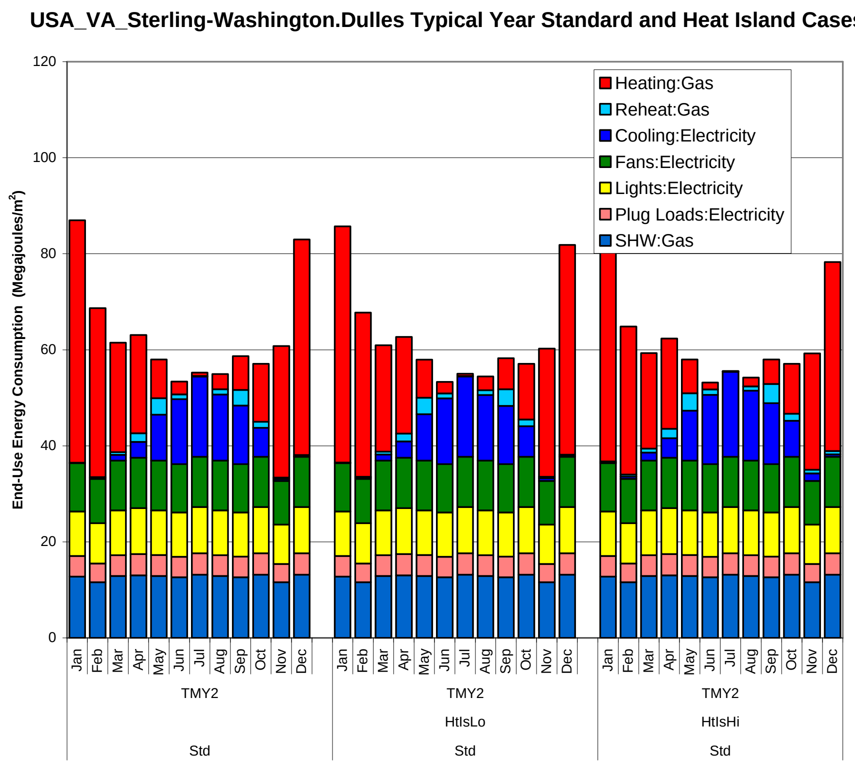

Figure 7. Predicted Monthly Energy Energy-Use Consumption, in MJ/m^2, for Small Office Building in Washington, DC, USA for Baseline and High and Low Heat Island Cases

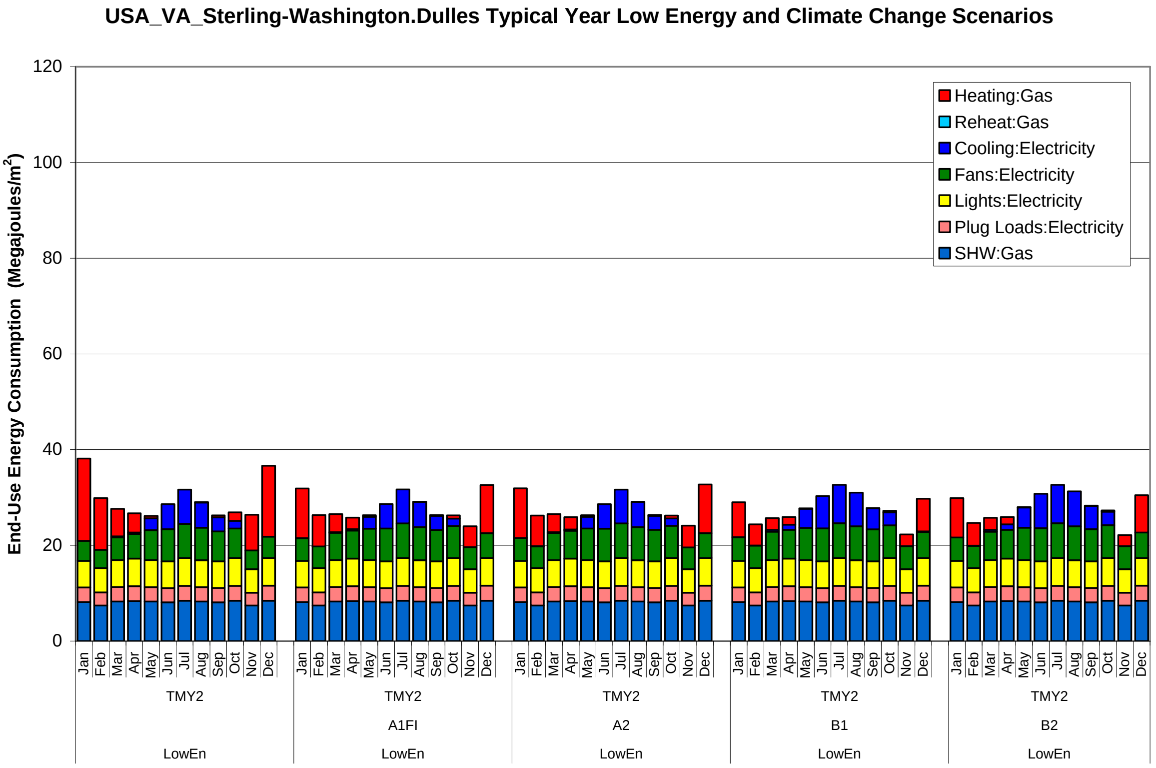

Figure 8. Predicted Monthly Energy Energy-Use Consumption, in MJ/m^2, for Small Office Building in Washington, DC, USA for Baseline and Four Climate Change Scenarios

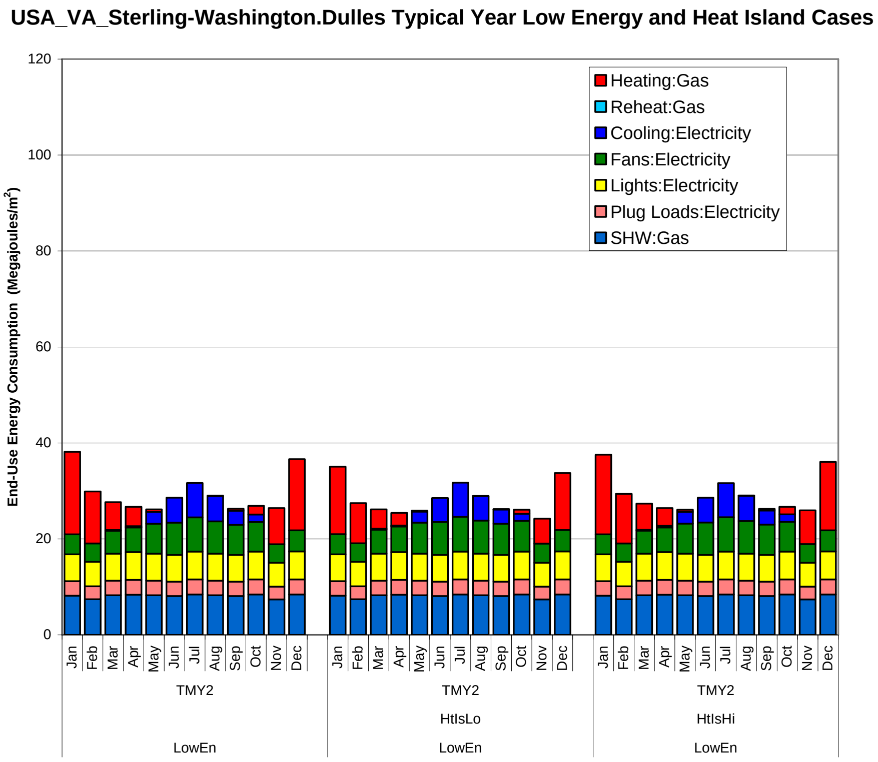

Figure 9. Predicted Monthly Energy Energy-Use Consumption, in MJ/m^2, for Small Office Building in Washington, DC, USA for Baseline and High and Low Heat Island Cases