

# Energy Demands for Commercial Buildings with Climate Variability Based on Emission Scenarios

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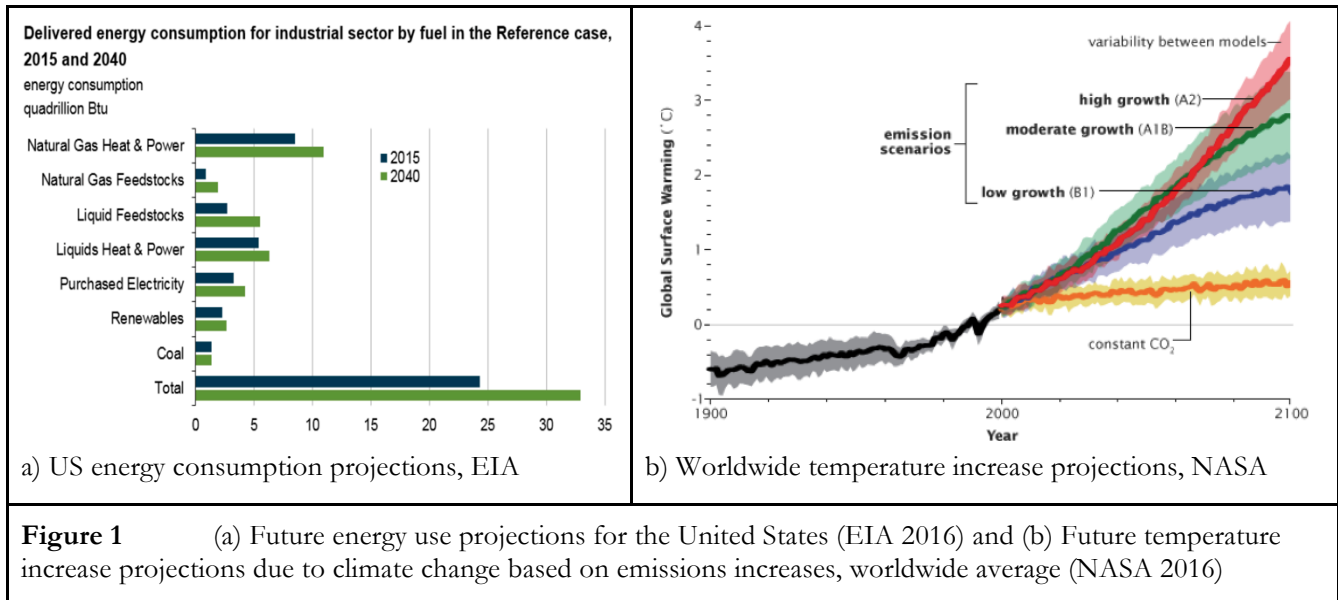
## ABSTRACT

*The impacts of a changing climate are wide-ranging in both impact and scope. This paper investigates the effect that realistic climate variability would have on building energy demands in Salt Lake City, UT to inform planning for air quality impacts. Energy demand scenarios were derived using climate projections through the year 2040, at two different scales: individual model buildings, representing recent construction codes; and a group of actual buildings in the central business district of Salt Lake City, encompassing a primarily commercial set of the existing building stock. Current weather data observations and future weather based on climate predictions were obtained from Atmospheric Sciences researchers at the University of Utah. The corresponding changes in energy consumption are illustrated using detailed building energy modeling (BEM) for the three representative individual model buildings: large and small office buildings and a hospital. Then changes in energy consumption are modeled using simplified BEM for the group of actual buildings. Finally, related changes in associated building-related emissions of CO<sub>2</sub> are presented. Results indicate that both direct and indirect emissions tend to increase as the climate warms and temperature variability increases. However, heating load decreases under these climate variability scenarios, which may result in small decreases in direct emissions, for gas heating, or indirect emissions, for electrical heating.*

## INTRODUCTION

The energy consumed by the U.S. commercial sector, as of 2016, is 18 quads, and is projected to increase up to 21 quads by 2040 (U.S. Energy Information Administration 2016). As Fig. 1(a) shows, energy intensity is expected to decrease as a result of efficiency standards and technological progress, even though miscellaneous electric loads are expected to grow (U.S. Energy Information Administration 2016). Total energy consumption will still increase because of population growth and building stock expansion. These projections, though, are business-as-usual estimates, considering the current state of knowledge and technology. Building energy models and technologies were developed in a more moderate climate system than that predicted for the future. Earth surface temperature is projected to increase by 2 to 6°C (3.6-10.8°F) by the end of the 21st century, as shown in Figure 1(b) (National Aeronautics and Space Administration 2016). Because climate predictions are more difficult at smaller time scales and longer time periods (Lean and Rind 2008), we consider the time period from the present to 2040, and assume that the temperature rise in this region will reflect the global average. If worldwide CO<sub>2</sub> emissions remained constant through 2040, the average temperature rise would remain under 1°C, while a moderate to high growth in emissions could result in a temperature rise of 1°C or slightly higher (National Aeronautics and Space Administration 2016).

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Without considering the effects of temperature increases and new temperature extremes, building designers, managers and engineers cannot capture the technological responses of existing or future structures. Many previous studies have been conducted, using different projections, which have resulted in contradictory scenarios for the impact of climate change on building energy loads. Scott et. al. (1994) investigated this, and they suggest environmental factors, such as humidity, solar radiation and wind speed strongly influence this impact. However, they show the relationship between ground temperature increase and building energy loads as nonlinear being influenced by climate change as well. It has been noted how northern regions in the U.S. will likely have decreasing building energy needs, with greater reductions in end-use heating than the corresponding increase in cooling needs. Southern regions would have the opposite trend (Hadley et al. 2006). As stated by Belzer et al. in 1996 (Belzer et al. 1996): "Engineering models linked to a large statistical sample of buildings may be necessary to answer to these questions." This approach is a logical next step in a more rigorous investigation of this issue.

Due to its geographic situation and rapid urban growth, the Salt Lake Valley in Utah is highly concerned about energy intensity and associated emissions, primarily due to air quality concerns. The mountains surrounding the valley and winter time cold air pools create a trap that frequently allows for air pollutants to build up and collect at or near ground level. Global climate change is a significant concern for the U.S. Southwest as a whole (U.S. EPA Climate Change Division 2012). The temperate Zone 5, Subtype B climate of Salt Lake City, which requires significant cooling and heating on an annual basis, makes for an interesting study of the effects of temperature extremes. Finally, the quality of weather data available (University of Utah Department of Atmospheric Sciences 2016; National Oceanic & Atmospheric Administration 2016) in this location allows for the use of highly accurate actual meteorological year weather data to drive the building simulations.

## METHODS

Energy demand scenarios were investigated for the current (2015) and future (until 2040) climate in Salt Lake City. Because future climate predictions depend on the model(s) used and the scenarios which drive them, a moderate emissions growth scenario was used to perform building simulations every five years through 2040, with alternate scenarios considered in the year 2040, for which the change in energy demands relative to 2015 was greatest. These energy demand scenarios are modeled at two different scales: (1) individual buildings: large office, small office, and hospital prototypes, representing current construction codes; and (2) a city block of the central business district of Salt Lake City, encompassing a mixed-use group of buildings in the existing building stock.

## Weather Data for Energy Modeling

**Current Weather (Existing Weather Data).** To represent the recent climate in Salt Lake City, actual measured weather observations from 2015 were used to drive the building energy simulations. Weather measurements, including

dry bulb temperature, were obtained from the MesoWest atmospheric monitoring network (University of Utah Department of Atmospheric Sciences 2016), with the exception of radiation data, which was obtained from the National Oceanic and Atmospheric Administration's Integrated Surface Irradiance Study (National Oceanic and Atmospheric Administration 2005).

**Future Weather (Projected Weather Data).** To represent the future climate in Salt Lake City, the most recent existing weather data (2015) was adjusted according to compiled climate model estimates (National Aeronautics and Space Administration 2016) as follows: New weather data files were created every five years until 2040 using the expected temperature rise under a moderate emissions growth scenario, and to capture different potential trajectories for climate change during this period, additional weather files were created for 2040 to represent the lowest and highest emissions growth scenarios, along with the constant CO<sub>2</sub> emissions scenario.

### Building Energy Modeling for Individual Buildings

Building energy modeling for the individual simulations was conducted with EnergyPlus (EP), a free, open-source software package developed by the DOE (U.S. Department of Energy 2016), using example building files to illustrate the impacts of temperature variations on buildings of recent construction. The U.S. Department of Energy (DOE) and Pacific Northwest National Laboratory developed 16 commercial prototype building models (U.S. DOE Office of Energy Efficiency and Renewable Energy, 2016), covering 80% of the commercial building stock for new construction in the United States, across all the American climate zones. These prototype buildings are modeled according to the ANSI/ASHRAE/IES Standard 90.1-2010 and have been customized for all eight U.S. climate zones. Three commercial building models have been modeled in Salt Lake City, UT for this work. These specific building models have been chosen in order to comprise different power-heat ratios and different load curves for electricity and fuel usage. This will indicate how, under the study conditions, different weather conditions affect building energy loads across building types.

### Simplified Energy Modeling for a Business District

Building energy simulations for the district simulations have been conducted using the aggregated totals from eQUEST simulations. eQUEST is also a free, open-source software package that was initially supported by the DOE and is based on the DOE-2 simulation engine (JJ Hirsch & Associates 2012).

Although EP is designed to deal with more complex systems and provides more accurate results, eQUEST is quicker and more popular in the business world.

eQUEST similarly uses input files describing building properties and local weather, but generally represents less detailed physics and requires less detailed information to run a simulation. Here, settings were customized to represent the actual buildings on the block as closely as possible according to parcel data. The exact same weather data was used for these simulations as was used for the EP simulations, but it was converted to the appropriate format for the eQUEST software.

The modeling approach is derived from the Hestia project, an advanced bottom-up emissions inventory initially developed for the city of Indianapolis, and recently completed for Salt Lake City (Patarasuk et al., 2016). The current Hestia model uses a set of



**Figure 2** Selected study area for a group of existing buildings in the downtown business district of Salt Lake City.

classifications for residential (U.S. DOE 2016b) and commercial (U.S. DOE 2016a) buildings to attribute a non-electric energy use intensity, NE-EUI (fuel usage) on a per-area basis (in kWh/m<sup>2</sup>) (Gurney et al. 2012). While these values are derived from eQUEST building energy models, the absolute values for energy consumption are not used in the Hestia model, and because upstream emissions are excluded (Gurney et al. 2012), electricity use is not provided by

Hestia. Therefore, we present a modified method using more detailed individual building models for a selected area to evaluate the effects of temperature extremes in an energy-dense block of the urban environment. Inter-building effects such as the urban heat island and building shadowing are not accounted for here, but these topics are the subject of previous and ongoing investigations by the authors and their collaborators, and are planned for inclusion in future iterations of the modeling method.

The district chosen as the study area is one city block in central Salt Lake City, as illustrated in Figure 2. It contains a dense mix of heavy-use buildings, including offices, an apartment complex, and retail space, with buildings constructed between 1880 and 2011.

### Emissions Calculations

To evaluate the emissions associated with energy consumption of the modeled buildings, direct emissions were assumed to result from natural gas combustion on site and indirect emissions from electricity purchased from the local grid. The resulting CO<sub>2</sub> emissions from gas combustion are provided here based on the method used by the U.S. Environmental Protection Agency (U.S. EPA Center for Corporate Climate Leadership 2016), with an emissions factor of 53.06 kg CO<sub>2</sub>/MMBTU<sub>gas</sub>. The resulting CO<sub>2</sub> emissions from electricity purchases are highly dependent on the time-varying fuel mix used to generate electricity sold on the grid, but they are provided here based on the average expected CO<sub>2</sub> emissions associated with the generation mix used by Rocky Mountain Power (PacifiCorp) with an emissions factor of 1,824.5 lb CO<sub>2</sub>/MWh<sub>elec</sub>. (Diem and Quiroz 2012).

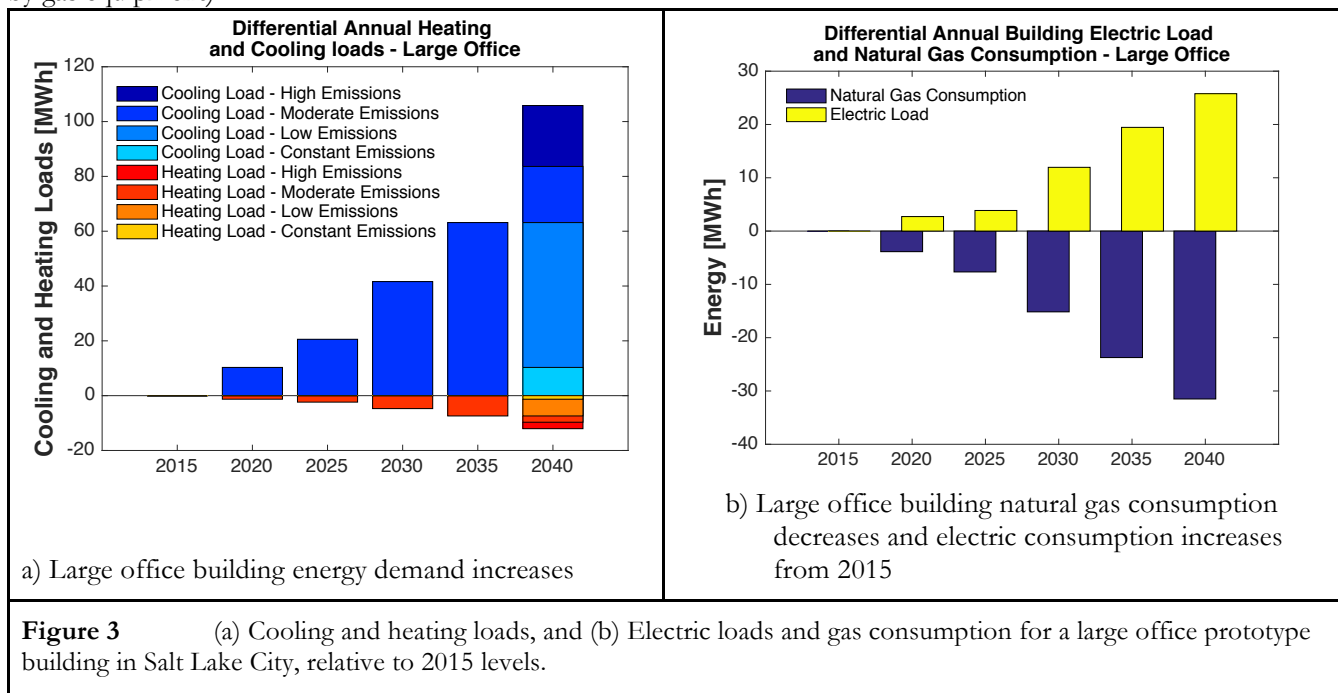
## RESULTS

### Individual Buildings

To highlight the changes in energy demands due to the climate variability present in the future year weather files, the results in Figs. 3-7 below are presented relative to 2015: the building was first simulated with actual meteorological data from 2015, and then with the subsequent weather files, all other parameters held constant.

#### Large Office

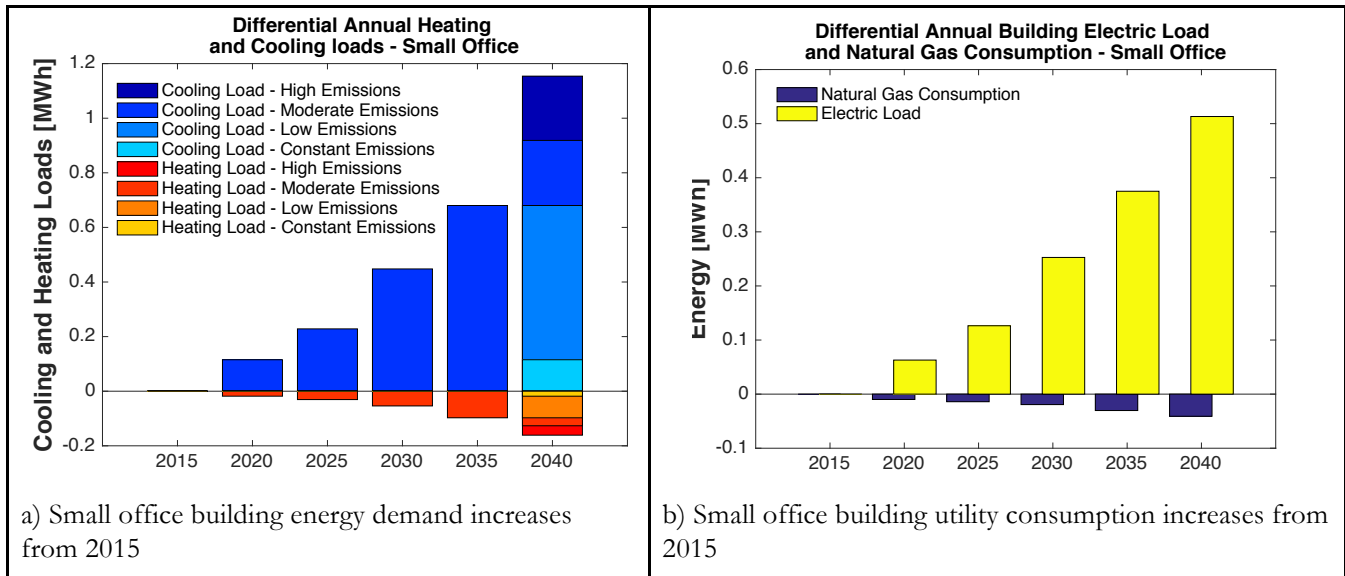
The large office model represents a 46,320 m<sup>2</sup> (498,584 ft<sup>2</sup>) commercial office building facility. Climate variability under the moderate emissions scenario would result in increased electricity consumption and decreased gas consumption, due to increased cooling loads (met by electrical equipment) and decreased heating loads (primarily met by gas equipment).



**Figure 3** (a) Cooling and heating loads, and (b) Electric loads and gas consumption for a large office prototype building in Salt Lake City, relative to 2015 levels.

### Small Office

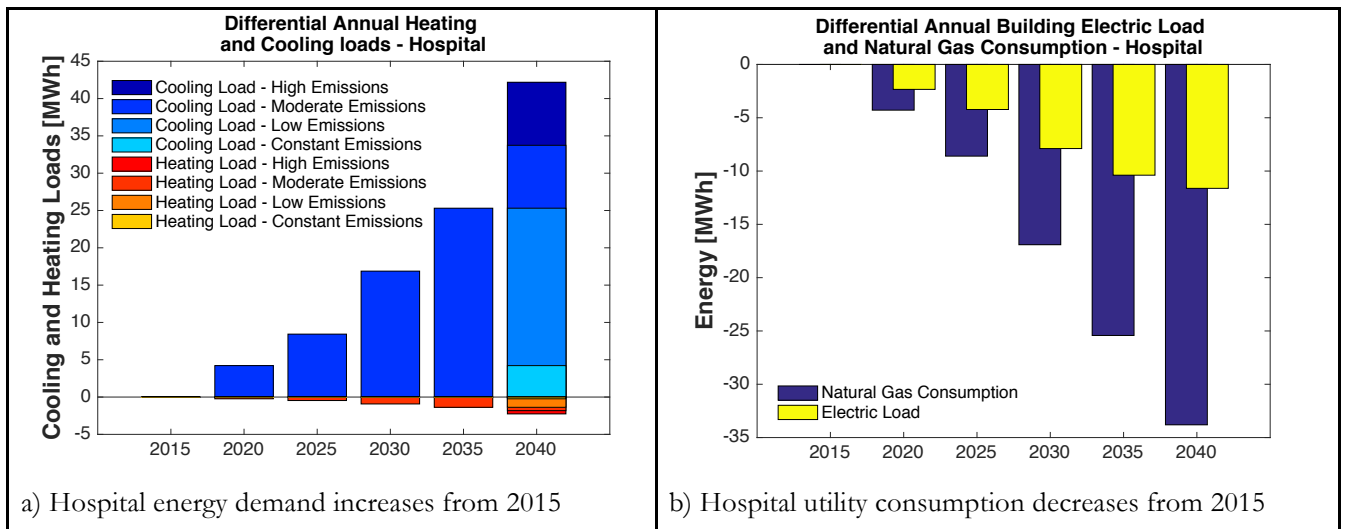
The small office model represents a much smaller and simpler 511 m<sup>2</sup> (5,500 ft<sup>2</sup>) commercial office building facility. Climate variability under the moderate emissions scenario would again result in increased electricity consumption and decreased gas consumption. However, the increases in electricity usage are significant while the decreases in gas usage are so small as to be almost negligible (less than 50 kWh additional in 2040). This is due to a high power-to-heat ratio in the demand patterns of the small office prototype, which is also related to its high skin ratio, or surface area to internal volume. It is therefore highly impacted by the temperature and cooling load increases.



**Figure 4** (a) Cooling and heating loads, and (b) Electric loads and gas consumption for a small office prototype building in Salt Lake City, relative to 2015 levels.

### Hospital

The hospital model represents a 3739 m<sup>2</sup> (40, 246 ft<sup>2</sup>) healthcare facility with significant energy consumption, particularly electrical demands due to heavy equipment and high occupancy.



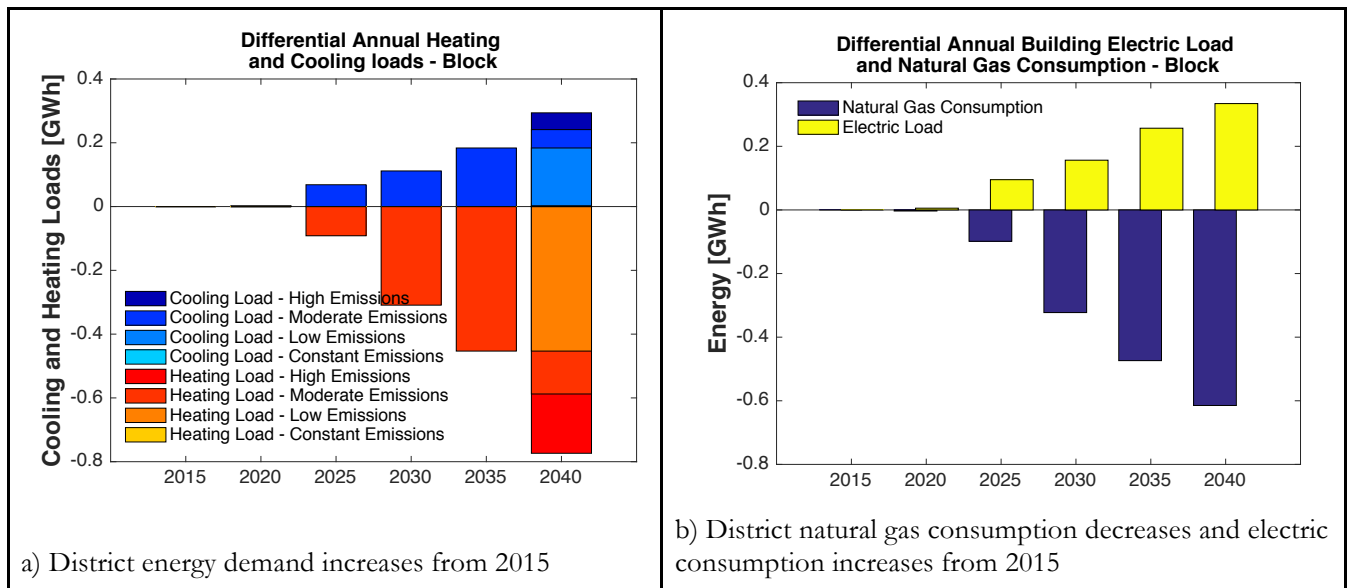
**Figure 5** (a) Cooling and heating loads, and (b) Electric loads and gas consumption for a hospital prototype building in Salt Lake City, relative to 2015 levels.

Climate variability (increased temperatures and temperature extremes) under the moderate emissions scenario would result in increased cooling loads, as with the office buildings, and a slight decrease in heating loads. However, the hospital uses a large quantity of electricity for non-heating or non-cooling purposes, and meets a large portion of heating needs using electricity. Therefore, future years show decreases to gas consumption, as before, but also minor decreases to electricity consumption due to an overall decrease in heating loads and a decrease in electricity used for dehumidification.

### Business District

The business district represents a square block of downtown Salt Lake City, as described above in “Simplified Energy Modeling for a Business District.” Climate variability under the moderate emissions scenario would result in increased electricity consumption and decreased gas consumption, similarly to the commercial prototype building model simulations.

However, differently from the large office and the hospital models, for the business district the cooling load is supplied by electric power and the heating load is supplied by natural gas. This coupling allows to have the same trends for cooling load and electric power and for heating load and natural gas. Therefore, increased cooling loads are met by electrical equipment, and result in increased electricity usage; decreased heating loads require less gas, and result in decreased natural gas consumption, as shown in Figure 6.

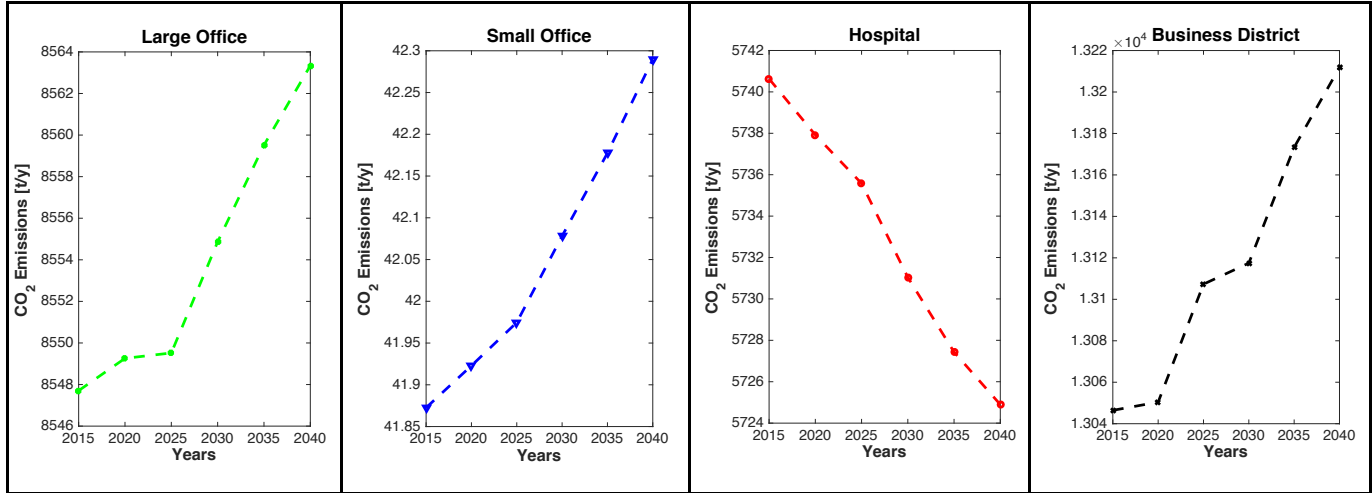


**Figure 6** (a) Cooling and heating loads, and (b) Electric loads and gas consumption for a group of mixed use buildings (see Figure 2) in a mixed-use district of downtown Salt Lake City, relative to 2015 levels.

Compared with the heating load for the hospital model, the heating load for the business district is going to be highly reduced. This is due to the very different power-heat ratio that characterizes the buildings in the business district, with respect to the power-heat ratio of the hospital.

### CO<sub>2</sub> Emissions

Overall CO<sub>2</sub> emissions are presented in Figure 7. Although the graphs here represent both direct and indirect emissions, direct emissions are the result of gas combustion and indirect emissions are the result of electrical purchases. The emissions factors used will influence the magnitude of these emissions, though not the general shape of the curves shown below. In each building except the hospital, emissions increase each year, with the 2030-2040 period being most pronounced in terms of steady increase due to additional electrical usage (and therefore indirect emissions). Because both electricity and gas consumption decrease for the hospital, it actually reduces emissions.



**Figure 7** CO<sub>2</sub> emission trends for large office, small office, hospital and business district.

## DISCUSSION AND CONCLUSION

The impacts of climate change, in terms of both energy consumption and emissions, are highly dependent on the actual technologies used to meet energy needs. Because climate change results in higher average temperatures and increased weather variability throughout the year, temperate climates will face increases in overall cooling demands and decreases in overall heating demands. These decreases in heating, though, are smaller in magnitude than the change in cooling demand.

Cooling demands are typically met by electrical equipment, which means increased electricity usage under the climate scenarios shown. The emissions associated with electricity purchases, however, is highly dependent on the nature of the generators used to provide electricity to the grid, so that a decrease in the emissions intensity of the grid could mitigate the increase in indirect emissions.

Heating demands are often, but not always, met by natural gas combustion equipment. Interestingly, when electricity is used to meet heating loads, electricity usage will reduce in a warmer climate because of decreased need for heating over the year. In each case, the decreased need for heating results in a decreased need for natural gas combustion, although this is a relatively small effect.

In Salt Lake City, direct emissions are a major health concern due to air quality issues, and almost all indirect emissions occur outside of the city's airshed at distant power generation stations. For such a location, reducing or mitigating increases in local emissions may take priority over reducing or mitigating increases in electricity consumption. Because both gas and electricity consumption for heating will decrease as the ambient temperature rises, a shift toward a mixture of gas and electric heating could be beneficial for reducing or mitigating locally emitted pollutants from buildings. If the emissions intensity of the electrical grid is high, though, this could result in increased emissions overall when compared with a primarily combustion-driven pool of heating equipment.

## ACKNOWLEDGMENTS

This material is based upon work supported by the National Science Foundation under the following grants: CBET 1512740 and 1137336 and the National Oceanic and Atmospheric Administration NA14OAR4310178.

## NOMENCLATURE

BEM	Building Energy Modeling
DOE	U.S. Department of Energy
EIA	U.S. Energy Information Administration
NASA	U.S. National Aeronautics & Space Administration

## SUBSCRIPTS

<i>elec</i>	=	electricity purchased from the grid
<i>gas</i>	=	natural gas consumed for on-site combust

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