Analysis of the Impact of Urban Heat Island on Energy consumption of Buildings in Phoenix

By

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ABSTRACT

The Urban Heat Island (UHI) has been known to have been around from as long as people have been urbanizing. The growth and conglomeration of cities in the past century has caused an increase in the intensity and impact of Urban Heat Island, causing significant changes to the micro-climate and causing imbalances in the temperature patterns of cities. The urban heat island (UHI) is a well established phenomenon and it has been attributed to the reduced heating loads and increased cooling loads, impacting the total energy consumption of affected buildings in all climatic regions. This thesis endeavors to understand the impact of the urban heat island on the typical buildings in the Phoenix Metropolitan region through an annual energy simulation process spanning through the years 1950 to 2005. Phoenix, as a representative city for the hot-arid cooling-dominated region, would be an interesting example to see how the reduction in heating energy consumption offsets the increased demand for cooling energy in the building. The commercial reference building models from the Department of Energy have been used to simulate commercial building stock, while for the residential stock a representative residential model prescribing to IECC 2006 standards will be used. The multiyear simulation process will bring forth the energy consumptions of various building typologies, thus highlighting differing impacts on the various building typologies. A vigorous analysis is performed to see the impact on the cooling loads annually, specifically during summer and summer nights,

when the impact of the 'atmospheric canopy layer' - urban heat island (UHI) causes an increase in the summer night time minimum and night time average temperatures. This study also shows the disparity in results of annual simulations run utilizing a typical meteorological year (TMY) weather file, to that of the current recorded weather data. The under prediction due to the use of TMY would translate to higher or lower predicted energy savings in the future years, for changes made to the efficiencies of the cooling or heating systems and thermal performance of the built-forms. The change in energy usage patterns caused by higher cooling energy and lesser heating energy consumptions could influence future policies and energy conservation standards. This study could also be utilized to understand the impacts of the equipment sizing protocols currently adopted, equipment use and longevity and fuel swapping as heating cooling ratios change.

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TABLE OF CONTENTS

Page

CHAPTER Page

LIST OF TABLES

Table | Page

LIST OF FIGURES

Figure Page

Figure Page

Figure Page

Figure Page

Figure | Page

Chapter 1

1. INTRODUCTION

Urbanization trends have been closely linked to modernization, industrialization and the movement from an agrarian society to industrial and more recently post-industrial societies. As the industrial revolution that started in England spread throughout Europe and eventually in United States, The United states completed its transformation from a rural to an urban nation between 1820 and 1920 (Kim). In 1820, the great majority or 93% of the population lived in rural areas; by 1920, a majority or 51% resided in cities. In the succeeding decades, the share of urban population rose modestly to 57% in 1940 and then to 64% in 1960 (Kim, 1999) and as of year 2010 stands at 82%. Thus see that highest urban growth has occurred in the twentieth century, during which time unprecedented growth of cities and conglomeration of cities into metropolitan regions in the south and southwest, has led to development of the Sunbelt Cities.

The impact population growth and urbanization cannot be seen as clearly in any part of the United States than in the Southwest. Arizona has seen an increase in population of 2,880% over the last 90years leading even the state of Nevada that posted a 2,840% increase (Chourre & Wright, 2004). The city of Phoenix founded in 1870's is located at 33˚North and 112˚West, started off as a small farming community and was surrounded by other small farming communities like Hayden Ferry (now known as City of Tempe) and Mesa, but has developed into one of the biggest cities and as a anchor of the Phoenix Metropolitan region. Maricopa County (Phoenix), accounts for a majority of the growth in Arizona, with a 100year growth rate of 10, 275% with most that growth occurring between 1960 and 1990. (Chourre & Wright, 2004) There have been many socio-economic, political influences for the unprecedented growth. Industrialization during and post World War II (http://en.wikipedia.org/wiki/Phoenix,_Arizona) started a steady migration towards the Southwest by the pioneers, but the harsh climatic conditions especially the unrelenting summer heat had prevented the large scale growth and migration. By the late 20th century increased availability of inexpensive electricity and widespread adoption of inventions like the air conditioner helped overcome the harsh environmental conditions affecting a year-round settlement (http://pubs.usgs.gov/circ/2004/circ1252/) leading to the growth boom during 1960 to 1990.

The sustained growth patterns, low-density urbanization of the Phoenix Metropolitan region, which now includes eight other cities – Chandler, Gilbert, Glendale, Mesa, Peoria, Scottsdale, Surprise, Tempe; has caused pressures on the environment and the micro-climate of the region including but not limited to water issues, demand for electricity (especially for air conditioning) and Urban Heat Island a phenomenon that's has been for long ignored. The impact of the Urban Heat Island phenomenon in the Phoenix Metropolitan Region, which falls under Hot-

Dry climatic zone according to the Ashrae, is different from its usual characterization as seen in the general literature (**Error! Reference source not found.Error! Reference source not found.**) and in other climatic conditions due to the fact that its outskirts is mostly comprised of barren desert lands.

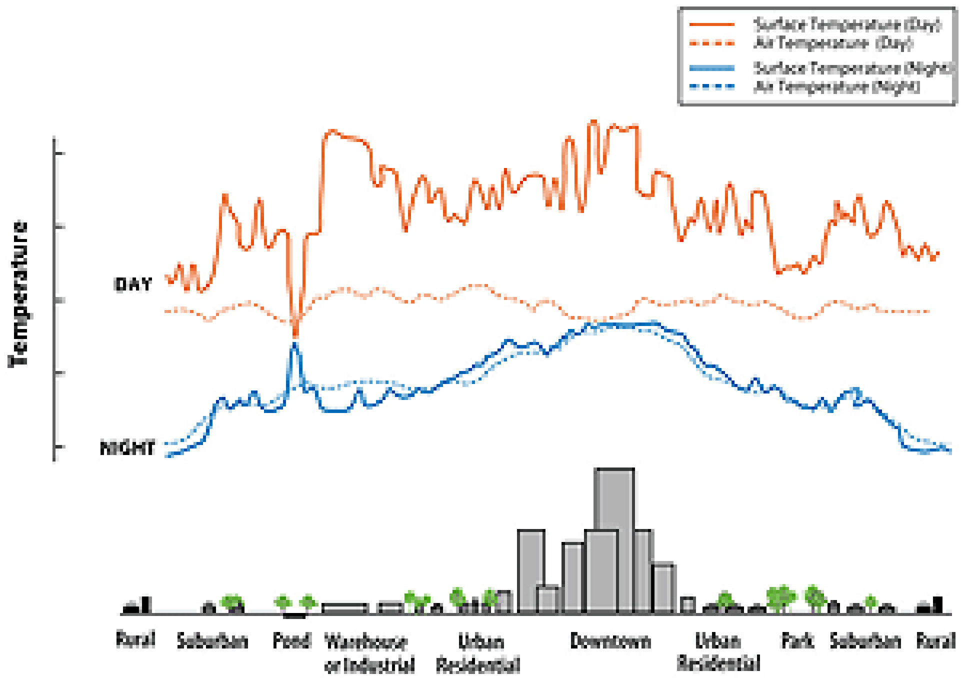


Figure 2.3.1-1: Diurnal temperature swing in a typical city experiencingUrban Heat Island

1.1 Urban Heat Island

The distinct climatic patterns exclusive of cities have been a subject of study from as early nineteenth century in London when Howard L. first wrote about the disparity in temperature of the urban core and the surrounding farm lands (Howard, 1833). The term 'Urban Heat Island' or 'UHI' was coined by Gordon Manley in the late 1950's (Landsberg, 1981). The research in the later years focused on the energetic processes of the urban heat island, especially the work done by Dr. T.R. Oke in the field of urban climatology.

As we try to understand the phenomenon of urban heat island and its impact on the energy consumption patterns of the built forms, it is imperative for us to understand and define the boundaries of the constituent elements that are part of the urban energy balance. Literature reviews shows two main classifications - surface and atmospheric urban heat islands, with the atmospheric urban heat island subdivided into the Urban Canopy Layer (UCL) and the Urban Boundary Layer (UBL) (Reducing Urban Heat Islands: Compendium of Strategies - Urban Heat Island Basics, 2009) (OKE, 1988).

a. Surface Urban Heat Island

As urban areas develop, the physical characteristics of the ground surfaces are modified by human interventions, with the replacement of open lands and vegetation with buildings, roads, pavements and other infrastructure whose thermal properties are very different. These surfaces tend to have surface temperature 27 to 50˚C higher than the ambient air temperatures (Reducing Urban Heat Islands: Compendium of Strategies - Urban Heat Island Basics, 2009). Although the Surface Urban Heat Island has a significant impact on energy consumption of buildings, it is highly site specific phenomenon and is characterized by the infrastructure surrounding the areas of contention, hence it is difficult to generalize it to an urban scale.

b. Atmospheric urban heat island

The volume directly above any urbanized land that has a direct influence on the urban energy balance is known as the Atmospheric Urban Heat Island. This is further subdivided into two distinct layers. Urban Canopy Layer and Urban Boundary Layer (OKE, 1988), with distinctive impacts on the energy consumption of the buildings and the microclimate –

- **Urban canopy layer** – the layer from the ground to the roof-level in an urban condition is defined as the urban canopy layer (UCL) and is dominated by the microscale effects of the site's physical and thermal characteristics. It is in this layer that most of the microclimatic observations are made, which includes data recorded from standard climate weather stations and those recorded through mobile traverses. The UCL is significant in areas of high building density; it may tend to be discontinuous or absent, in suburban areas or areas with extremely low density. The Urban Heat Island influences in this layer affects the built-form significantly can be tracked down through historical weather data available through weather stations in the urban realm.

- **Urban Boundary Layer** – the boundaries of the UBL layer extends from the top of the UCL, to a point vertically above where the influence of the urban surface is no longer significantly perceptible and typically extends to no more than one mile (1.5km) from the surface.

The basic characteristics of Surface and Atmospheric Urban Heat Islands (UHIs) are represented in a tabular form in Table 1-1 (Climate Protection Partnership Division in the U.S. Environmental Protection Agency's Office of Atmospheric Programs, 2009).

Table 1-1: Basic Characteristics of Surface and Atmospheric Urban Heat Islands (UHIs)

Feature	Surface UHI	Atmospheric UHI
Temporal Development	• Present at all times of the day and night • Most intense during the day and in the summer	• May be small or non-existent during the day • Most intense at night or predawn and in the winter
Peak Intensity (Most intense UHI conditions)	More spatial and temporal variation: • Day: 10 to 15˚C (18 to 27˚F) • Night: 5 to 10˚C (9 to 18˚F)	Less variation: • Day: -1 to 3˚C (-1.8 to 5.4˚F) • Night: 7 to 12˚C (12.6 to 21.6˚F)

Typical Identification Method	Indirect measurement: • Remote sensing	Direct measurement: • Fixed weather stations • Mobile traverses
Typical Depiction	Thermal image	• Isotherm map • Temperature graph

The tremendous interest in understanding the phenomenon of Urban Heat Island is due to the fact that it has an impact on the human health and comfort, air quality, water quality and is the cause of drastic changes in the energy consumption patterns in built-forms.

1.2 Impact of Urban heat Island (UHI) in Phoenix

Rapidly urbanizing regions have been seen to have the most rapidly changing microclimate on earth, and Phoenix Metropolitan region, one of the fastest growing regions in the US and in the world, has been known to have one of the largest urban climate effects (microclimatic variations due to Urban Heat Island (UHI) effects) in the world (Hansen., Ruedy, Glascoe, & Sato, 1999). For the first time in the last century the night-time minimum low of 35.6℃ was recorded on July 17, 2003 and the city has been experiencing a minimum temperature rise of 0.47℃ per decade from 1960-2000 (Hedquis, Brazel, Sabatino, Carter, & Fernando). Phoenix, Arizona is characterized by a daytime 'oasis' effect and a very strong hysteresis lag effect at night, this is fairly unique to this region.

Owing to practical difficulties in measuring the influence of urbanization (measure with the urban growth and the same place in without the urbanity), several other common approaches have been outlined in various literature studies to characterize the magnitude of the urban effect. Weather data collection through mobile traverses using a automobile-mounted sensors, accessing remotely sensed thermal images, developing weather-network spatial interpolations, conducting time-trend analyses of key sites and calculating urban and rural site differences are some of the methods. Phoenix urban heat island experiment: micrometeorological aspects (Hedquist, Brazel, Sabatino, & Fernando, 2009) details the mobile traverse methodology used to collect surface and ambient temperatures within various landscapes in central Phoenix Arizona to show variations in temperatures within an urban center due to UHI.

A study by (Brazel, Nancy, Vose, & Heisler, 2000) has shown an intra-urban variability in maximum and minimum temperatures in the order of 1-2℃ and 6℃ respectively, for a dry month – May, data being acquired from several urban sites in Phoenix. Hawkins et.al (Hawkins, Brazel, Stefanov, Bigler, & Saffell, 2004) in their study to determine the Urban Heat Island (UHI) using the rural variability methodology in their study, showed that the average urban heat island of 11℃ and a maximum of 12.6℃ existed during the period of study.

These variations in day and night time temperatures has led to increased energy consumption of buildings especially in meeting the increased cooling loads.

1.3 Objective

The objective of the study is to

- Quantify the changes in energy consumption patterns through an annual energy simulation process spanning the years 1950 to 2005, in the representative set of commercial building types and a typical residence, due the impact of Urban Heat Island Effect in Phoenix a hot-arid cooling dominated region utilizing the acquired recorded weather data.
- To show that the result of such studies could be utilized for targeted and informed energy efficiency programs that focus on those building typologies which show greater impact due to the changes in the micro-climate due to UHI.
- To document the methodologies and processes, to enable similar studies in other cities in hot-arid or other climatic regions.
- To act as a base for a national level enquiry through a ‘bottom-up’ engineering estimate of the impact of Urban Heat Island on the U.S. Building stock.

- To predict the changes in the building loads with the help of climate change scenario based synthetic weather files created through the IPCC protocols for the milestone years (2020, 2050, 2080), to enable policy decisions regarding fuel switching, CO_2 emissions and equipment sizing protocols.
- To discuss the variations/anomalies in the results of annual energy simulation runs while using a representative weather pattern e.g., Typical Meteorological Year (TMY) building the case for utilization normalized weather data from a shorter range of representative years (to better account for local weather phenomenon like UHI and global warming).
- Focusing the impact of the micro-climatic changes to the urban environment due to Urban Heat Island (UHI) on the building sector, building energy loads as the building sector forms a major chunk of the total energy consumption and is the only sector affected directly.

1.4 Scope and Limitations

- Potentially the underlying methodology in the project could be utilized to understand the true impact of Urban Heat Island on the energy consumption patterns for the Phoenix Metropolitan Region, but the inability to model the true representative buildings of various types and vintages limits the scope of the project to show the magnitude of increase/decrease in the energy consumption in each of the representative commercial building types and the residential building.

- It is difficult isolate the change microclimate due to UHI from the global changes in weather patterns that influence the weather conditions of the city, thus only informed conclusions can be made regarding the actual magnitude of the influence of UHI in the energy consumption patterns of the Building.
- 90.1 prototype building models (prototype models) developed by PNNL, for Phoenix region have been used in the study for the commercial buildings, while for the residential building type a IECC 2007 complaint building has been modeled. Thus the ability of the model to closely mimic the stock of buildings existing in the city is minimal and any conclusions thus arrived at would only be representative to the actual impact on the existing buildings with a higher or lower magnitude depending on the variation from the model under study.

Chapter 2

2 METHODOLOGY

Introduction

The study involves gathering and processing of the annual recorded weather data, selection of representative commercial reference buildings, building of the IECC 2007 complaint residential model, keeping the model definitions same annual simulations are carried out for multiple years starting from 1950 until 2005 (period of study) to understand the impact of Urban Heat Island (UHI) on the various building typologies.

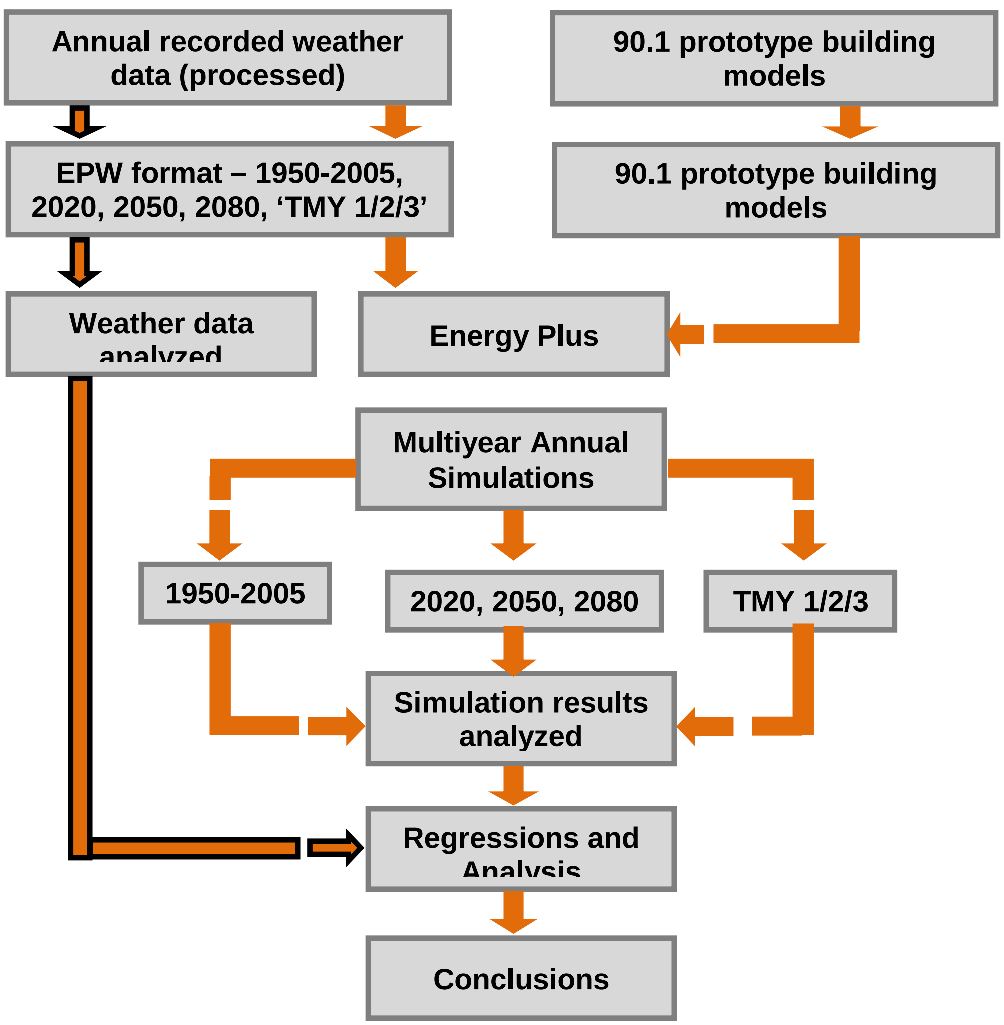


Figure 2.3.1-1: Process Diagram of the study

Annual energy simulations were also carried for each of the typical building types with three vintages of the Typical Meteorological Year (TMY) files TMY1, TMY2 and TMY3. Future climate change weather files generated through the climate change world weather file generator (CCWorldWeatherGen) gave weather files for years 2020, 2050 and 2080 which also became a part of the overall study.

2.1 Weather data

Annual recorded weather data

Surface Airways Hourly Observations – ASOS, recorded at Phoenix (33.4 N and -111.9 W) and archived at the National Climatic Data Center; was acquired through Earth Info Inc (http://www.earthinfo.com). This data set contains hourly surface weather observations recorded midnight to midnight for the 24-hour period. The major data parameters are clouds, visibility, wind, temperature, sky cover, relative humidity, pressure and descriptive weather (National Center for Atmospheric Research). The data thus received has to be reformatted into the EPW which is the chosen format to run simulations through EnergyPlus, with the help of the Weather converter program available and with other components of EnergyPlus simulations software. This utility also makes the necessary calculations for interpolating data for missing values and calculates the illumination data- a value not typically recorded by the meteorological stations. It also generates a statistical analysis file for a quick overview of the year's weather conditions.

Typical Meteorological year (TMY1, TMY2 and TMY3)

TMY files are a concatenation of representative months selected through an empirical approach from statistics determined by using five elements: global horizontal radiation, direct normal radiation, dry bulb temperature, dew point temperature and wind speed, from the period of record years to form a complete year. Due to inherent selection criterion the TMYs are not suited for designing systems and their components to meet the worst case conditions occurring at a location. A TMY is not necessarily a good indicator of conditions over the next year, or even the next 5 years.

TMY1 – The TMY1 data sets were derived from the widely accepted (years) 1952-1975 SOLMET/ERSATZ data base. The original TMY1 files were ASCII text files contain data in one hour time intervals accrue to one year worth of weather information. The TMY1 data has both direct normal and global horizontal surface radiation data; with the direct normal radiation data being generated from the corrected global horizontal data, using algorithms developed by the Aerospace Corporation under contract with the Department of Energy (DOE). It is important to note that the TMY1 data were recorded in increments of solar time rather than standard time and that the first record is for hour 1 rather than hour 0; most current simulation programs require the TMY1 files to be reformatted/upgraded or converted into a different format to facilitate compliance during simulation runs. All relevant information about TMY1 files have been obtained from the TMY User Manual, unless specified otherwise.

TMY2 – The TMY2 data sets were derived from the (years) 1961-1990 National Solar Radiation Data Base (NSRDB). The TMY1 and TMY2 files are principally different from each other in time format (solar versus local), overall formatting, elements, and units. The TMY2 data sets contain one year of weather data, comprising of hourly values of solar radiation and meteorological elements. It was intended to be used for computer simulations of solar energy conversion systems and building systems to facilitate performance comparisons of different systems types, configurations and locations in the United States and its territories (Marion & Urban, 1995). The Sandia method (developed by Sandia National Laboratories) developed to create the TMY1 file was modified slightly to better optimize the weighting of the indices and to provide preferential selection to months which had measured solar radiation data and to account for missing data.

TMY3 – The TMY3 data sets have been derived from the (years) 1976-2005 for sites from the National Solar Radiation Data Base (NSRDB) , version 1.1 and for those sites which were included in the NSRDB update the selection period is confined from 1991 to 2005, with the exclusion of a few atypical years (1982-1984 and 1992-1994) caused by volcanic eruptions. The format for the TMY3 data is radically different from the TMY and TMY2 data, diverting from the columnar or positional format, to a widely accepted comma separated value (CSV) format. The TMY3 data set finds the addition of new fields for surface Albedo and liquid precipitation; with the removal of fields for present weather, snow-depth and days since last snowfall as compared to the TMY2 data set. The measurement units have been changed to SI or equivalent.

The 'Phoenix' TMY3 data set uses a selection period between 1976 and 2005 and falls under the class I site i.e. lowest uncertainty data.

Future Weather files (Climate Change)

The climate change world weather file generator (CCWorldWeatherGen) has been used to generate climate change weather file for Phoenix. It uses the Intergovernmental Panel on Climate Change's (IPCC) Third Assessment Report model summary data of the HadCM3 A2 climate change model predictions, to transform a 'present-day' EPW weather file into climate change EPW for milestone years 2020, 250 and 2080. The climate change world weather file generator (CCWorldWeatherGen) tool is a free-ware and can be downloaded and used to generate climate change weather file any location on earth (Sustainable Energy Research Group, 2010).

The recorded weather data, TMY files and the future weather files processed into the EPW weather format can easily be accessed by a spreadsheet based software by opening it as a ‘comma separated value’ (.csv) file. Each weather file contained 8760 rows of data representing hourly weather data such as dry bulb temperature, dew point, relative humidity, various solar radiation data, wind speed and direction and precipitation values amongst other things. Each weather file is considered to have and an equal number of days (365), including leap years where the extra day is dropped for parity in simulation results.

For all analysis purposes pre and post energy simulations the data points have been segregated into their respective seasons and as days and nights. Different studies and reports have different criterion for defining the start and end date for each of the seasons and also for the delineation of night and day, but for the purpose of this study the following structure outlined below shall be used -

Summer - Start date: 15th May, End date: 15th September

Winter - Start date: 1st January, End date: 28th February and Start date: 1st November, End date: 31st December

Spring/Fall - Start date: 1st March, End date: 14th May and Start date: 16th September, End date: 31st October

Daytime hours - 6 AM to 8 PM

Nighttime Hours – 8 PM to 6 AM

Site to Source Energy conversions – Most annual energy simulation results output energy consumption as would be measured at the site. Although these results are useful in understanding the performance of the building and the building systems, it is not a good indicator of the environmental impact due to the type of energy (fuel) used and the resource consumption and emissions associated to them. Site energy consumption values would also not be a good metric while comparing similar building types that use different energy types, i.e. buildings with on-site energy generation such as photovoltaic (PV) or co-generation systems. Thus we see that the Source energy consumption from energy used on site must be calculated' post energy simulation energy consumption reporting, to understand the true environmental impact of buildings. The Site to Source conversion factors for the following fuels is -

Electricity - 3.2 source Btu per site Btu (10,918 source Btu per site kWh)

Natural Gas - 1.090 source Btu per site Btu

2.2 Codes and Compliancy of Energy Models

For the purpose of thesis, prototype commercial building representative of the building stock modeled to be compliant to ASHRAE 90.1 2007 developed by PNNL have been used along with a residential building modeled to be compliant to IECC 2006.

Commercial Building Model

Code Applicable: ASHRAE Standard 90.1

The purpose of ASHRAE Standard 90.1 is to provide minimum requirements for the energy efficient design of buildings except low-rise residential buildings. It was first published 1975 and revised editions were published in 1980, 1989, and 1999; since 2001 the standard has been updated every third year with editions in 2004, 2007 and the latest edition released in 2010, applicable to commercial buildings and other building other than Low-Rise Residential.

Energy Model: DOE's 90.1 Prototype Building Models

For the purpose of this thesis the commercial energy models developed by Pacific Northwest National Laboratory (PNNL) in support of DOE's Building Energy Codes Program (BECP) have been used. The 90.1 Prototype Building Energy Models have been based on DOE's Commercial Reference Building Models, with substantial changes to bring it up to the ASHRAE 90.1 standards for each of its 2004, 2007, 2010 versions. These prototype building have been tweaked to represent each of the 8 climatic zones, which were further divided into moist and dry regions, represented by the 15 climate zones in the United States. Models representing the Zone 2B, with Phoenix as the representative city are available on the public domain through DOE's website and have been used.

The International Energy Conservation Code (IECC) sets the requirements for the "effective use of energy" in all building, with the separation of building into two categories – residential and commercial. The IECC codes are updated about every three years. The most current version available version is the 2012 IECC. For the purpose of this thesis the residential model was modeled to be compliant to 2006 IECC for Residential Buildings.

Mandated by the Energy Policy Act of 1992, all states must review and consider adopting the national model energy standard; with ASHRAE 90.1 – 2007 and IECC 2009 specified as the most current model energy codes. Adoption of energy codes varies from state to state and even from editions to edition of codes developed by the same authority. Phoenix currently has adopted the '2006 International Energy conservation Code, As Amended by the City of Phoenix' (International Code Council, 2011) as the energy efficiency standard.

2.3 Details of Commercial and Residential energy models

Of the sixteen commercial building prototypes made available through Pacific Northwest National Laboratory (PNNL) (U.S. Department of Energy - Energy Efficiency and Renewable Energy, 2011), seven prototype ASHRAE 90.1 2007, commercial buildings and one Single-family Residential building model developed have been chosen to be used in this study. Further iterations of one the building models namely the Medium office building was conducted to further isolate the impact of the building working schedule and the percentage of outside air component in the building. The Commercial building types used in the study are

- Small Office
- Medium Office
- Iterations – 24hr, 100% OA, 24hr & 100% OA
- Large Office
- Mid-Rise Apartment
- Single-family (Detached) Residential
- Hospital
- Retail Standalone
- Warehouse

Details of each of the building models are as follows-

2.3.1 Small Office – Prototype ASHRAE 90.1

Form

- Total Floor Area (Sq Ft) - 5500 (90.8 ft x 60.5 ft)
- Building Shape

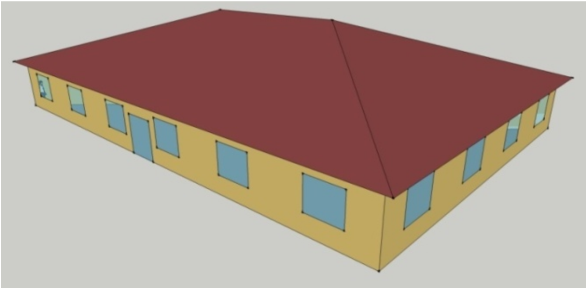


Figure 2.3.1-1**:** 3-D view of Small Office – Prototype ASHRAE 90.1

- Aspect Ratio - 1.5
- Number of Floors - 1
- Window Fraction (Window-to-Wall Ratio) - 24.4% S & 19.8% N, E & W (Dimensions: 6.0 ft x 5.0 ft punch)
- Windows Locations - Evenly distributed along four facades
- Shading Geometry - none
- Thermal Zoning

  Perimeter zone depth -16.4 ft.

  No. of Zones - Four perimeter, one core & an attic.

  Percentages of floor area - Perimeter 70%, Core 30%

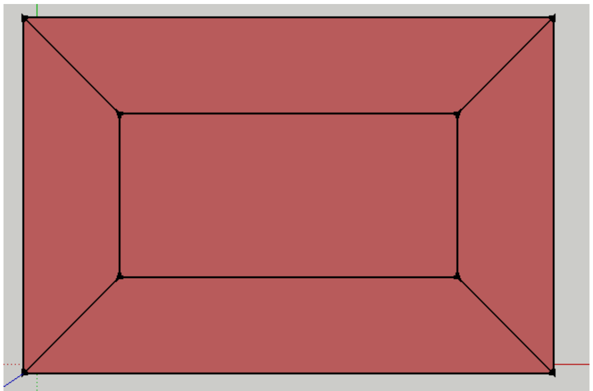


Figure 2.3.1-2: Plan of the thermal zones.

- Floor to floor Height (ft) - 10
- Floor to ceiling height (ft) - 10
- Glazing sill height (ft) - 3 (top of the window is 8ft with 5ft high glass)

Architecture

Exterior walls

- Construction - Wood-Frame Walls (2x4 16in OC) 1in. Stucco + 5/8in. gypsum board + wall insulation + 5/8in. gypsum board
- U-factor and/or R-value - ASHRAE 90.1 Requirements Non-Residential; Walls, Above-Grade, Wood-Framed

Roof

- Construction - Attic Roof with Wood Joist: Roof insulation + 5/8th in. gypsum board
- U-factor - ASHRAE 90.1 Requirements

Non-Residential; Roofs, Attic

Window

• Dimensions	- 5ft high by 6ft wide, punch
• Glass-Type and frame	- Hypothetical window with the exact U-factor and SHGC shown below
• U-Factor & SHGC	- ASHRAE 90.1 Requirements Non-Residential; Vertical Glazing, 20-30%, U_fixed.
• Visible transmittance	- Hypothetical window with the exact U-factor and SHGC shown above

Foundation

• Foundation type	- Slab on-grade floors (unheated)
• Construction	- 8” concrete slab poured directly on to the earth
• Thermal properties Ground level floor U-factor and/or R-value	- ASHRAE 90.1 Requirements Non-Residential; Slab-on-Grade Floors, unheated

Interior Partitions

• Construction	- 2 x 4 un-insulated stud wall
• Dimensions	- based on floor plan and floor-to-floor height

Air barrier System

- Infiltration - Peak: 0.2016 cfm/sf of above grade exterior wall surface area (fan off)
  - Off Peak: 25% of peak infiltration rate (fan on)

HVAC

System type

- Heating type - Air source heat pump with gas furnace as back-up
- Cooling type - Air-Source heat pump
- Distribution and terminal unit - Single zone, constant sir volume air air distribution, one unit per occupied thermal zone

HVAC Efficiency

- Air conditioning - Various by climate location and design cooling capacity
  ASHRAE 90.1 Requirements
  Minimum equipment efficiency for Packaged Heat Pumps
- Heating - Various by climate location and design heating capacity
  ASHRAE 90.1 Requirements

Minimum equipment efficiency for Packaged Heat Pumps and Warm Air Furnaces

HVAC Control

- Thermostat Set-point - 75˚F Cooling/70˚F Heating
- Thermostat Setback - 85˚F Cooling/60˚F Heating
- Supply air temperature - Maximum 104˚F /Minimum 52˚F
- Chilled water supply Temp - 44˚F
- Hot water supply Temp - 180˚F
- Economizers - Air-side economizer
- Ventilation - .085 cfm/ft^2 (ASHRAE Ventilation Standard 62.1)
- Demand Control Ventilation - ASHRAE 90.1 Requirements
- Energy Recovery - ASHRAE 90.1 Requirements

Service Water Heating

- SWH type - Storage Tank
- Fuel type - Natural Gas
- Thermal efficiency (%) - ASHRAE 90.1 Requirements; Water Heating Equipments, Gas storage water heaters, >75,000 BTU/h input
- Tank Volume (gal) - 40
- Water temperature set-point - 120˚F

Lighting

- Average power density(W/ft2) - ASHRAE 90.1 Requirements
  Lighting Power Densities using the
  Building Area Method
- Daylighting Controls - ASHRAE 90.1 Requirements
- Occupancy Sensors - ASHRAE 90.1 Requirements

2.3.2 Medium Office – Prototype ASHRAE 90.1

Form

- Total Floor Area (Sq Ft) - 53600 (163.8 ft x 109.2 ft)
- Building Shape

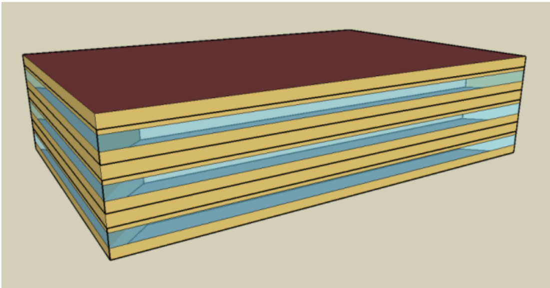


Figure 2.3.2-1 : 3-D view of Medium Office – Prototype ASHRAE 90.1

- Aspect Ratio - 1.5
- Number of Floors - 3 no.
- Window Fraction - 33% (163.8 ft x 4.29 ft on long side)
  (Window-to-Wall Ratio) (109.2 x 4.29 ft on the short side)
- Windows Locations - Evenly distributed on all four sides
- Shading Geometry - none

- Thermal Zoning

  Perimeter zone depth - 15 ft.

  No. of Zones - Each Floor has Four perimeter zones, one core.

  Percentages of floor area - Perimeter 70%, Core 30%

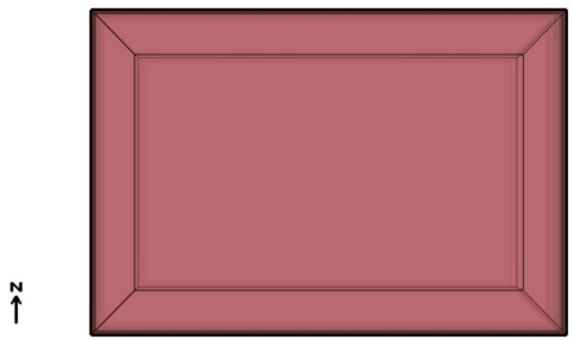


Figure 2.3.2-2: Plan of the thermal zones on each floor.

- Floor to floor Height (ft) - 13 ft
- Floor to ceiling height (ft) - 9 ft
- Glazing sill height (ft) - 3.35ft (top of the window is 7.4 ft with 4.29 ft high glass)

Architecture

Exterior walls

- Construction - Steel-Frame Walls (2x4 16in OC) .4in. Stucco + 5/8in. gypsum board + wall insulation + 5/8in. gypsum board

- U-factor and/or R-Value - ASHRAE 90.1 Requirements Non-Residential; Walls, Above-Grade, Steel-Framed

Roof

- Construction - Built-up Roof: Roof membrane + Roof Insulation + metal decking
- U-factor and/or R-Value - ASHRAE 90.1 Requirements; Non-Residential; Roofs, Insulation entirely above deck

Window

- Dimensions - based on window fraction, location, glazing sill height, floor area and aspect ratio
- Glass-Type and frame - Hypothetical window with the exact U-factor and SHGC shown below
- U-Factor & SHGC - ASHRAE 90.1 Requirements Nonresidential; Vertical Glazing, 31.1-40%, U_fixed
- Visible transmittance - Hypothetical window with the exact U-factor and SHGC shown above

Foundation

- Foundation type - Slab on-grade floors (unheated)

- Construction - 8” concrete slab poured directly on to the earth
- Thermal properties Ground Fl. **(**U-factor and/or R-value) - ASHRAE 90.1 Requirements Non-Residential; Slab-on-Grade Floors, unheated

Interior Partitions

- Construction - 2 x 4 un-insulated stud wall
- Dimensions - based on floor plan and floor-to-floor height

Air barrier System

- Infiltration - Peak: 0.2016 cfm/sf of above grade exterior wall surface area (fan off)
  - Off Peak: 25% of peak infiltration rate (fan on)

<u>HVAC</u>

System type

- Heating type - Gas furnace inside the package air conditioning unit
- Cooling type - Packaged air conditioning unit
- Distribution and terminal unit - VAV terminal box with damper and electric reheating coil. Zone control type: minimum supply air at 30% of the zone design peak supply air.

HVAC Efficiency

- Air conditioning - Various by climate location and design cooling capacity. ASHRAE 90.1 Requirements; Minimum equipment efficiency for Air Conditioners and Condensing Units
- Heating - Various by climate location and design heating capacity. ASHRAE 90.1 Requirements; Minimum equipment efficiency for Warm Air Furnaces

HVAC Control

- Thermostat Set-point - 75˚F Cooling/70˚F Heating
- Thermostat Setback - 80˚F Cooling/60˚F Heating
- Supply air temperature - Maximum 104˚F /Minimum 55˚F
- Chilled water supply Temp - NA
- Hot water supply Temp - NA
- Economizers - Various by climate location and cooling capacity. Control type: differential dry bulb
- Ventilation - .085 cfm/ft^2 (ASHRAE Ventilation Standard 62.1)
- Demand Control Ventilation - ASHRAE 90.1 Requirements

- Energy Recovery - ASHRAE 90.1 Requirements

Service Water Heating

- SWH type - Storage Tank
- Fuel type - Natural Gas
- Thermal efficiency (%) - ASHRAE 90.1 Requirements; Water Heating Equipments, Gas storage water heaters, >75,000 BTU/h input
- Tank Volume (gal) - 260 gallons
- Water temperature set-point - 120˚F

<u>Lighting</u>

- Average power density(W/ft2) - ASHRAE 90.1 Requirements Lighting Power Densities using the Building Area Method
- Daylighting Controls - ASHRAE 90.1 Requirements
- Occupancy Sensors - ASHRAE 90.1 Requirements

2.4 Simulation Process Methodology

The study seeks to understand the impact of the increasing night-time minimum low, during the harsh summer months, on typical buildings in the Phoenix Metropolitan region through annual energy simulation process spanning through the years 1950 to 2005. Typical Meteorological Year

(TMY) file vintages TMY1 and TMY2 were simulated along with TMY3 to understand the disparity caused by using the normalized typical weather data sets that represent more than 30years of actual recorded weather. Future climate change weather change files at year time steps 2020, 2050 and 2080 are simulated to understand the impacts of the climate change on each of these building types.

EnergyPlus, an annual energy analysis and thermal load simulation program, has been chosen to run the simulation over other existing simulation software due its ability to perform vigorous analysis and provide accurate results. The Prototype commercial building energy models – ASHRAE 90.1 complaint (U.S. Department of Energy - Energy Efficiency and Renewable Energy, 2011), developed and available in the public domain through Pacific Northwest National Laboratory (PNNL), available in EnergyPlus format would enable the study to be standardized to ensure that no anomalies creep in while trying to progress the or replicate the study.

Each of the eight chose building types are simulated against weather data of fifty-six years (actual recorded data), three TMY files (TMY1,TMY2 and TMY3) and the three Climate Change weather files (2020, 2050, and 2080) . The medium office building chosen for further analysis of the impact of 100%percentage of OA and scheduled increase in working hours to create a 24Hr 7days a week work profile of the building, thus three more iterations of the medium office building are created –

- Medium Office – 24hrs, 7days a week work schedule
- Medium Office – 100% Outside air
- Medium Office – 24hrs, 7days a week work schedule with 100% outside air

The EP-Launch sub-program of EnergyPlus is a graphical user interface (GUI) that enables the setting up of simulation and provides access to other sub-programs that which would enable the examination and editing of the IDF files (model input file). All models are set to run an annual simulation from the EP-Launch – 'batch run tab' and generate a set of result files which are written into folders representing each of the weather files, this set-up is repeated to run each of the building models to run with the 61 weather files. The IDF files are edited to generate and output results need to analyze the energy consumption patterns. The start day for each annual simulation is set to as a Sunday to ensure uniformity in the results.

This would create 62 sets of results for each of the building typologies, 7 Commercial building types, the 3 iterations of the Prototype Medium Office Building ASHRAE 90.1 and 1 Single Family detached Residential building, accounting up to 682 Annual simulation runs. This brute force method for analysis is chosen due the manageable size of the data to be processed and due to the fact that no existing valid heuristics are available to replicate the impacts of the changing weather conditions over the years; this bottom-up engineering assessment has been shown in a lot of literature to be the chosen method to understand and estimate the energy consumption patterns of the building stocks.

Chapter 3

3 ANALYSIS

3.1 Analysis of the weather data

The various sets of weather data obtained for the study form the various sources i.e. recorded weather data (1950 -2005), the TMY 1, 2 and 3 and future weather files created using the weather tool from IPCC are processed into the EPW weather format using the methodology mentioned. The EPW can not only be easily accessed by a spreadsheet based software by opening it as a ‘comma separated value’ (.csv) file, but is also the chosen file format to run annual energy simulation runs in EnergyPlus. Each of year’s data sets contained 8760 rows of data representing hourly weather data such as temperature, solar data, humidity amongst other data, but analysis in this study shall stay confined to studying the changes to the Dry Bulb Temperatures during the summer season. In the Phoenix Metropolitan Region which is a hot and dry region, it is imperative that the summer seasons be analyzed with specific interest in the variations to the nighttime min lows; with literature studies attributing the increase in the night-time min lows to the Urban Heat Island (UHI).

The ‘**summer night-time minimum (season lowest)**’ is defined as the lowest dry-bulb temperature recorded in any particular ‘night-time’ of the season. The summer night-time minimum temperature (season lowest) is seen to have a distinct upward trend (as seen in Figure 2.3.2-1) since the 1970, this clearly matches the urban growth patterns of the

Phoenix Metropolitan Region. During the years 2000-2005 it has averaged higher than all previous decades, never going below 17.2˚C, and averaging around 19.2˚C, increasing by 8.4˚C in the year 2005 as compared to the year 1950. Although this might be considered not to have a significant impact on the energy consumption of the built forms themselves as they could be considered anomalies in the data set, the significant increase over the years show us that the summer night-time minimum temperature levels have made a steady increase.

TMY (1, 2 &3) fail to address the increasing summer night-time minimum (season lowest) value trends exhibited in the most current recorded weather data. The future weather files (2020, 2050 & 2080) also fails to capture the steep trends shown in the recorded data, which might be because of the fact that these weather files fail to completely address the increase in temperatures due to Urban Heat Island (UHI).

The '**summer night-time minimum (Season Highest)**' is defined as the highest 'night-time minimum' dry-bulb temperature recorded in any particular 'night-time' of the season. The 'summer night-time minimum (Season Highest)' (Figure 2.3.2-2) shows a trend upward although it is not a significant rise and these values only represent one such day in a season when the temperature reaches this high levels it is imperative we pay attention to these values; as each night within the summer season when the temperature fails to go below 35˚C it adds a burden to the cooling of the following day.

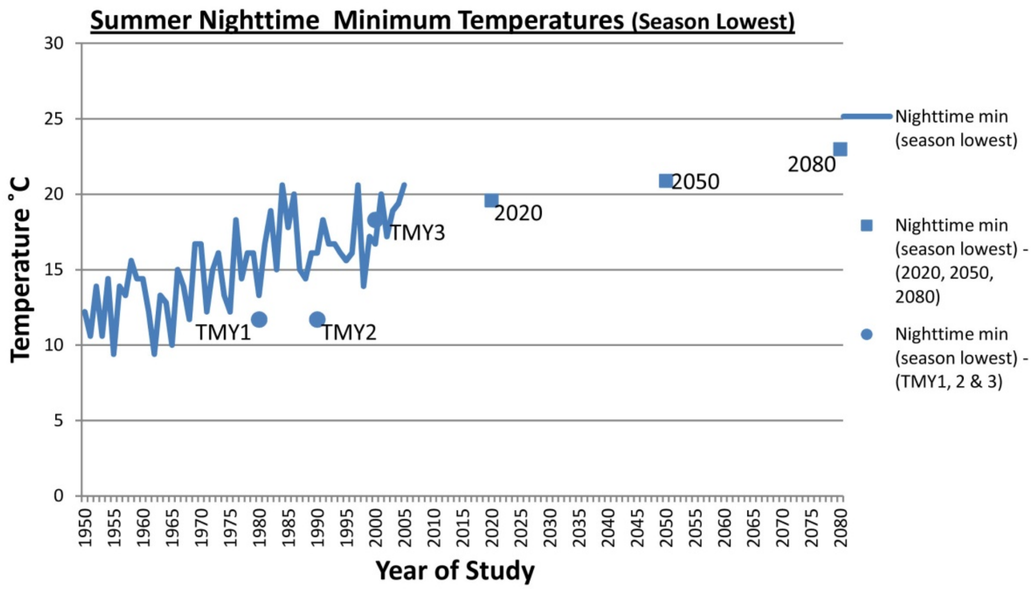


Figure 2.3.2-1: Summer Night-time Minimum Temperature (Season Lowest)

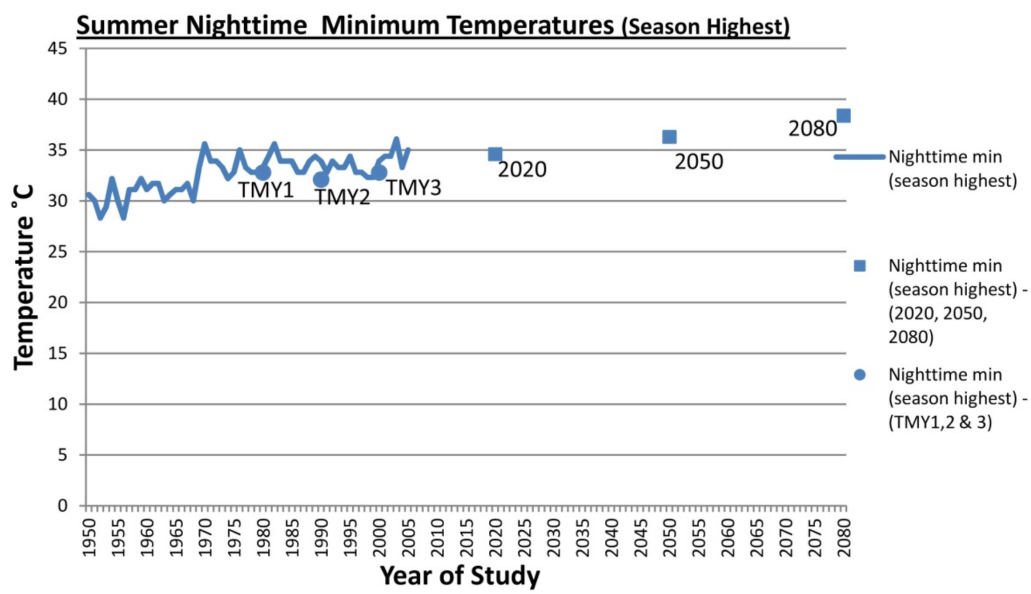


Figure 2.3.2-2: Summer Nighttime Minimum Temperature (Season Highest)

The night-time minimum temperatures averaged over the whole season, which has been defined as '**summer night-time minimum (seasonal average)**', shows a significant upward trend, increasing by up to 1˚F every decade (Figure 2.3.2-3 shows that it is not just the seemingly anomalous points of 'summer night-time minimum (season lowest)' and 'summer night-time minimum (season lowest)' that are showing an upward trend but the summer night-time minimum (seasonal average) temperatures are increasing each year. This trend of increasing temperature is also seen in the future weather files generated for the years 2020, 2050 and 2080, linear trend lines through them shows that the slope of this is not as significant as the recorded data, thus implying that future weather files might not contain the impact of Urban Heat Island.

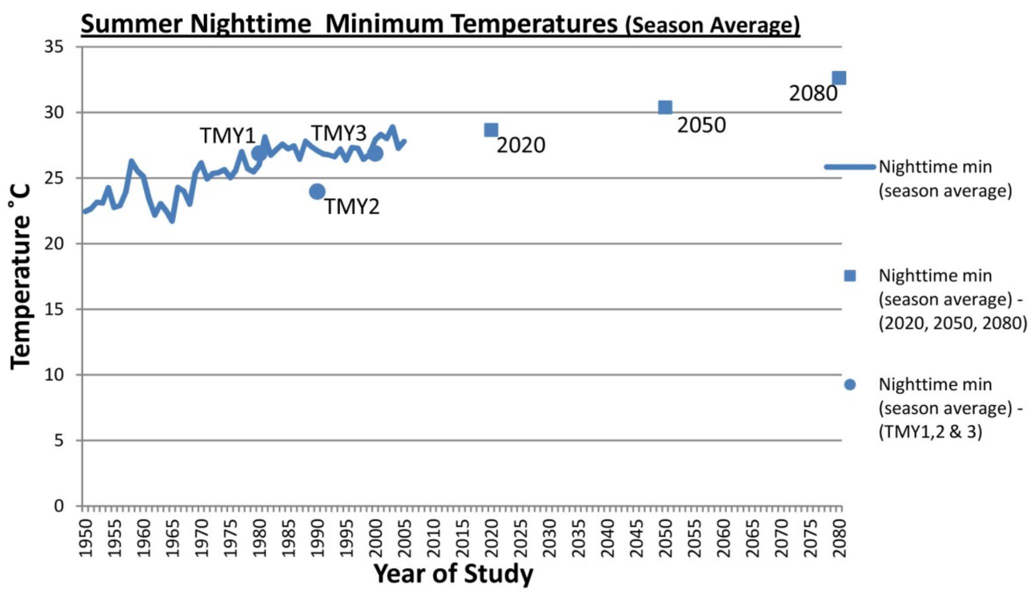


Figure 2.3.2-3: Summer Night-time Minimum Temperatures (Season Average)

As the focus is on the variation of the summer night time temperatures which have been shown to be the most impacted due to the Urban Heat Island (UHI) and the fact that in a hot-dry climate night-time minimum low, a comparative analysis of the cooling degree hours during the summer night-time is imperative and is compared to the summer day-time cooling degree hours. The comparative analysis of ‘Summer Nighttime Cooling Degree Hours (CDHr)’ and ‘Summer Day-time Cooling Degree Hours (CDHr)’ (Figure 2.3.2-5) explicitly shows that the former increases significantly as compared to the latter during the periods of study. This could be interpret as a direct increase in the energy consumption in buildings; but care should be taken to understand the hours of operation of the building in question as a day-time building would not experience the direct impact due to the night-time increase in cooling degree hours although a slight trickling effect is seen, while a building that runs on a 24hr operating schedule might see a direct impact on its cooling energy consumption values.

The summer night-time average temperature whisker-box plot gives us a statistical analysis of the data. This clearly shows that the statistically the summer night-time average temperatures show significant increases in the statistical framework.

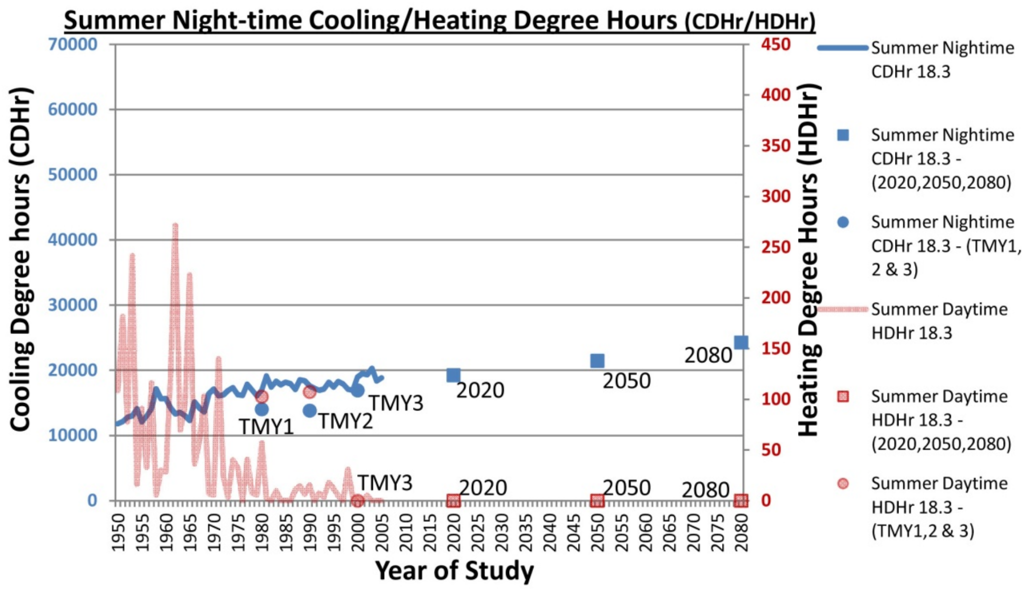


Figure 2.3.2-4: Summer Nighttime Cooling Degree Hours (CDHr)

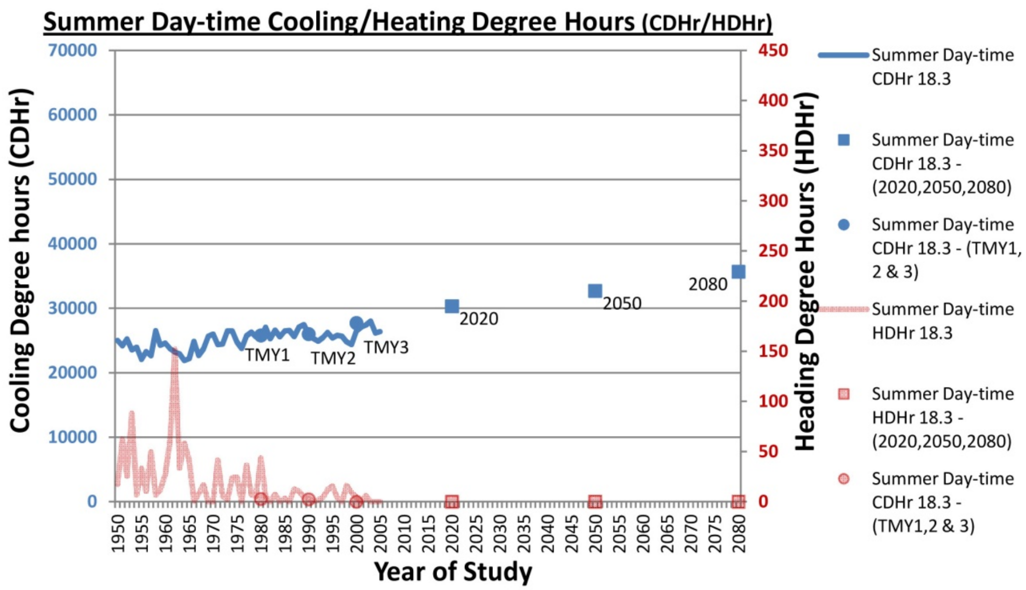


Figure 2.3.2-5: Summer Day-time Cooling Degree Hours

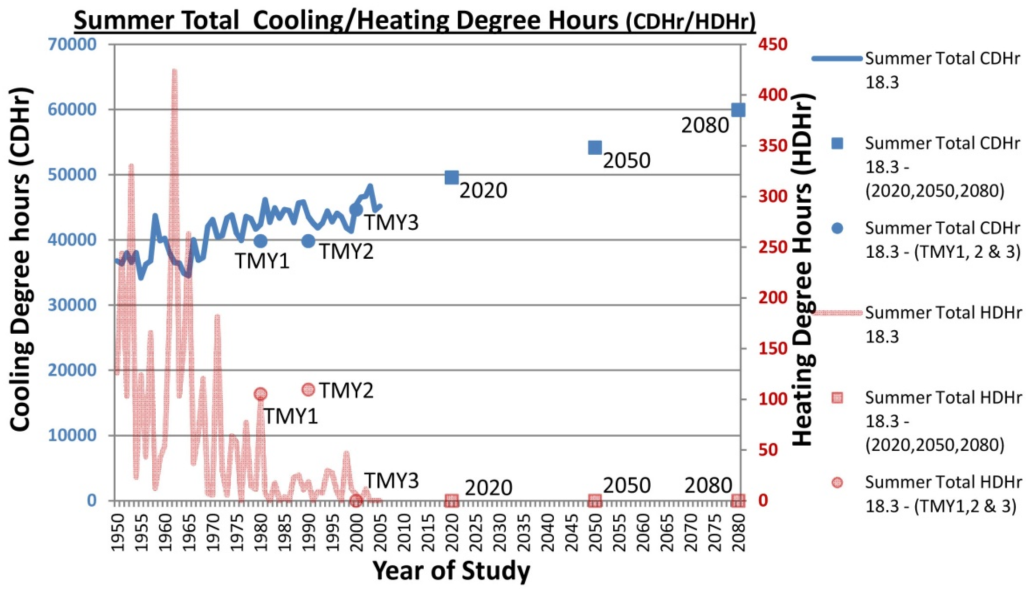


Figure 2.3.2-6: Summer Total Cooling Degree Hours (CDHr)

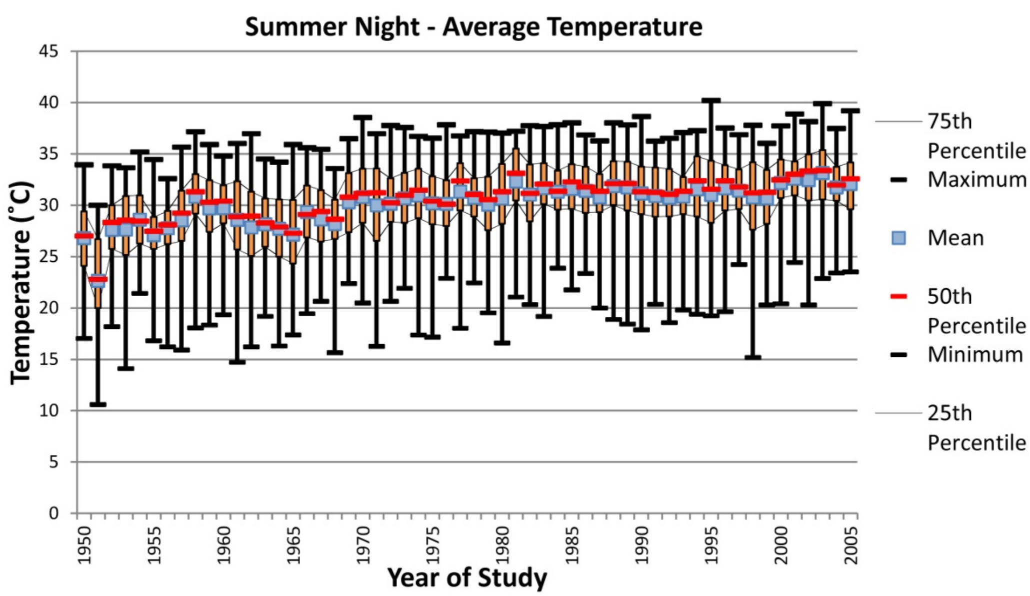


Figure 2.3.2-7: Summer Night - Average Temperature (Whisker-Box Plot)

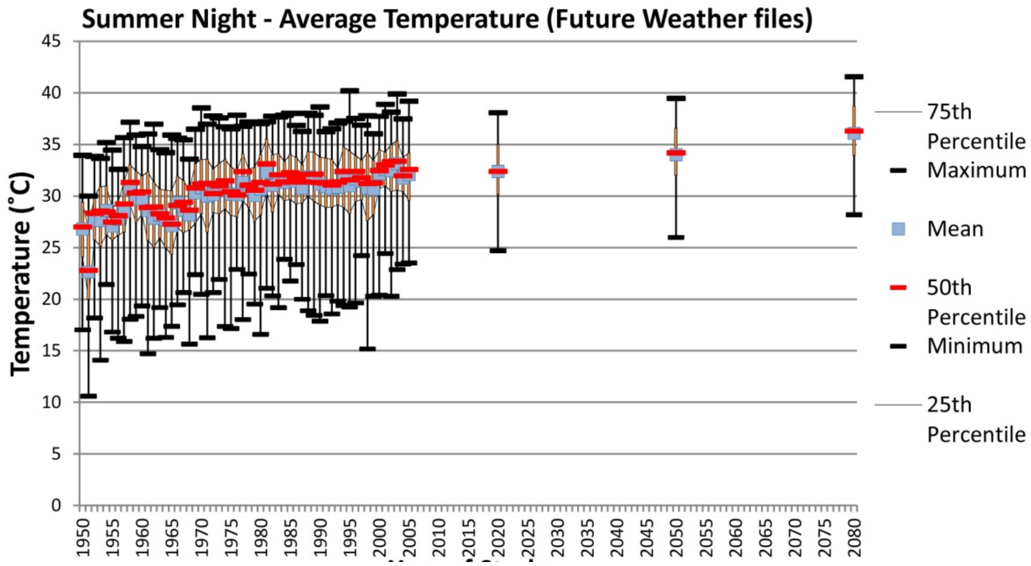


Figure 2.3.2-8: Summer Night - Average Temperature (Future Weather files) (Whisker-Box Plot)

3.2 Analysis of the Annual Simulation Results

Each of the eight building typologies included in the study and the iterations of the medium office building have been analyzed to show the changes to the annual energy consumption of the building annually and broken down into seasonal variances to understand the in detail the impacts of UHI, with emphasis on the summer night-time energy consumption patterns. EnergyPlus has various options to find output results - a HTML file generated usually comes packed with a previously defined set of results tables extracted during the simulation, it also has the capability of generating output reports for detailed variables and meters.

The intension of this study is to quantify and understand the energy consumption patterns in a building, particularly energy used for heating and/or cooling, which is directly impacted by the external weather conditions the building is exposed to and forms a significant part of the buildings total energy use. The type of systems used to meet the heating and cooling demands of the building dictates the type of fuel consumed; thus we see that in general the heating loads are met by two major fuel types- electricity or gas, while cooling loads are exclusively met the use of electricity. The type of fuel used is significant because of the differences in calorific values, cost implications and the source to site conversion ratios. The fan, pump energy is excluded from the cooling and heating energy consumption values. While 'total end-use' or annual 'total building energy' consumption value is defined as the summation of heating, cooling, base loads (lighting and equipments), fans, pumps and other miscellaneous energy consumed is included into the 'total end-use' or annual 'total building energy' consumption value.

The HTML output file thus generated by EnergyPlus after an annual energy simulation, is used to obtain the annual cooling and heating energy consumption values and the annual 'total end-use' or annual 'total building energy' consumption value in units Giga-Joules (GJ). EnergyPlus also has the capability of outputting hourly meter reports for a variety of variables and the appropriate ones can be chosen to be output into a comma separated value (.csv). To enable the hourly analysis of the changing cooling and heating energy consumption patterns over the years of study the following preset hourly reporting variables have also been enabled

Heating: Electricity [J]

This meter report variable is the sum of the electric output from all the electric baseboards in the HVAC systems in the simulation and would also include the parasitic electric consumption associated with boilers or any other heating systems modeled in the building.

Cooling: Electricity [J]

This meter report variable outputs the chiller electric consumption. In the case of steam or fuel-powered chillers, this represents the internal chiller pumps and other electric power consumption by cooling systems modeled in the building.

Heating: Gas [J]

This meter report variable outputs the gas consumption of the central boilers, absorption chiller-heater and any other heater systems modeled in the building.

The results obtained from for every one of the annual simulations runs with the recorded weather data, TMY weather files and future weather files have been compiled together analyzed for each one of the energy models representing a building type and represented as graphs in the following format –

- Graph 1 (G-1): 'Energy Consumption for Cooling and Heating'

  Each data point on the graph represents the Annual energy consumption value (site) in Kilo-British Thermal Units (kBtu) for heating or cooling in the respectively series on the primary 'Y' axis with the secondary 'Y' axis plotting the Heating and Cooling Degree hours with the year of simulation on the 'X' axis. This helps us show a correlation between the heating and cooling degree hours to the energy consumption for heating and cooling.

- Graph 2 (G-2): Combined Heating & Cooling Energy Use

  The energy consumption values for heating and cooling (Gas - Heating, Electric – Heating and Cooling) obtained from the hourly metered output are combined and are represented in series for the respective seasons (seasons as defined in the methodology) along with that for the annual consumption. This shows clarity in seasonal changes to the energy consumption values, which might be due to the increasing cooling energy requirement or decreasing heating energy requirement.

- Graph 3 (G-3): 'Summer and Night-time Cooling'

  This plot segregates and plots the cooling energy consumption (site) (electrical) (kWh) data on the 'Y' axis with the year of simulation on the 'X' axis primarily for the summer season with diurnal split and total energy consumption values in their representative series.

- Graph 4 (G-4): Summer Daily Cooling Energy (24Hrs – Weekdays only)

  Buildings, especially commercial buildings usually run on a normal weekday schedule with work hours from 8AM to 6PM and Monday to Friday, thus experience reduced energy consumption over the weekends when the temperature set-points in the thermostats are set higher and also the base loads are reduced. This causes a band of values of that are not representative of the energy consumption of such building's typical working day and might cause anomalous data points in any statistical analysis. This box-and-whisker plot is used to conveniently present the six descriptive statistical analysis data groups namely – Minimum (Data set minimum), 25th percentile (lower quartile), Mean (Mean of the data set), 50th Percentile (Median of the Dataset), 75th Percentile (upper quartile) and the Maximum (Dataset Maximum). Each Data point on the graph represents the total cooling energy of a day in the season of that particular year.

- Graph 5 (G-5): Cooling Energy Consumption Vs. Cooling Degree Hours

  A definite correlation has been established between the cooling degree hours and the energy consumption. This plot tries to explore the relation to try to fit a linear trend line that would help predict the impact of increasing cooling degree hours on the energy consumption annually and also in lesser time frames of interest such as summer season and summer day and night time.

- Graph 6 (G-6): Total (Heating & Cooling) Energy Consumption (Source)

  Heating and cooling traditionally uses different fuel types such as Natural Gas and Electricity respectively, which not only have a different calorific value but the Site to Source conversion factors is different which means the environmental impact of this fuel usage is different. This plot represents the total heating and cooling energy consumption factored to represent the at ‘source’ value for each of the fuels. This helps quell any disparity in caused by choice of fuel for heating or cooling, and helps bring parity while understanding the patterns of change in annual energy consumption.

- Graph 7 (G-7): Total (Heating & Cooling) Energy Cost ($) (Site)

  Most building managers/users would be concerned more about the cost implications of the rise in the energy consumption in buildings rather than the absolute values of the change. This plot address this primary concern; with the ‘x’ axis being representative of the combined cost of the fuels used for heating and cooling and ‘y’ axis the year of simulation. The costs implications are not a true representation due to the fluctuating fuel costs over the years under study, but as these simulations are being run in retrospect to see how a current building would have performed in the absence of the micro-climatic changes keeping the current fuel costs is justified.

- Graph 8 (G-8): Total (Summer Cooling) Energy Consumption (Site) – Percent Growth Rate (Average Value over the years)

  This graph plots the energy consumed for cooling during the summer season as percent growth rate with the base year assumed to be the average energy consumption for summer cooling for the years 1950-2005 and also plots the actual energy consumption values for the same dataset.

- Graph 9 (G-9): Total (Cooling) Energy Consumption (Site) – Percent Growth Rate (Average Value over the years)

  The total annual cooling energy consumption data is averaged for the years 1950-2005, to find a base value that is used to represent the percent growth rate, these values along with the actual annual cooling energy consumption values are plot in this graph.

- Graph 10 (G-10): Total Building Energy Consumption (Site)

  The previous analysis and plots focused on the heating and cooling energy consumption values, either independently or in a combined form, but the buildings total energy consumption usually also includes other energy consumptions due other HVAC related components such as Fans and Pumps and also base loads such as lighting and equipment. Most energy managers and building owners are concerned about the total building energy consumption values rather at the site than smaller break-up values of the same.

- Graph 11 (G-11): Total Building Energy Consumption (Source)

  This plot represents the Total Building Energy Consumption value computed to represent its values at source.

- Graph 12 (G-12): Total Building Energy Cost ($) (Site)

  This plot shows tracks the cost of the total energy, HVAC, Lighting, appliances and other miscellaneous energy consumptions, required to run a building during each of the study years.

3.2.1 Small Office

The small office building is one of the predominant office building typologies having a national weights by building type of 5.61% and 9.71% by weights in the ‘Climatic Zone 2B’ with Phoenix as its representative city (Jarnagin & Bandyopadhyay, 2010). Thus the analysis of this building type would give us an insight into the energy consumption patterns of almost 10% of the building stock in the climatic zone 2B.

The analysis of this building type using the methodology and all the types of weather files mentioned earlier brought out some interesting insights into the way it is affected by the Urban Heat Island (UHI). The results of the simulation were sorted, analyzed and plot as various graphs as mentioned earlier.

The energy consumed for cooling is seen to be steadily increasing with a visible upward trend; this matches the trending seen in the cooling degree hours. As the effects of Urban Heating Island Effect (UHI) and climate change causes an increase in the cooling degree hours, it also causes a decrease in the heating degree hours. The small office building type uses an Air-source heat pump for primary heating and cooling, with electricity as the primary fuel source, thus any changes to its heating and cooling requirements affects the consumption of electricity. The energy requirement for heating reduces as the overall temperatures have been seen to increase. The consumption of natural gas used in the back up furnace also sees a decrease. It is clearly seen that the TMY files fail to predict the increases in annual energy consumption in the recent years. The TMY1 and TMY2 weather data fails to predict even the average energy consumption for the time periods that they take their representative data set from (Figure 3.2.1-1).

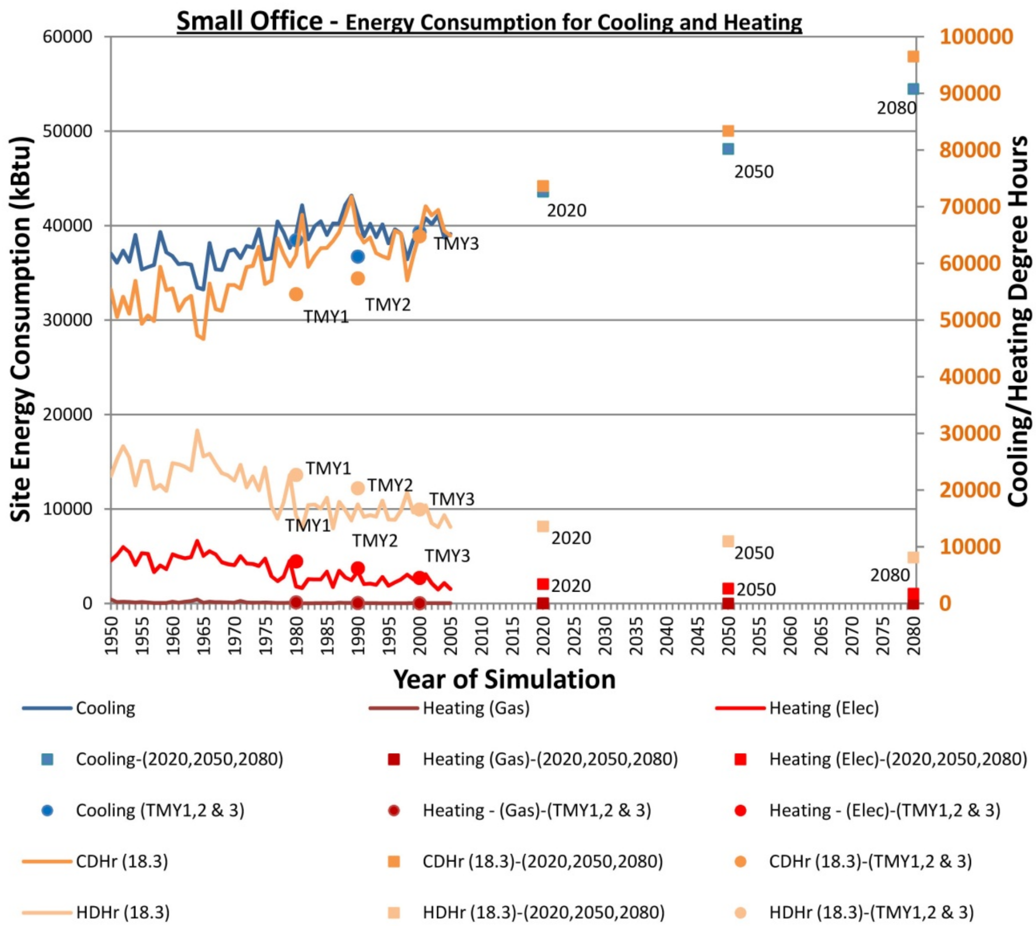


Figure 3.2.1-1: Small Office - Energy Consumption for Cooling and Heating (G-1)

While the annual cooling and heating energy consumption trends are indicative of the changes in the quantity of fuels that would have been consumed over the years in the period of study, in the Figure 3.2.1-2 we see the balanced effect the changes to the heating and cooling degree hours by summing the heating and cooling energy consumptions seasonally. As proof of validation of the hypothesis we see in Figure 3.2.1-2 that the summer and spring/fall seasons show an increase energy consumption values over the years of study, the winter season shows energy savings; the annual energy consumption values still shows an upward trend after accounting for the winter savings.

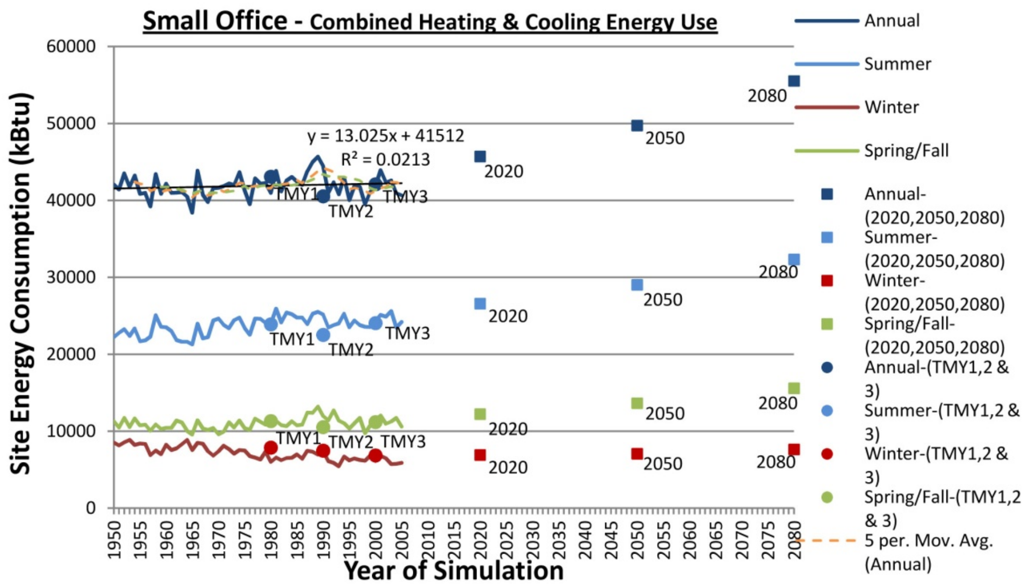


Figure 3.2.1-2: Small Office - Combined Heating & Cooling Energy Use (G-2)

The small office building type is a day-time/weekday occupancy building, and the trends in energy consumption as seen in Figure 3.2.1-3 clearly shows that the impact of the increasing temperatures in the summer night-time is having a much lesser impact than that caused due to the day-time increase in temperatures; we can thus conclude that although there is a penalty of cooling energy consumption values in the following day, buildings with day-time occupancy would see a lesser impact due to night-time increase in temperature or Urban Heat Island (UHI).

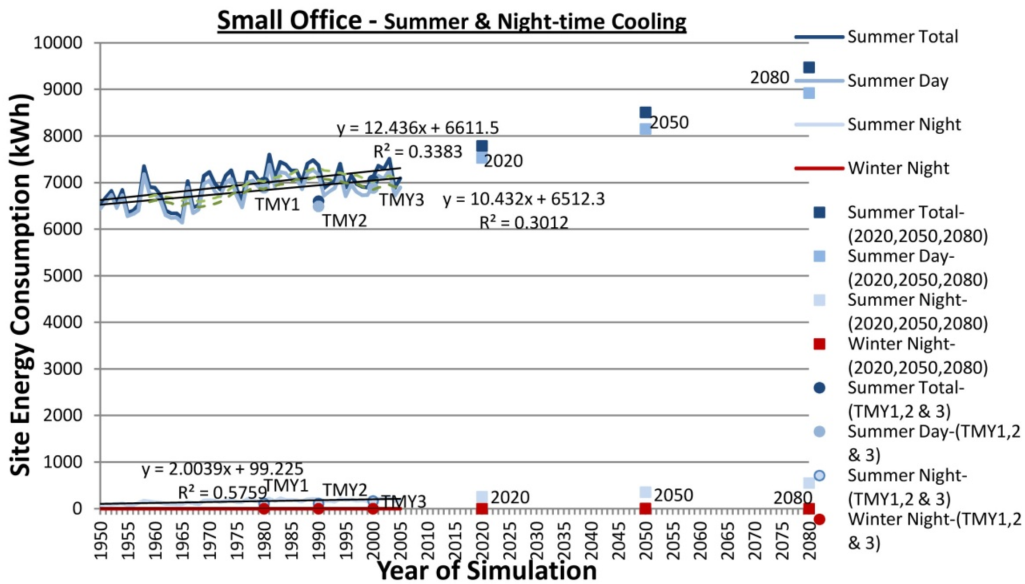


Figure 3.2.1-3: Small Office - Summer and Night-time Cooling (G-3)

A Descriptive statistical analysis of the hourly energy cooling energy consumption of the 24Hr cycle in the summer months, for the weekdays only helps us understand the statistical variations, understand the growth bands instead of just looking at the min or max values which might at times be misleading. Figure 3.2.1-4 shows that even a intense scrutiny of the energy consumption values show an increase across the board.

Figure 3.2.1-5: Small Office - Total (Heating & Cooling) Energy Consumption (Source) shows cost increases due to the temperature changes attributed to the Urban Heat Island effect. Not only does the absolute value of energy consumed as factor calculated at the source for each of these fuel sources i.e. Electricity and Gas, the magnitude of rise also increases as the conversion factor site to source is different for each of these fuels. This graph gives a clear indication of the environmental impact of the changes in annual heating and cooling energy consumption patterns due to the impact of Urban Heat Island (UHI).

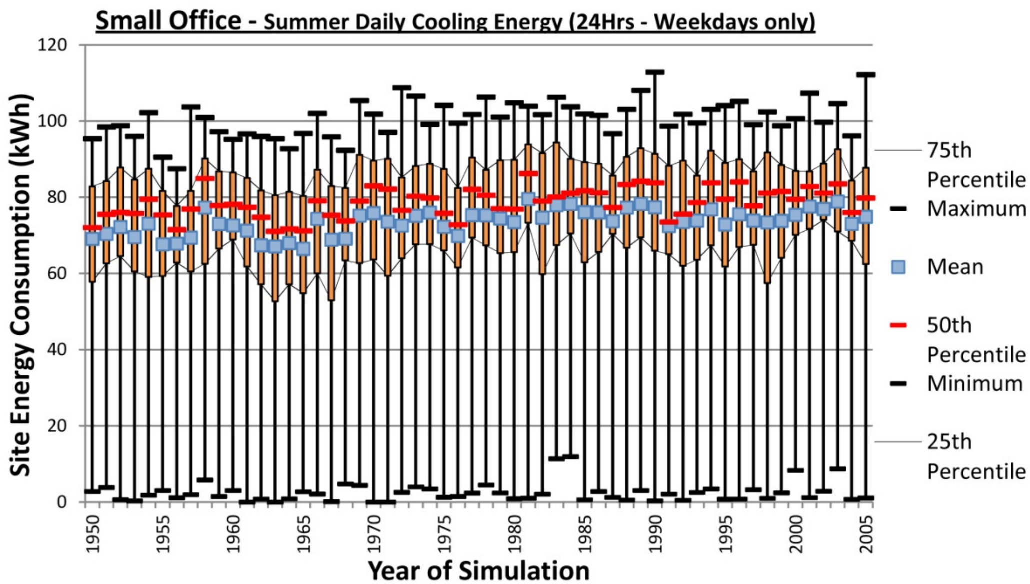


Figure 3.2.1-4: Small Office - Summer Hourly Cooling Energy (24Hrs - Weekdays only) (G-4)

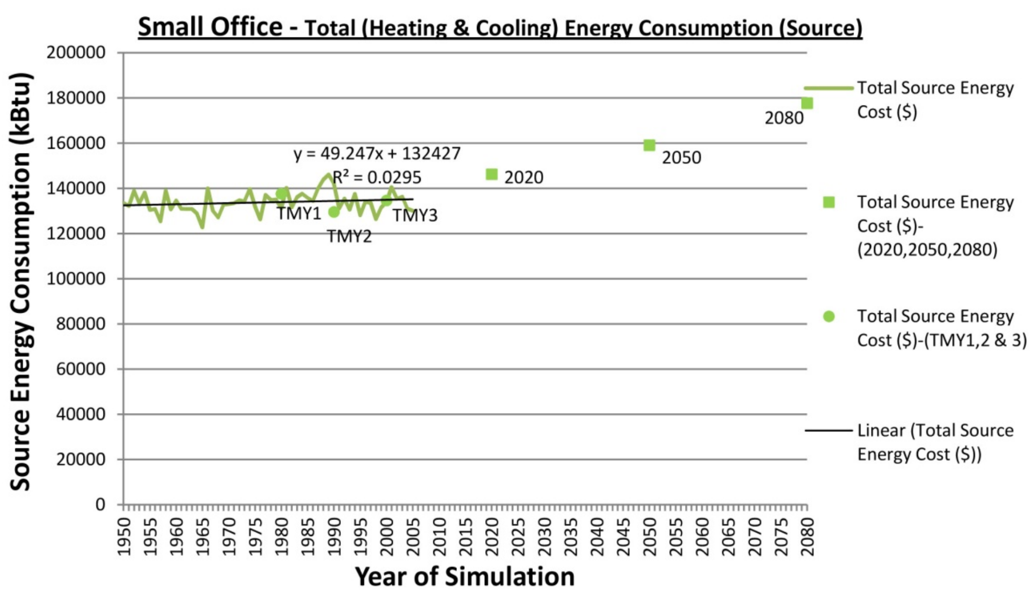


Figure 3.2.1-5: Small Office - Total (Heating & Cooling) Energy Consumption (Source) (G-6)

3.2.2 Medium Office

The Medium office building is one of the predominant office building typologies having a national weights by building type of 6.05% and 9.81% by weights in the ‘Climatic Zone 2B’ (Jarnagin & Bandyopadhyay, 2010) with Phoenix as its representative city. Thus the analysis of this building type would give us an insight into the energy consumption patterns of almost 10% of the building stock in the climatic zone 2B.

The medium office building type has been chosen to model iterations to the ASHRAE 90.1 2007, these models have tweaked to have 24Hr schedules, 100% outside air and combined 24Hr and 100% outside air. The Figure 3.2.2-1: Medium Office - Energy Consumption for Cooling and Heating (G-1), Figure 3.2.2-2: Medium Office (24/7) - Energy Consumption for Cooling and Heating, Figure 3.2.2-3: Medium Office (100% OA) - Energy Consumption for Cooling and Heating and Figure 3.2.2-4: Medium Office (24/7 & 100% OA) - Energy Consumption for Cooling & Heating, show the change in the annual energy consumption patterns of the medium office building type and the effect scheduling and the outside air component has in relation to the changing heating and cooling degree hours. Changes in working hours from 8AM to 6PM to a 24Hr schedule causes a jump in the cooling energy consumption and the 100% outside air causes an increase in the base value of the energy and also the rate of change shows an increase.

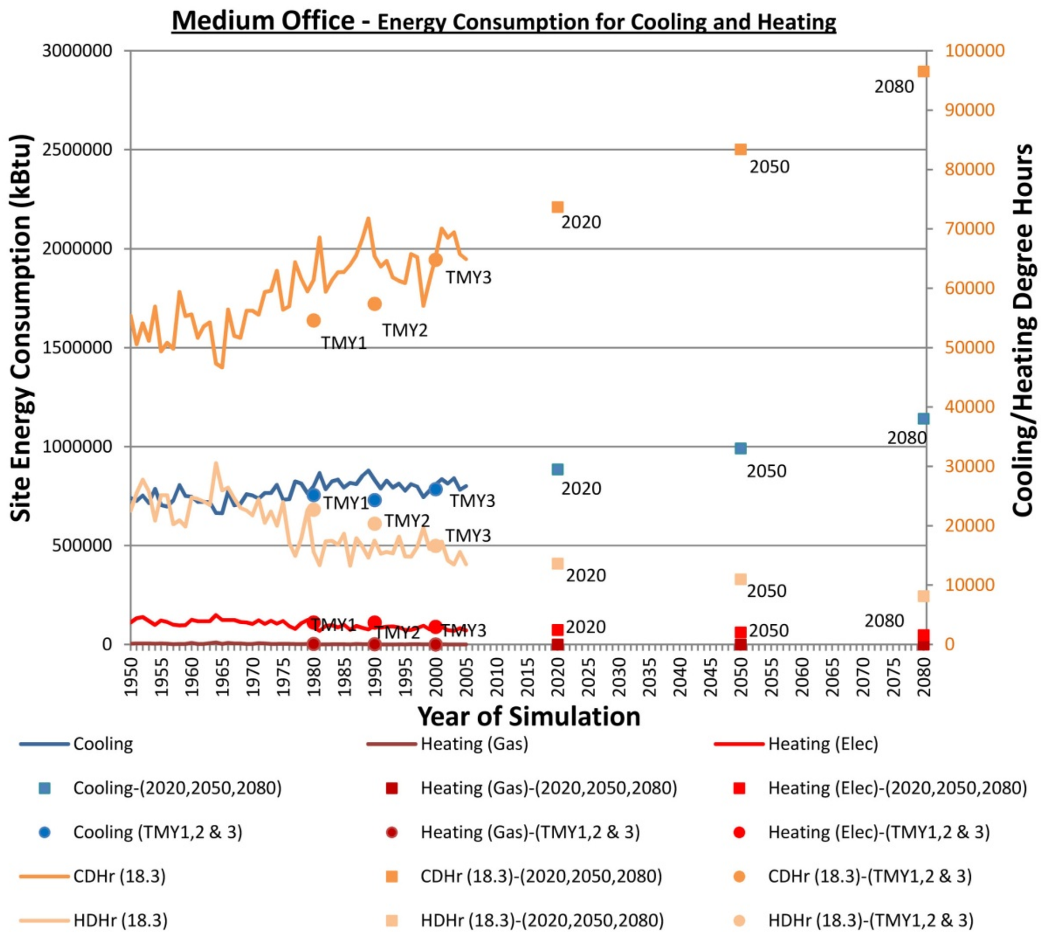


Figure 3.2.2-1: Medium Office - Energy Consumption for Cooling and Heating (G-1)

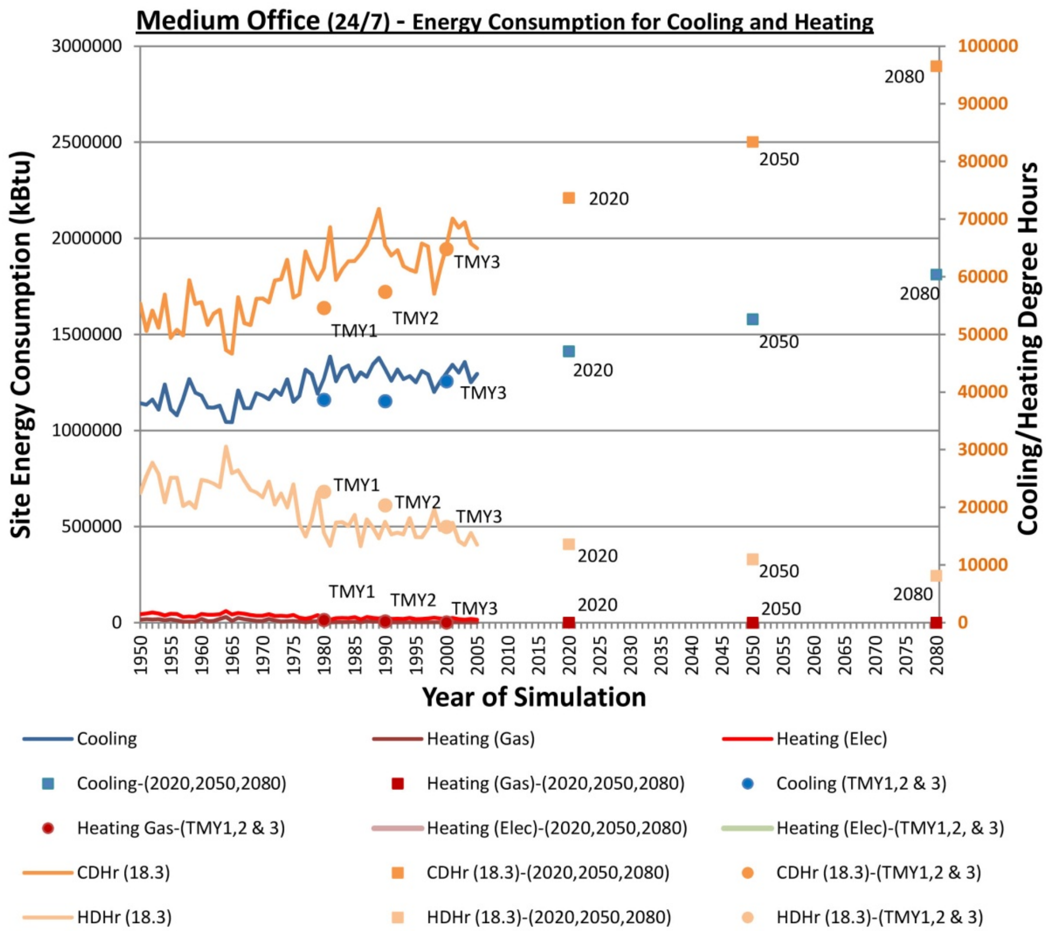


Figure 3.2.2-2: Medium Office (24/7) - Energy Consumption for Cooling and Heating (G-1)

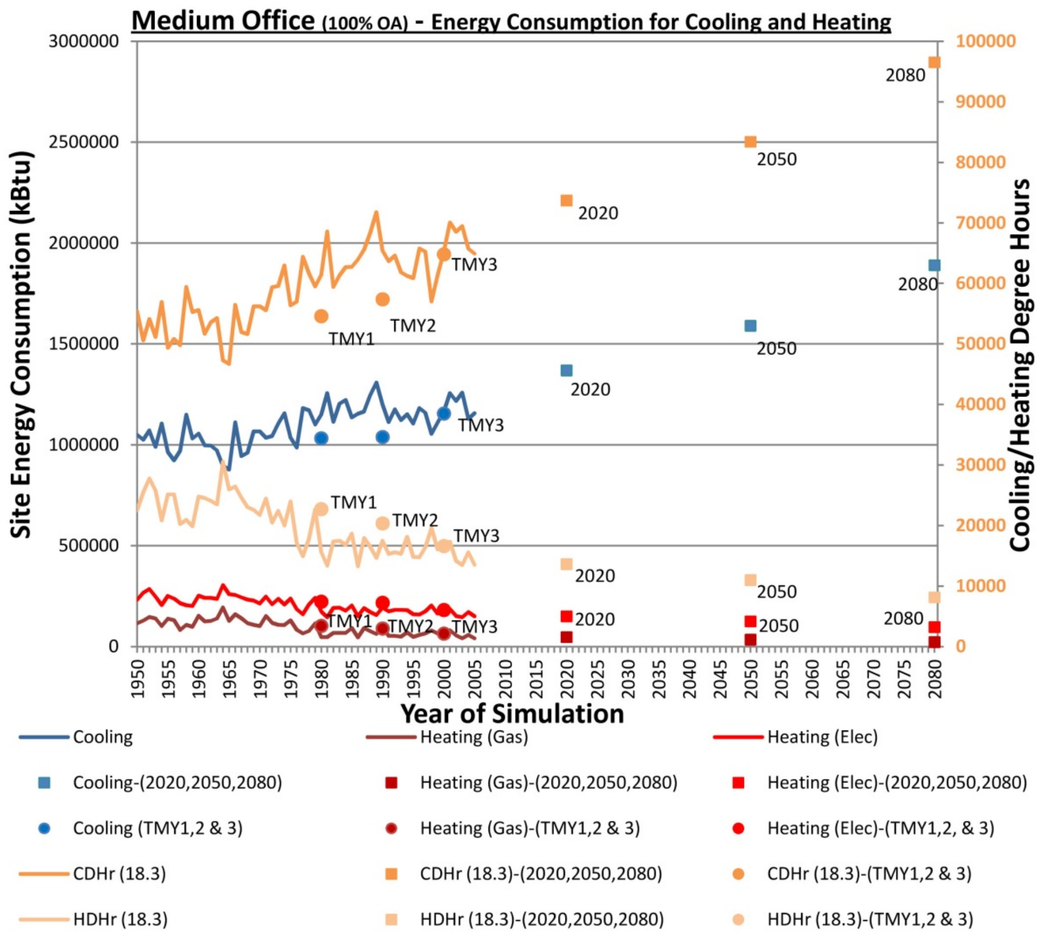


Figure 3.2.2-3: Medium Office (100% OA) - Energy Consumption for Cooling and Heating (G-1)

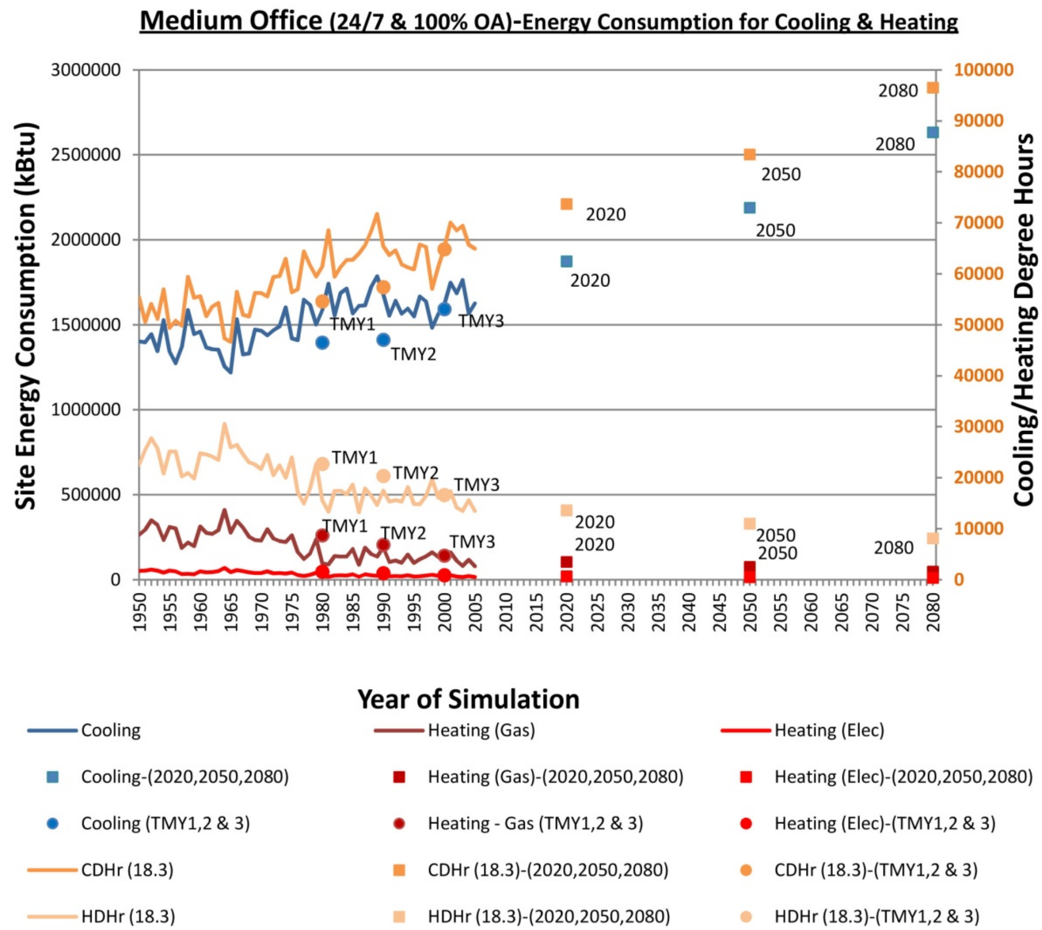


Figure 3.2.2-4: Medium Office (24/7 & 100% OA) - Energy Consumption for Cooling & Heating (G-1)

The Figure 3.2.2-5: Medium Office - Combined Heating & Cooling Energy Use (G-2) shows that the overall trend of the energy consumption shows a net positive growth. The graphs representing the combined heating and cooling energy use for the iterations of the Medium Office buildings show a similar trending pattern and are available for perusal in the Appendix ‘A’ section at the end of the report.

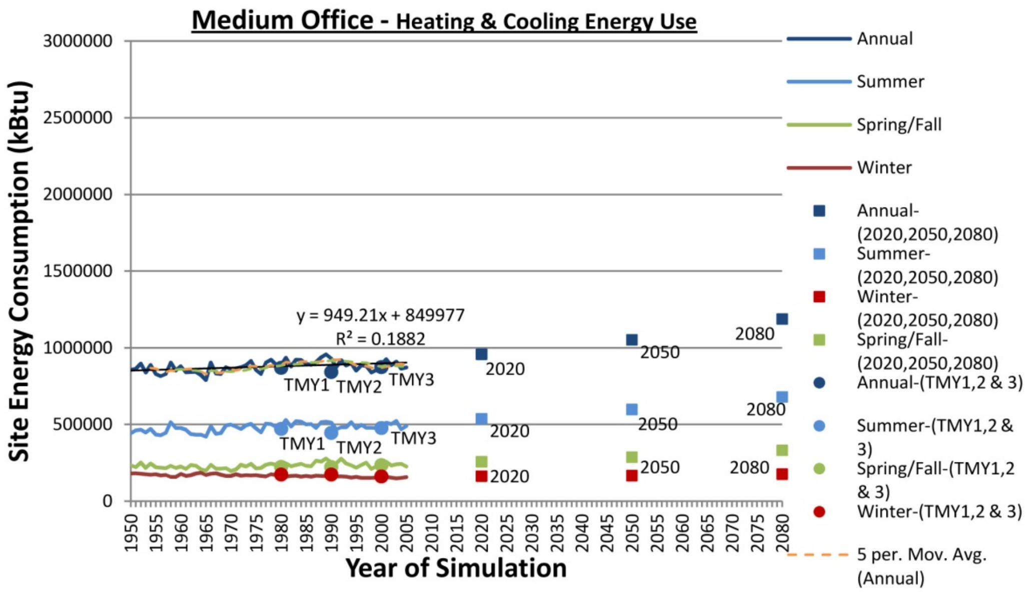


Figure 3.2.2-5: Medium Office - Combined Heating & Cooling Energy Use (G-2)

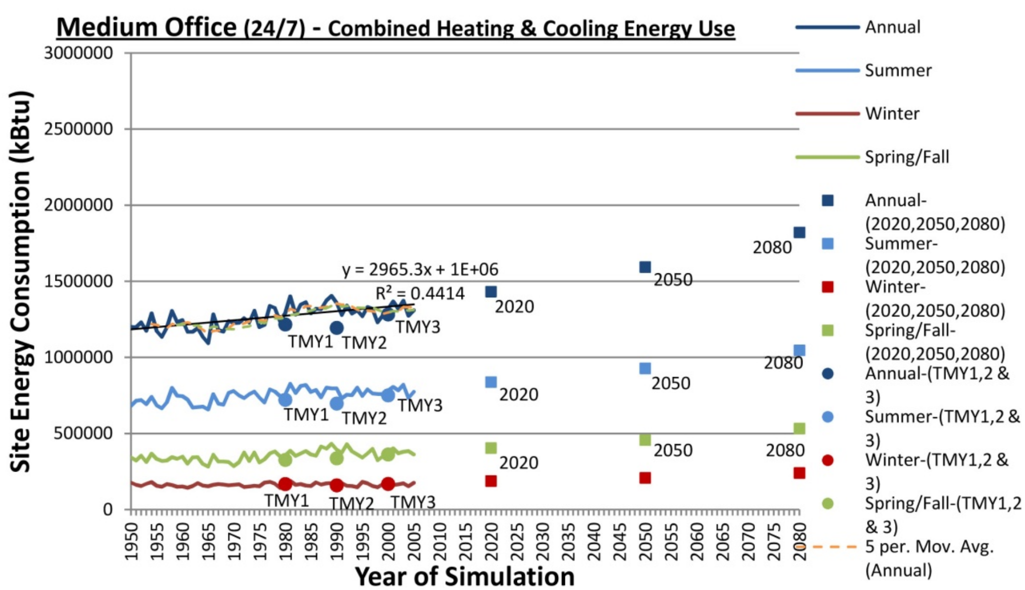


Figure 3.2.2-6: Medium Office (24/7) - Combined Heating & Cooling Energy Use (G-2)

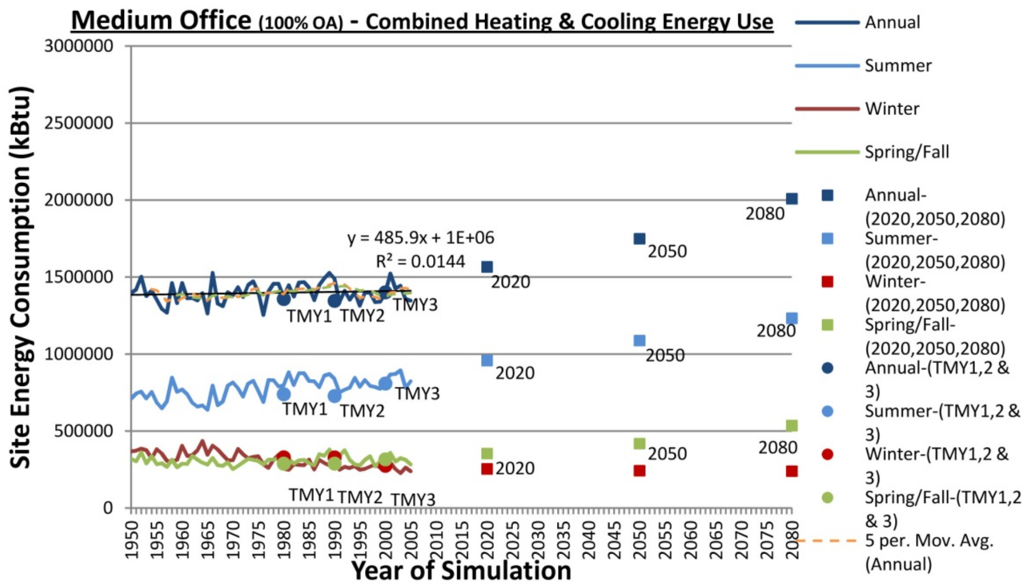


Figure 3.2.2-7: Meidum Office (100% OA) - Combined Heating and Cooling Energy Use (G-2)

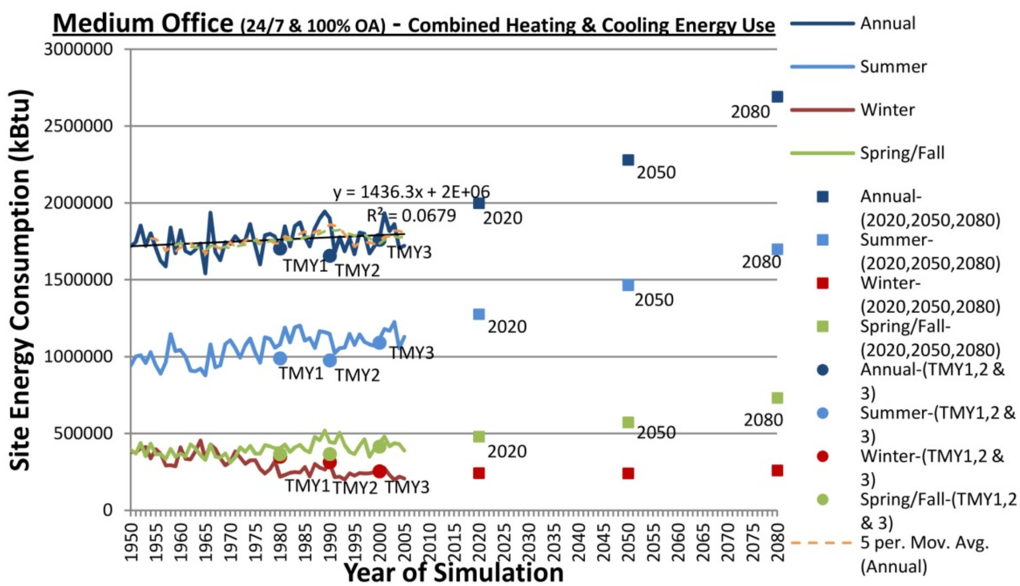


Figure 3.2.2-8: Medium Office (24/7 & 100% OA) - Combined Heating and Cooling Energy Use (G-2)

The Medium Office building seems to be more responsive to the night-time increase in temperatures and the seasonal increase in cooling energy consumption is split between the day-time and night-time increases. This trend of equal increase in all its iterations models too except for the model with 100% outside air, where the cooling energy penalty is higher during the day than during the night-time (Figure 3.2.2-9), (Figure 3.2.2-10), (

Figure 3.2.2-11) and (

Figure 3.2.2-12).

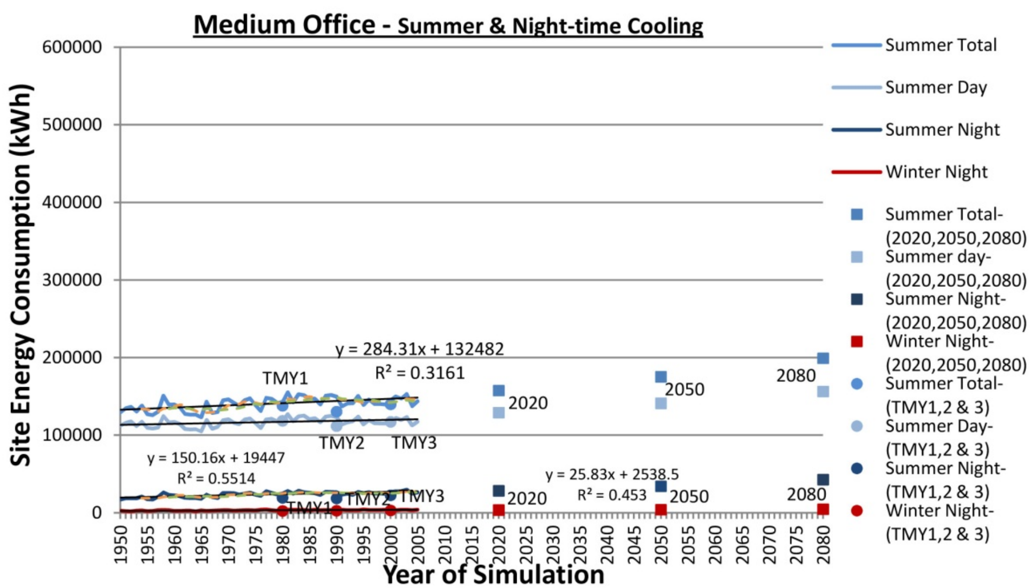
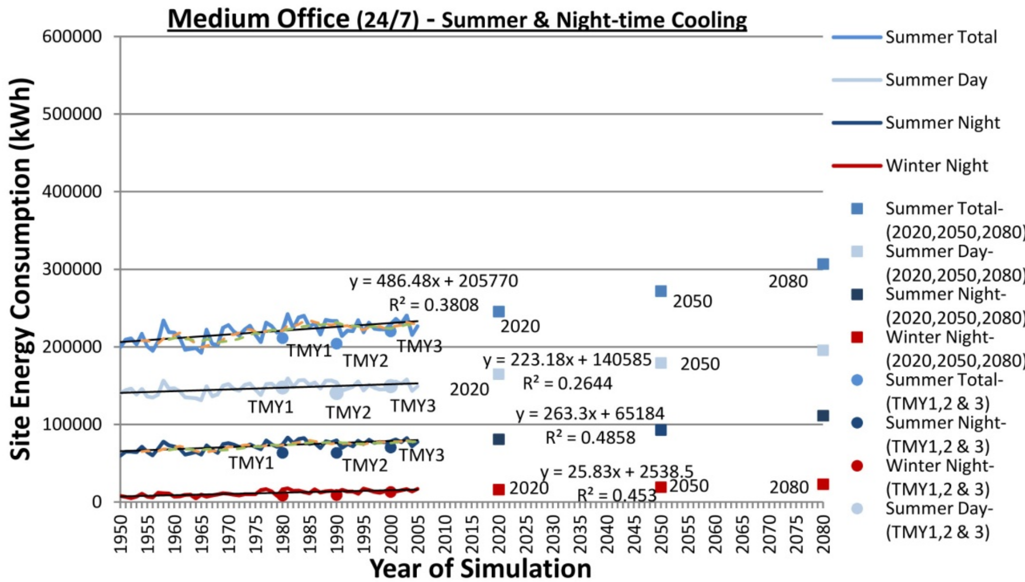


Figure 3.2.2-9: Medium Office - Summer & Night-time Cooling (G-3)



3)

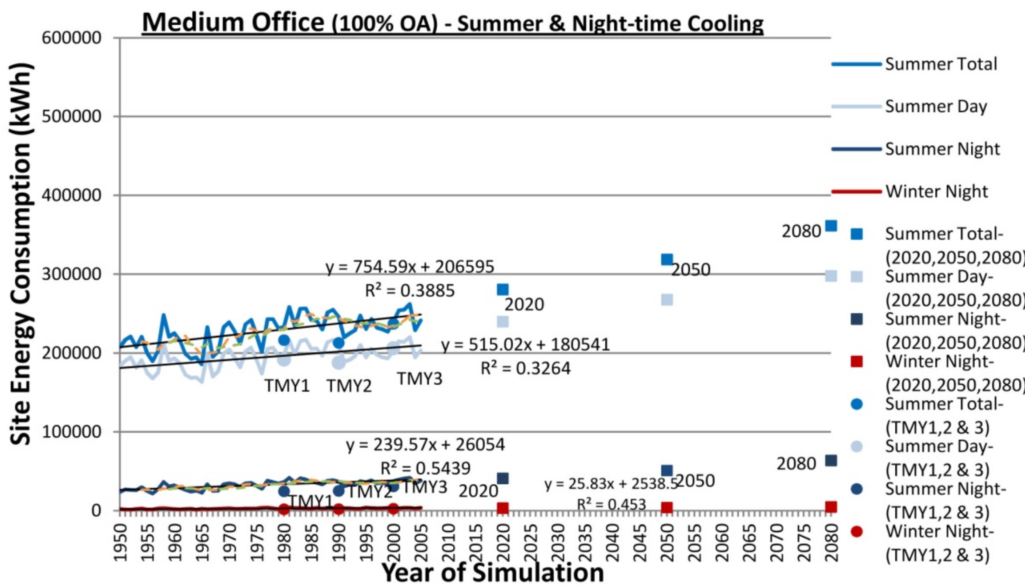


Figure 3.2.2-11: Medium Office (100% OA) - Summer & Night-time Cooling (G-3)

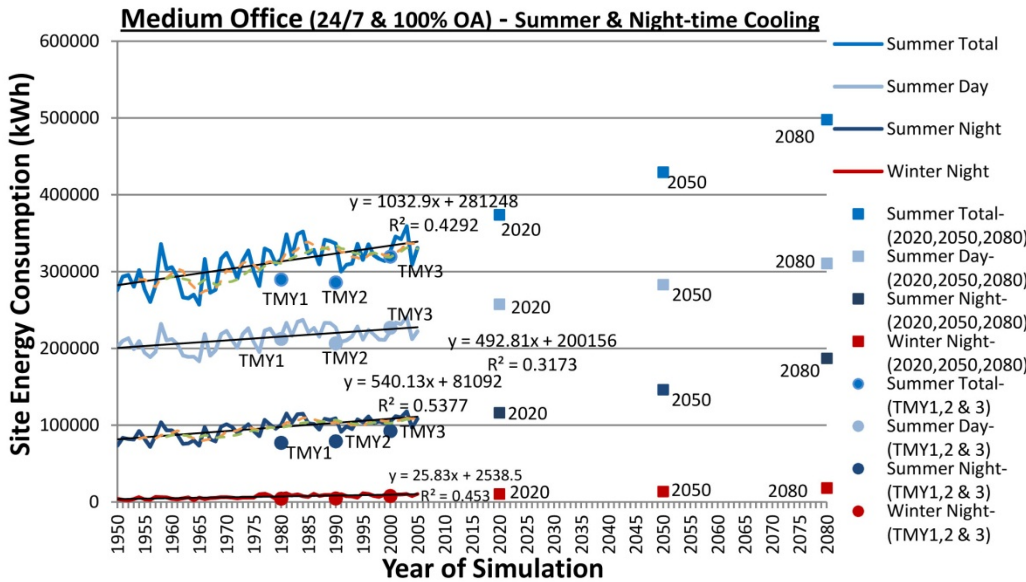


Figure 3.2.2-12: Medium Office (24/7 & 100% OA) - Summer & Night-time Cooling (G-3)

The

Figure 3.2.2-13: Medium Office - Summer Total Cooling Energy (24Hrs Weekdays only) (G-4) plots the descriptive statistical analysis values in a graphical way to that the energy. This plot clearly shows that cooling energy consumed per day in the summers is increasing widely and not just the maximum values. The Summer Daily Cooling Energy (24Hrs - Weekdays only) graphs representing the iterations of the Medium Office buildings show a similar trending pattern and are available for perusal in the Appendix 'A' section at the end of the report.

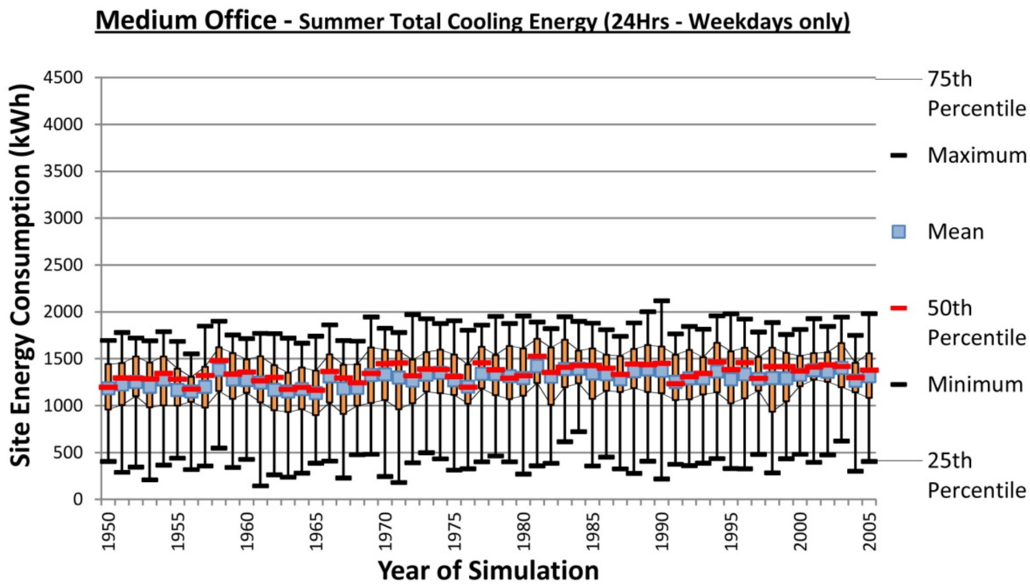


Figure 3.2.2-13: Medium Office - Summer Total Cooling Energy (24Hrs Weekdays only) (G-4)

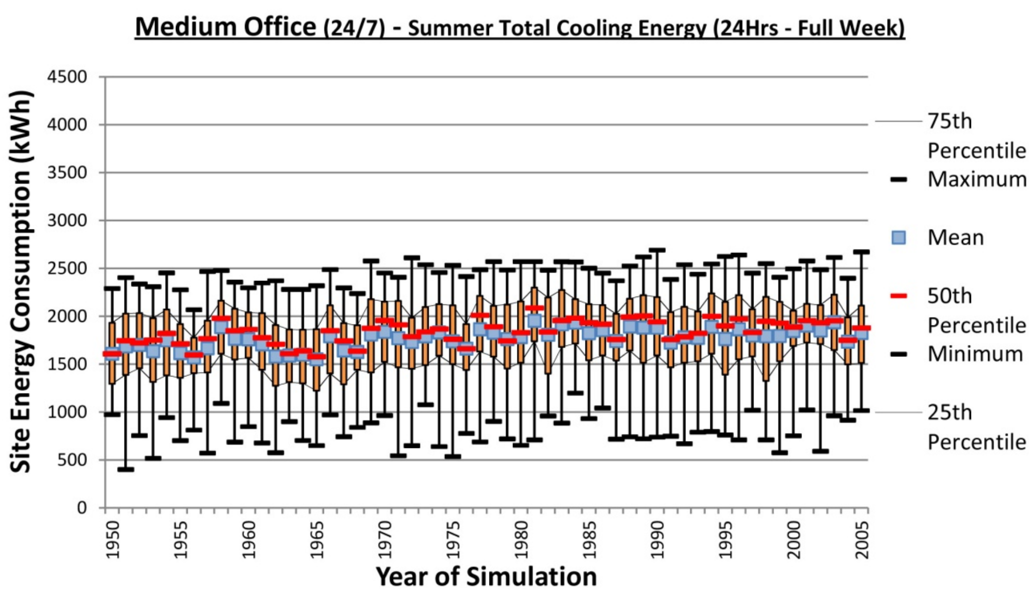


Figure 3.2.2-14: Medium Office (24/7) - Summer Total Cooling Energy (24hrs - Full Week) (G-4)

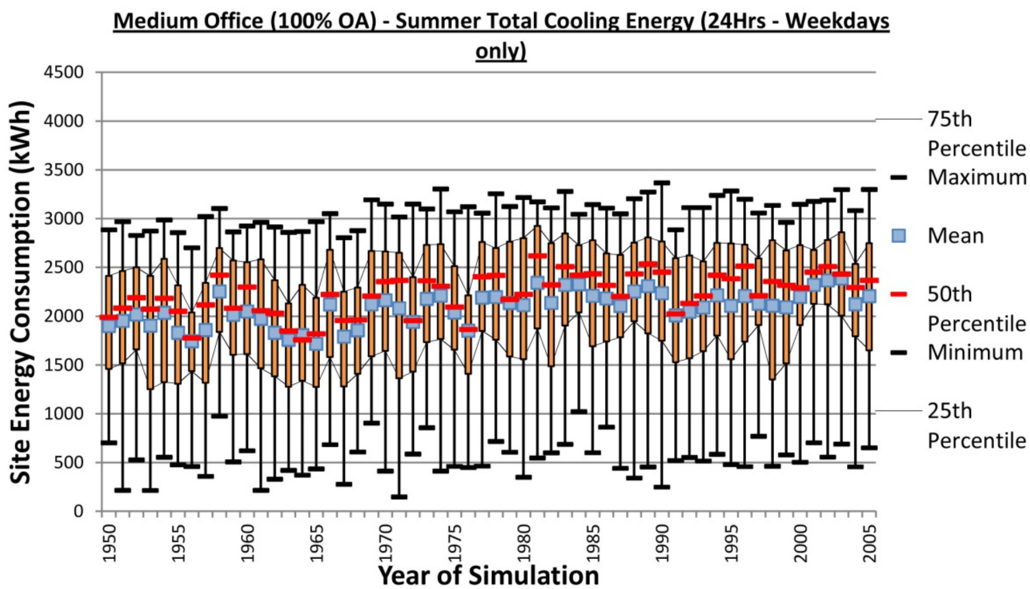


Figure 3.2.2-15: Medium Office (100% OA) - Summer Total Cooling Energy (24Hrs - Weekdays only) (G-4)

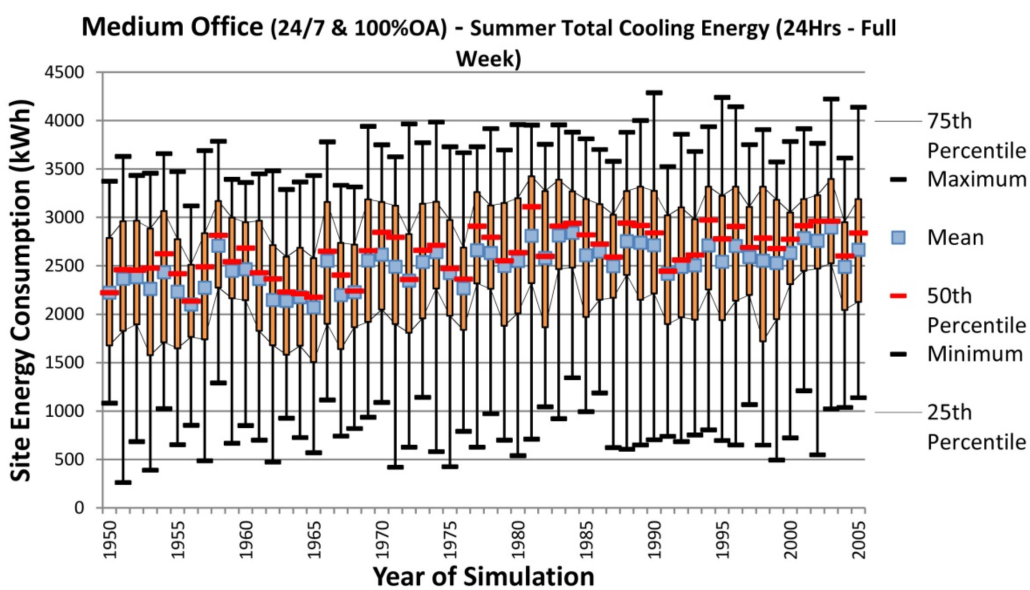


Figure 3.2.2-16: Medium Office (24/7 & 100% OA) - Summer Total Cooling Energy (24Hrs - Full Week) (G-4)

The series of scatter plots analyzing the correlation between the cooling degree hours and the cooling energy consumption. The plots (Figure 3.2.2-17, Figure 3.2.2-18, Figure 3.2.2-19 and Figure 3.2.2-20) show how the cooling energy consumption values change annually, for the summer season and summer days and nights with respect to the corresponding cooling degree hours for that time period. The is noticed that the slope of the lines correlating the summer day and summer night cooling energy consumption values slightly increases as the model is altered to behave like a 24hrs 7days a week work schedule office which is predicted as longer working hours means that the building has to maintain the regular habitable set-points into the night hours and hence savings due to thermostat setback is lost, also the rising summer night-time temperatures start to have a direct impact on the energy consumption values. The introduction of 100% OA pushes the cooling energy consumption during the daytime very high for every unit rise in cooling degree hours.

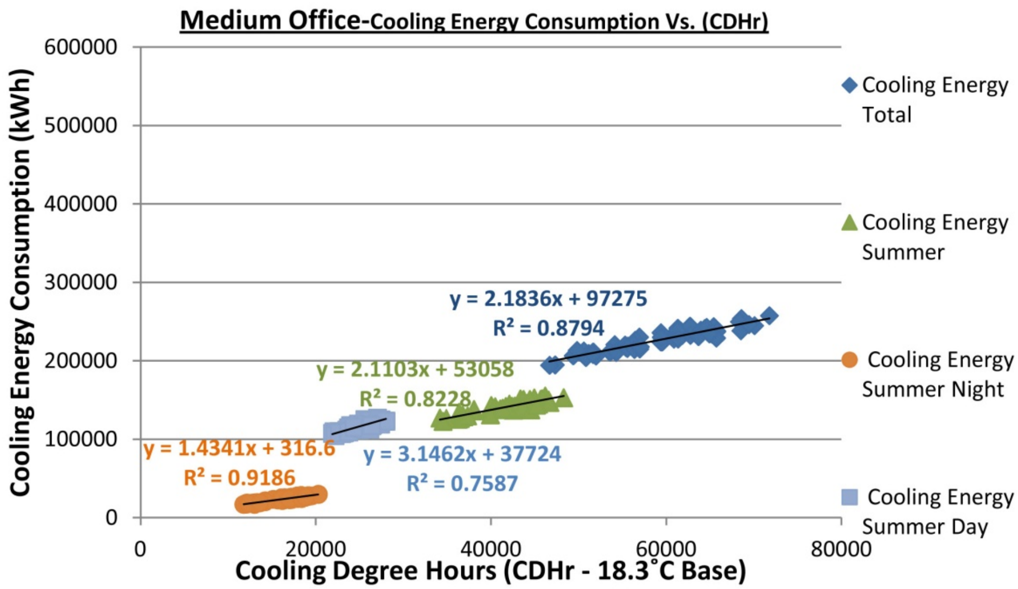


Figure 3.2.2-17: Medium Office - Cooling Energy Consumption Vs. Cooling Degree Hours (G-5)

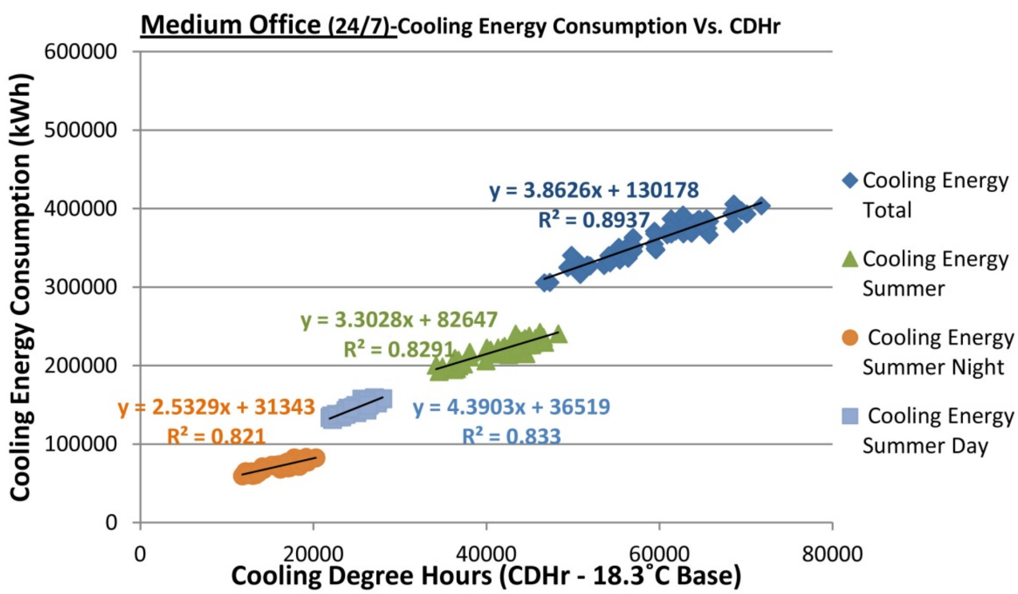


Figure 3.2.2-18: Medium Office (24/7) - Cooling Energy Consumption Vs. Cooling Degree Hours (G-5)

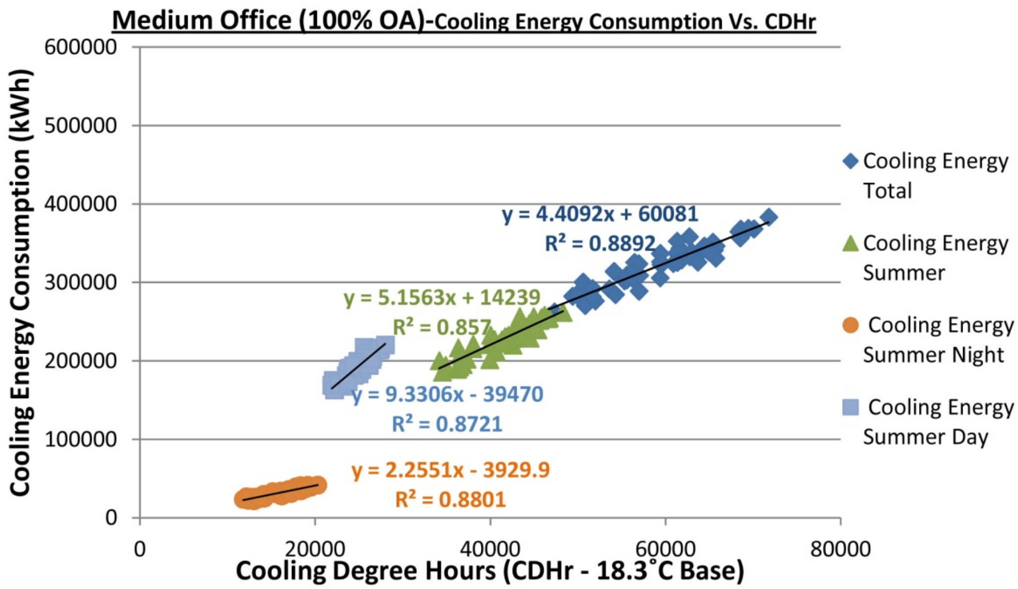


Figure 3.2.2-19: Medium Office (100% OA) - Cooling Energy Consumption Vs. Cooling Degree Hours (G-5)

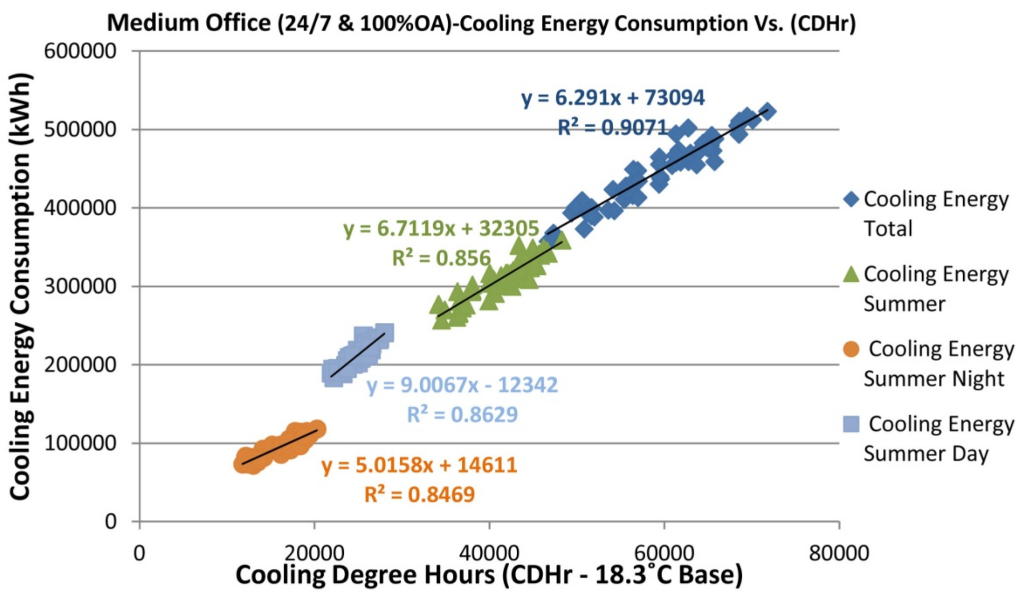


Figure 3.2.2-20: Medium Office (24/7 & 100%) - Cooling Energy Consumption vs. Cooling Degree Hours (G-5)

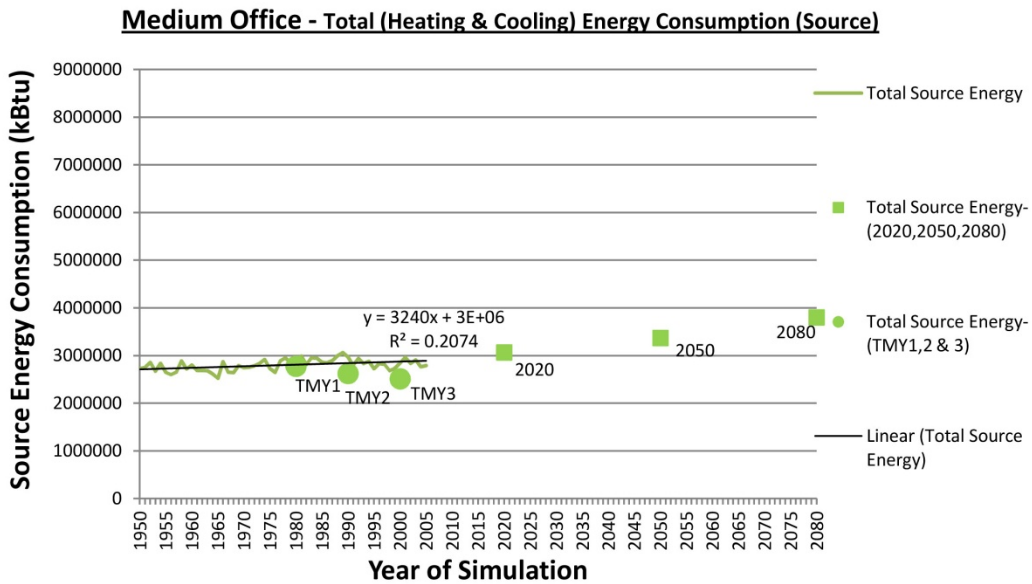


Figure 3.2.2-21: Medium Office - Total (Heating & Cooling) Energy Consumption (Source) (G-6)

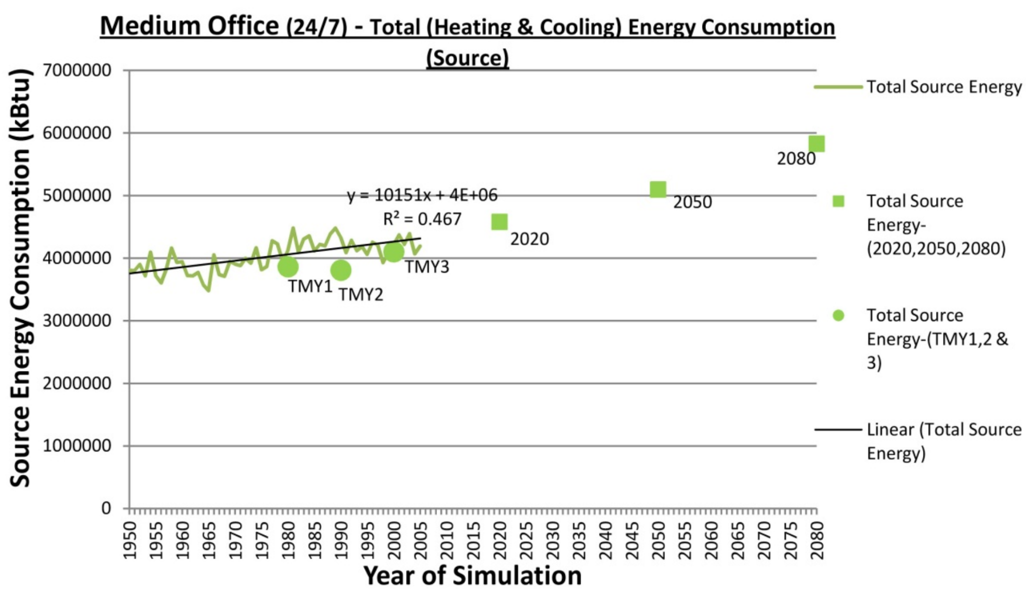


Figure 3.2.2-22: Medium Office (24/7) - Total (Heating & Cooling) Energy Consumption (Source) (G-6)

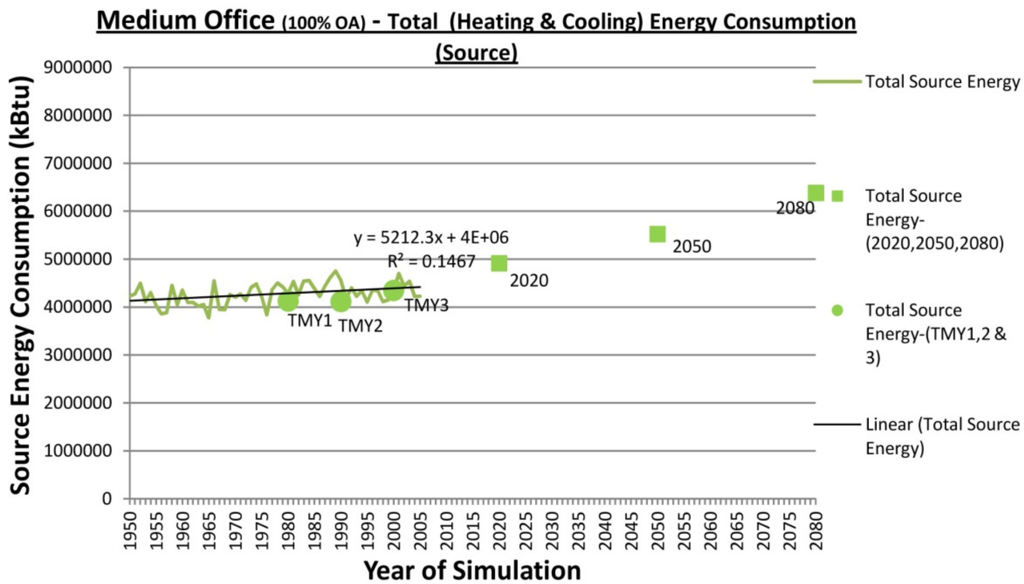


Figure 3.2.2-23: Medium Office (100% OA) - Total (Heating & Cooling) Energy Consumption (Source) (G-6)

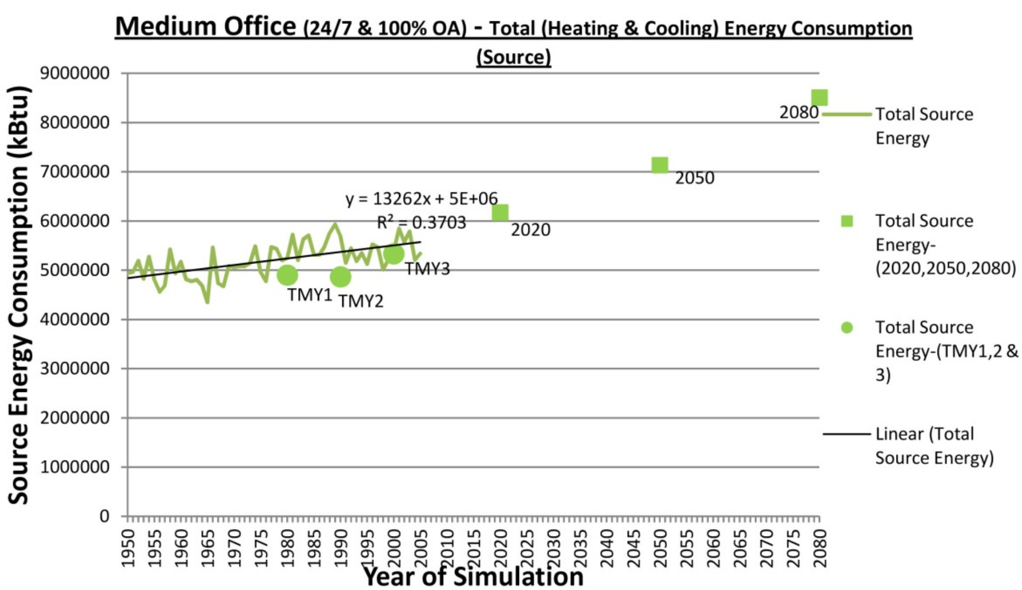


Figure 3.2.2-24: Medium Office (24/7 & 100% OA) - Total (Heating & Cooling) Energy Consumption (Source) (G-6)

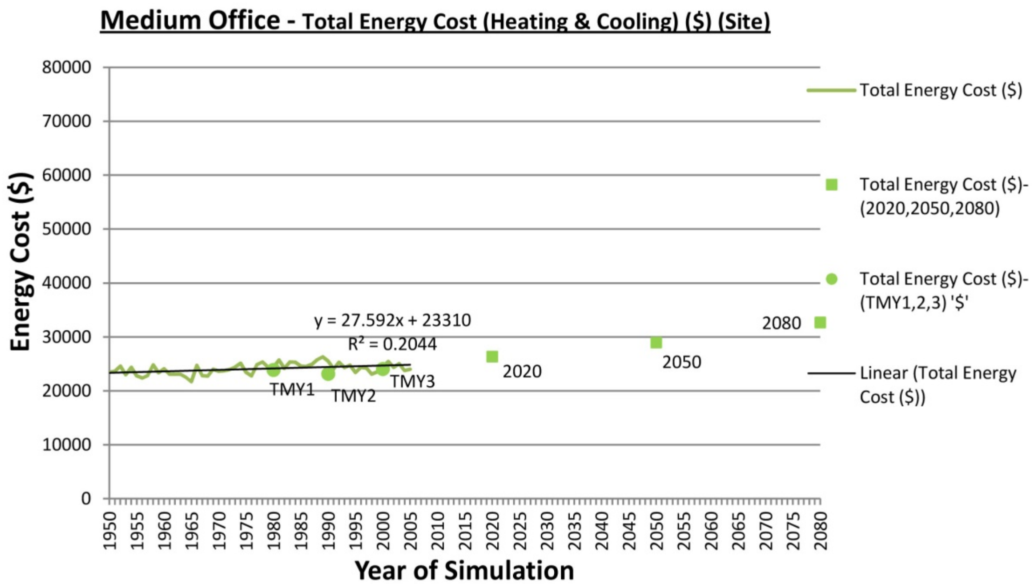


Figure 3.2.2-25: Medium Office - Total (Summer Cooling) Energy Consumption (Site) (G-7)

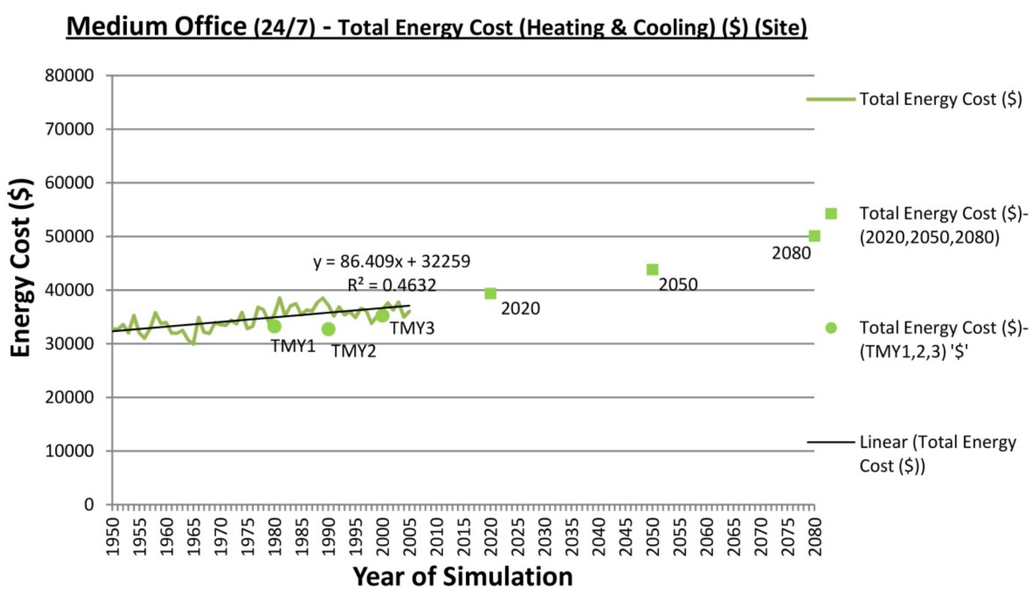


Figure 3.2.2-26: Medium Office (24/7) - Total (Summer Cooling) Energy Consumption (Site) (G-7)

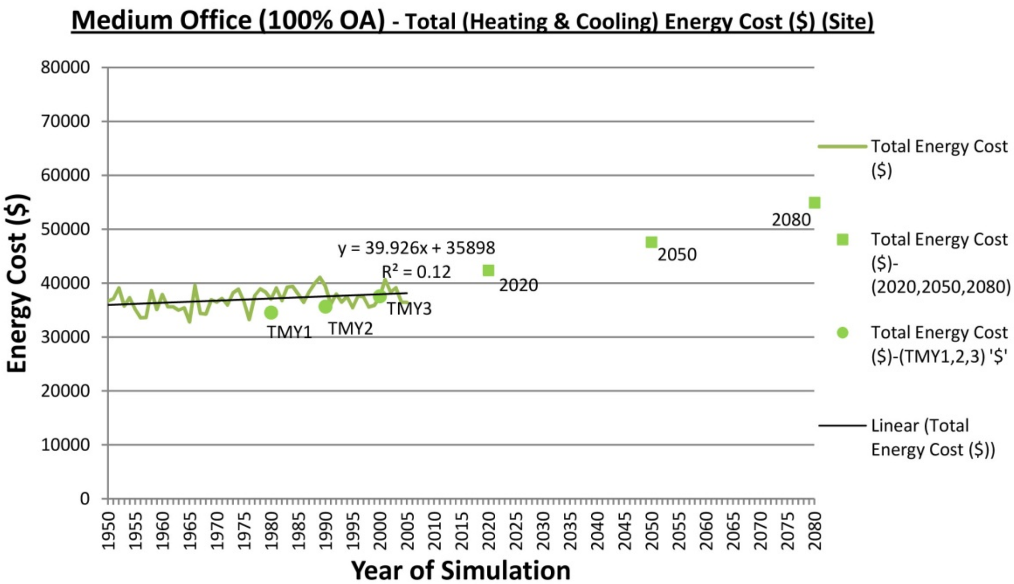


Figure 3.2.2-27: Medium Office (100% OA) - Total (Summer Cooling) Energy Consumption (Site) (G-7)

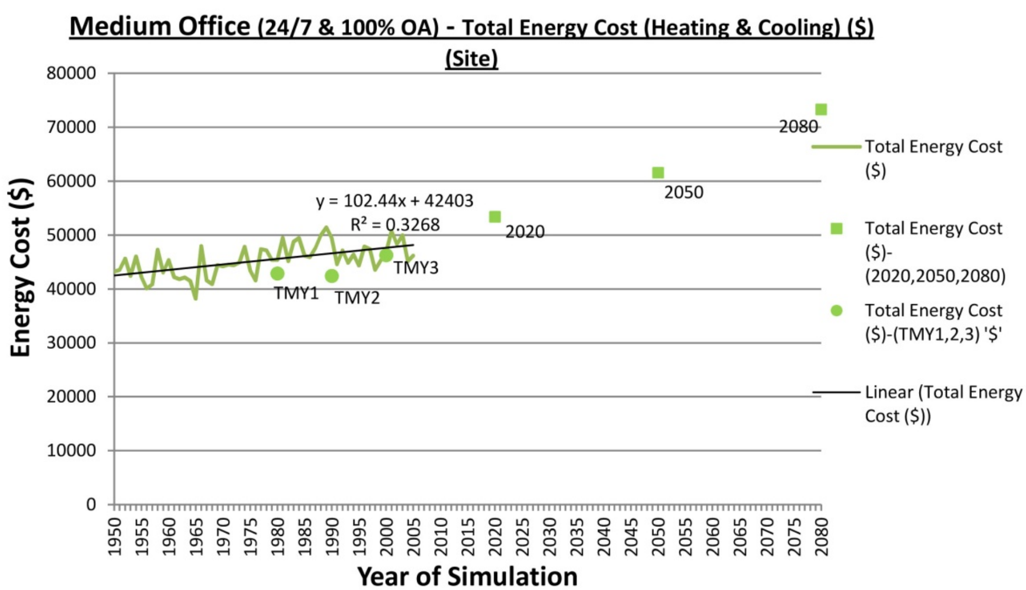


Figure 3.2.2-28: Medium Office (24/7 & 100% OA) - Total (Summer Cooling) Energy Consumption (Site) (G-7)

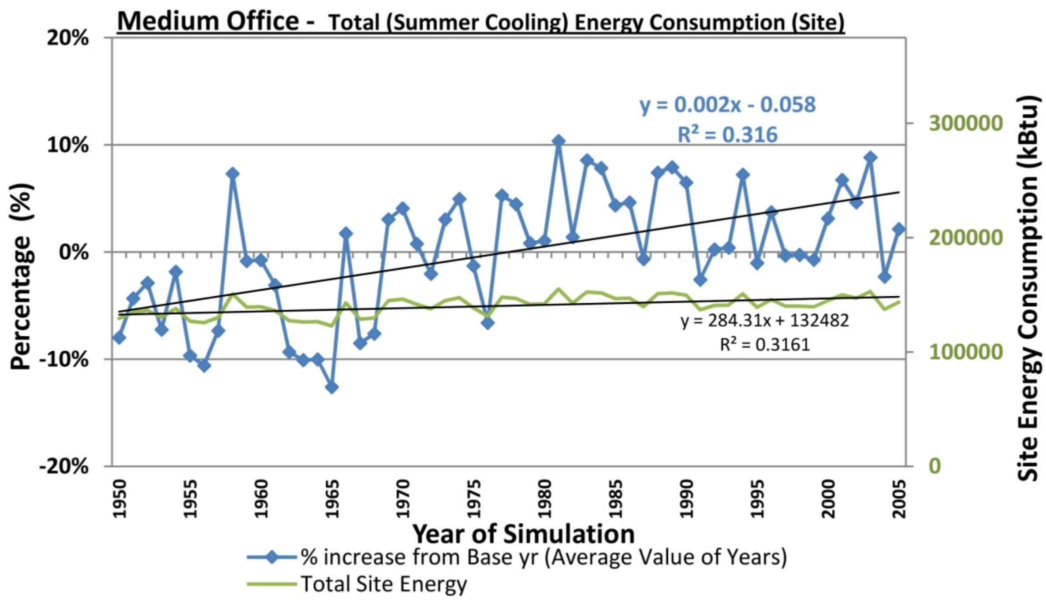


Figure 3.2.2-29: Medium Office - Total (Summer Cooling) Energy Consumption (Site) (G-8)

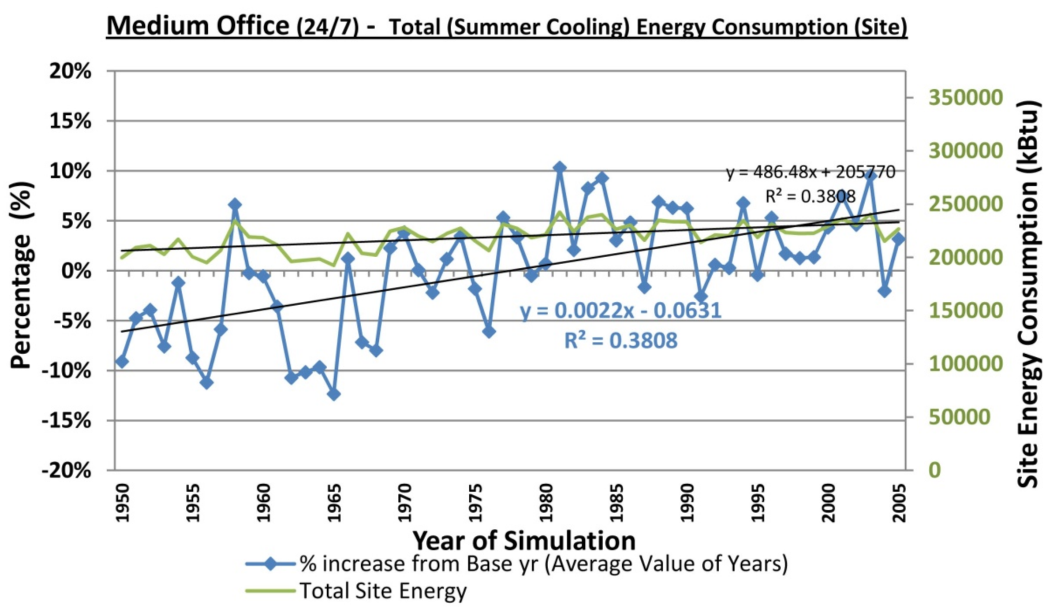


Figure 3.2.2-30: Medium Office (24/7) - Total (Summer Cooling) Energy Consumption (Site) (G-8)

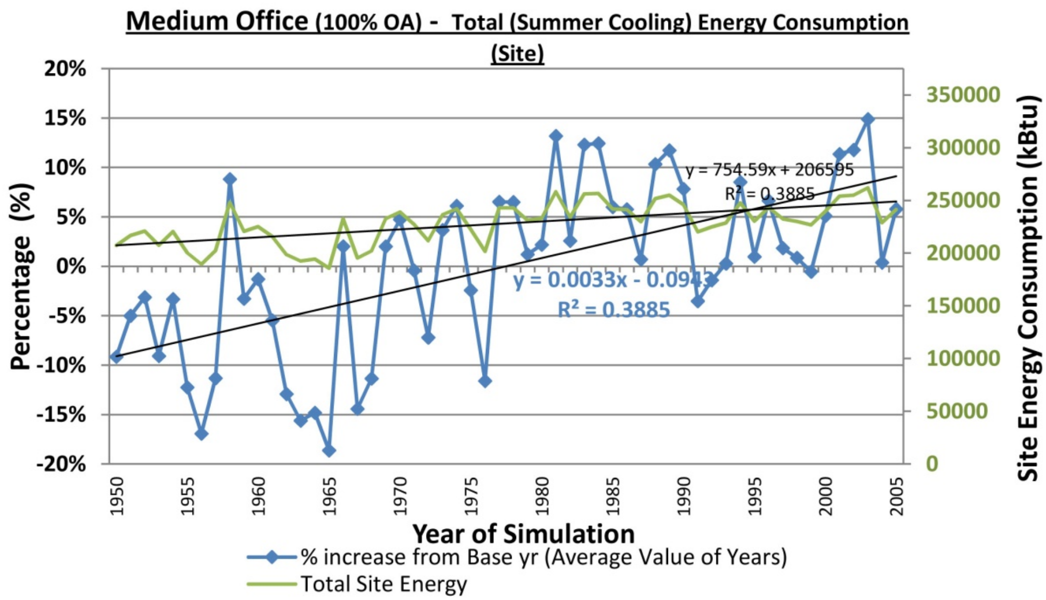


Figure 3.2.2-31: Medium Office (100% OA) - Total (Summer Cooling) Energy Consumption (Site) (G-8)

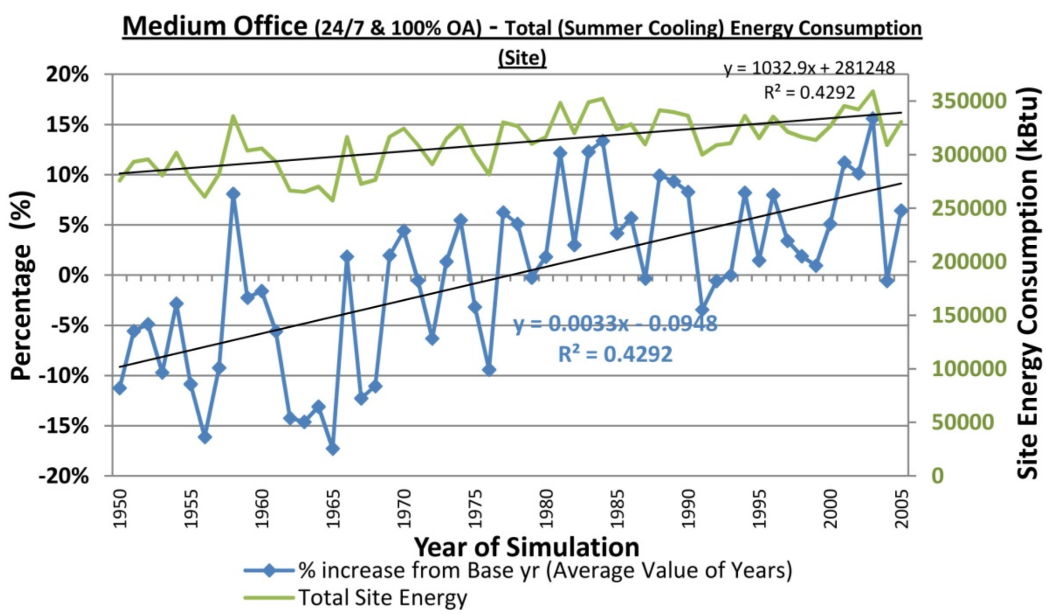


Figure 3.2.2-32: Medium Office (24/7 & 100% OA) - Total (Summer Cooling) Energy Consumption (Site) (G-8)

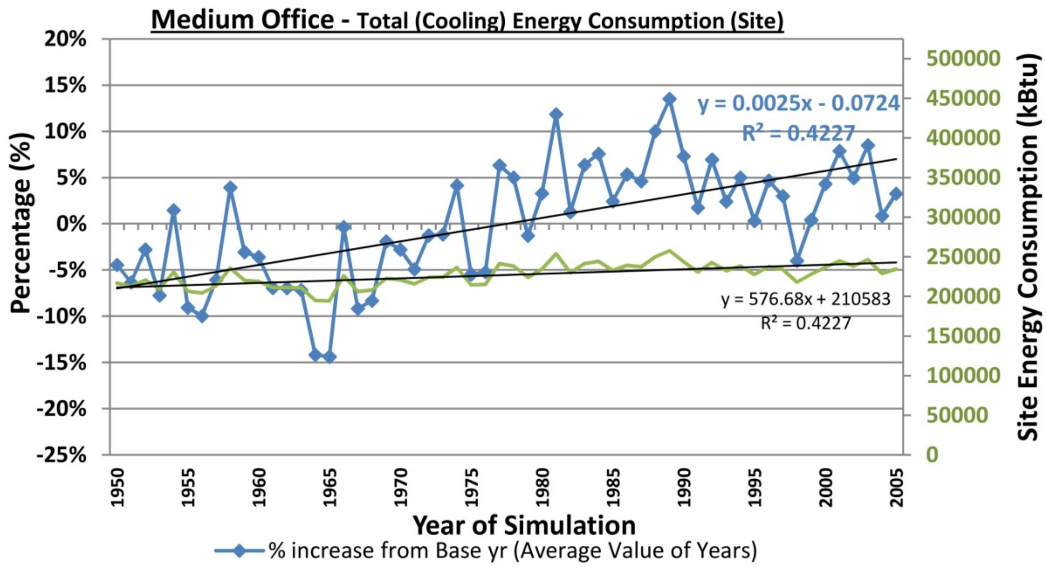


Figure 3.2.2-33: Medium Office - Total (Cooling) Energy Consumption (Site) (G-9)

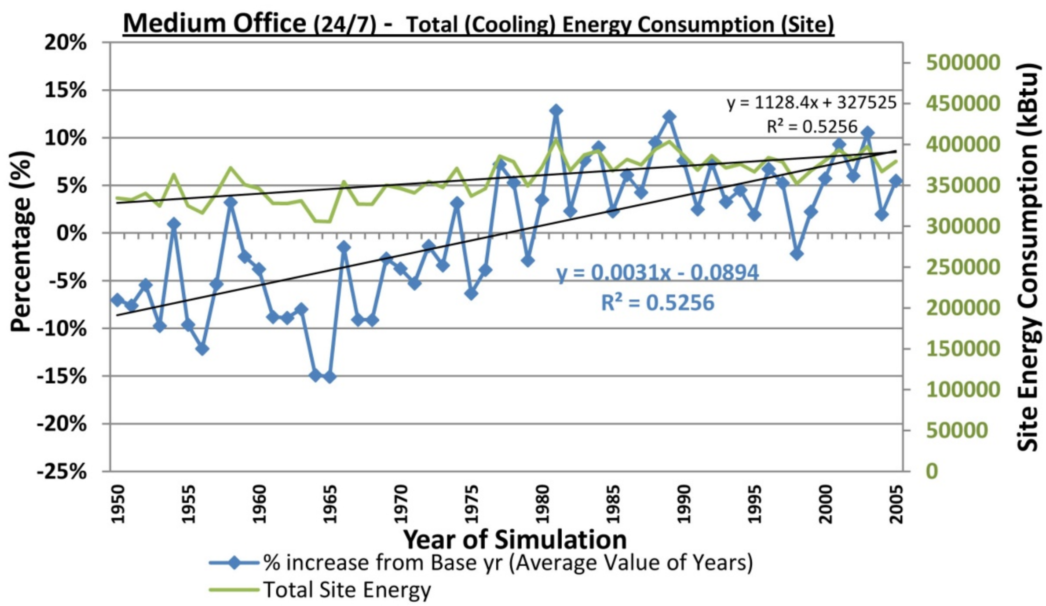


Figure 3.2.2-34: Medium Office (24/7) - Total (Cooling) Energy Consumption (Site) (G-9)

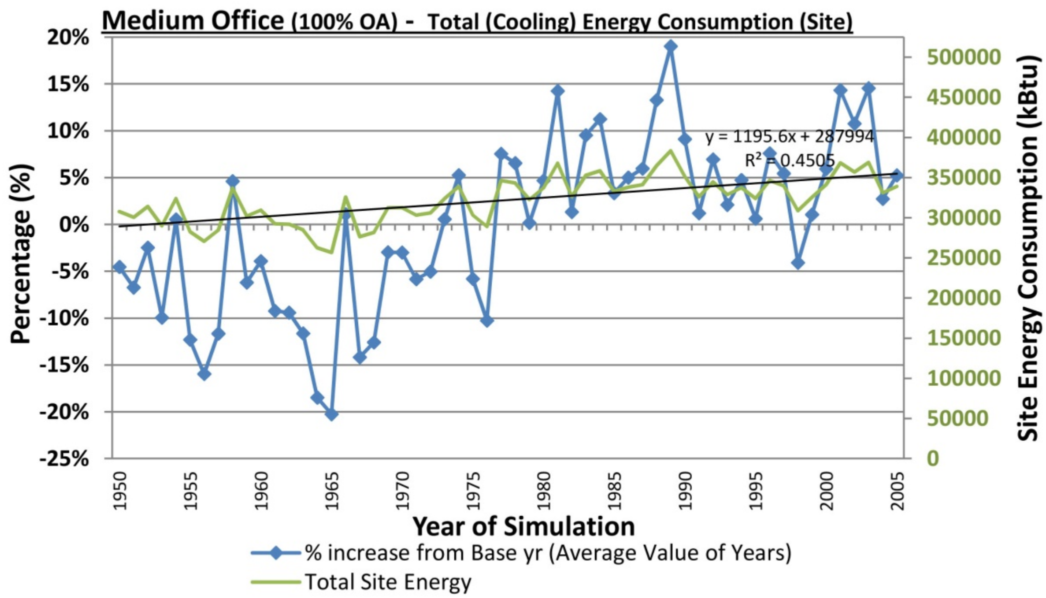


Figure 3.2.2-35: Medium Office (100% OA) - Total (Cooling) Energy Consumption (Site) (G-9)

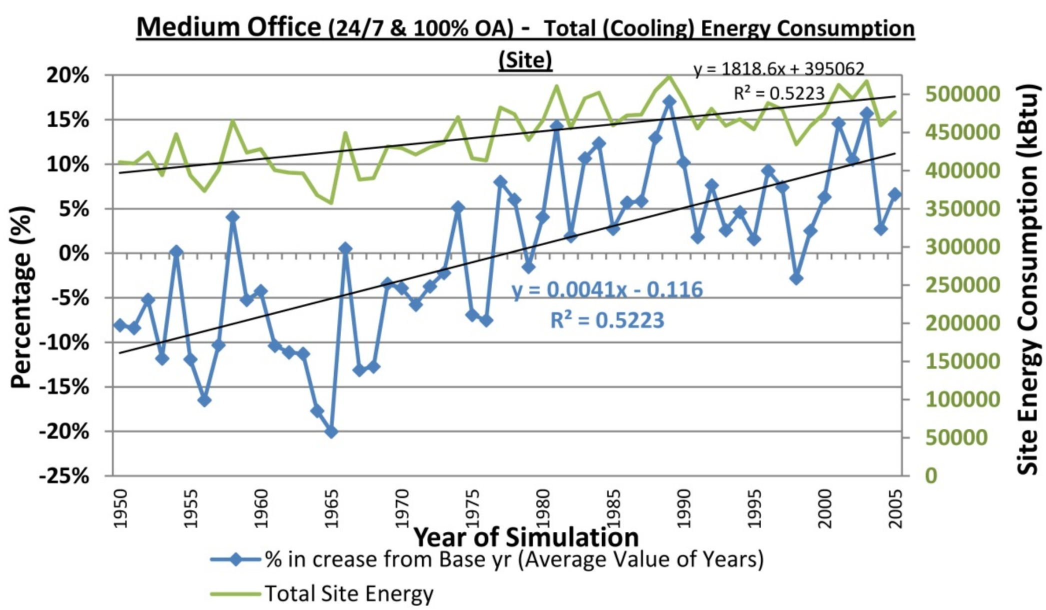


Figure 3.2.2-36: Medium Office (24/7 & 100% OA) - Total (Cooling) Energy Consumption (Site) (G-9)

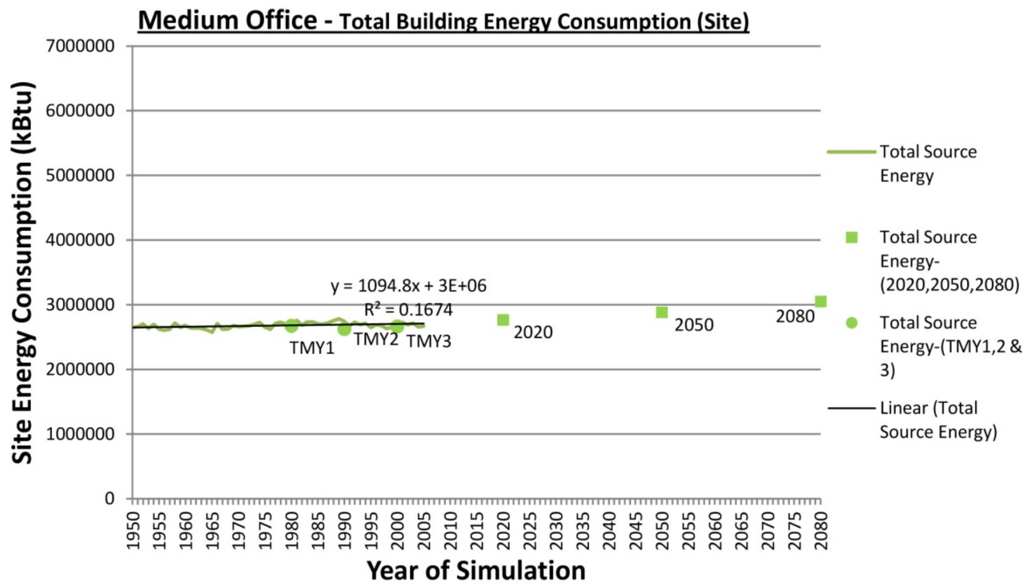


Figure 3.2.2-37: Medium Office - Total Building Energy Consumption (Site) (G-10)

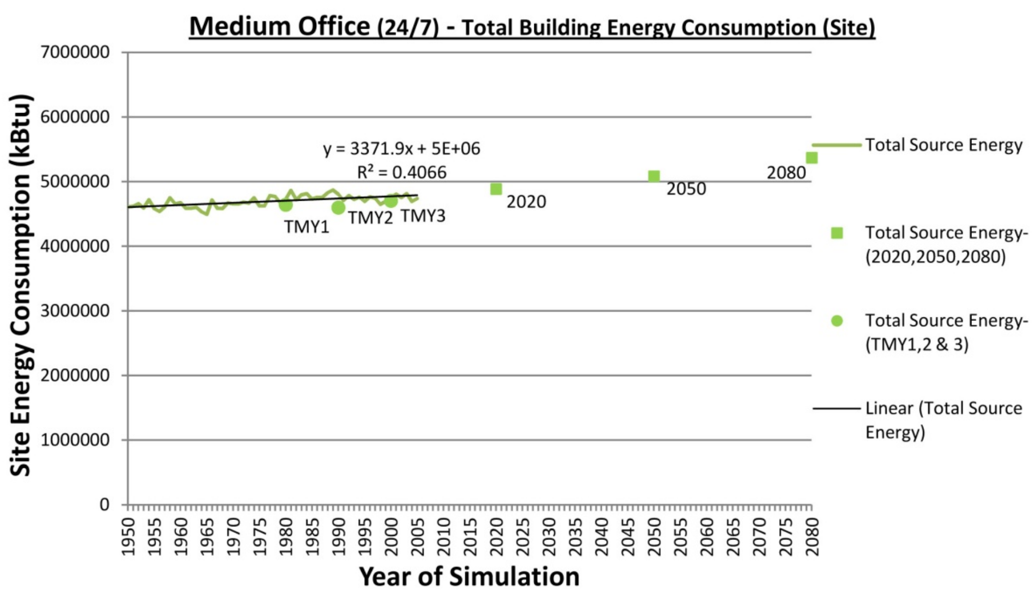


Figure 3.2.2-38: Medium Office (24/7) - Total Building Energy Consumption (Site) (G-10)

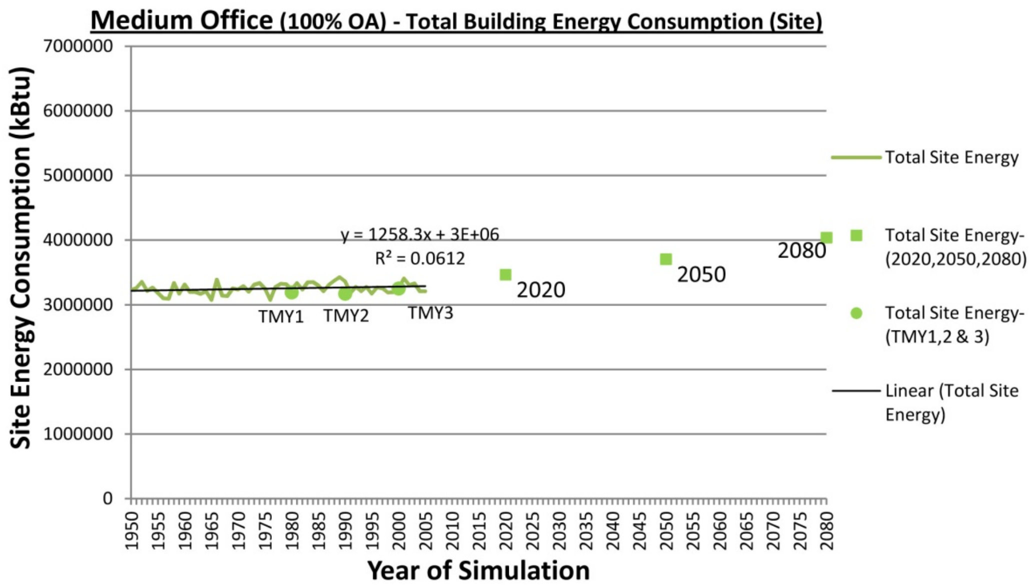


Figure 3.2.2-39: Medium Office (100% OA) - Total Building Energy Consumption (Site) (G-10)

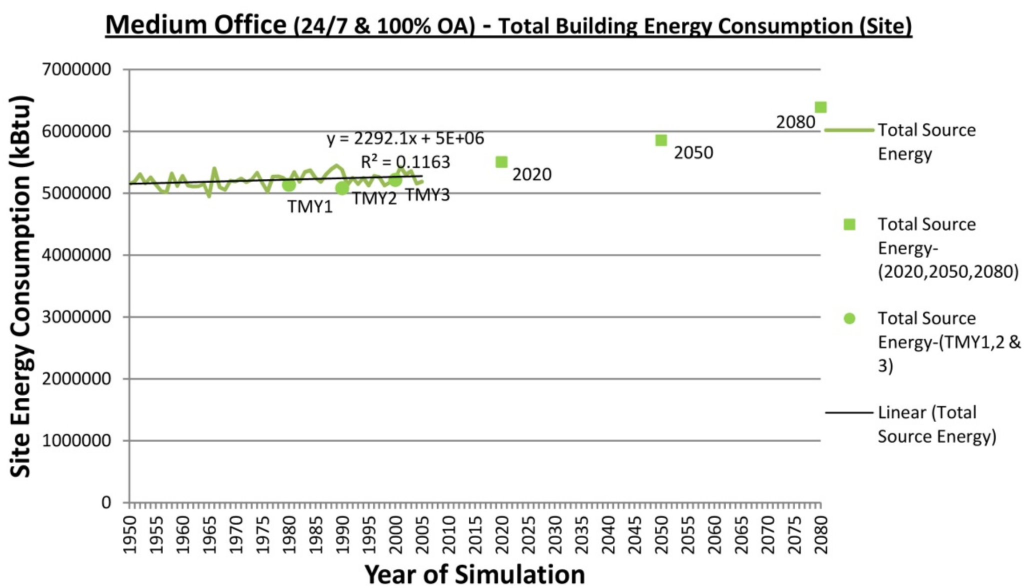


Figure 3.2.2-40: Medium Office (24/7 & 100% OA) - Total Building Energy Consumption (Site) (G-10)

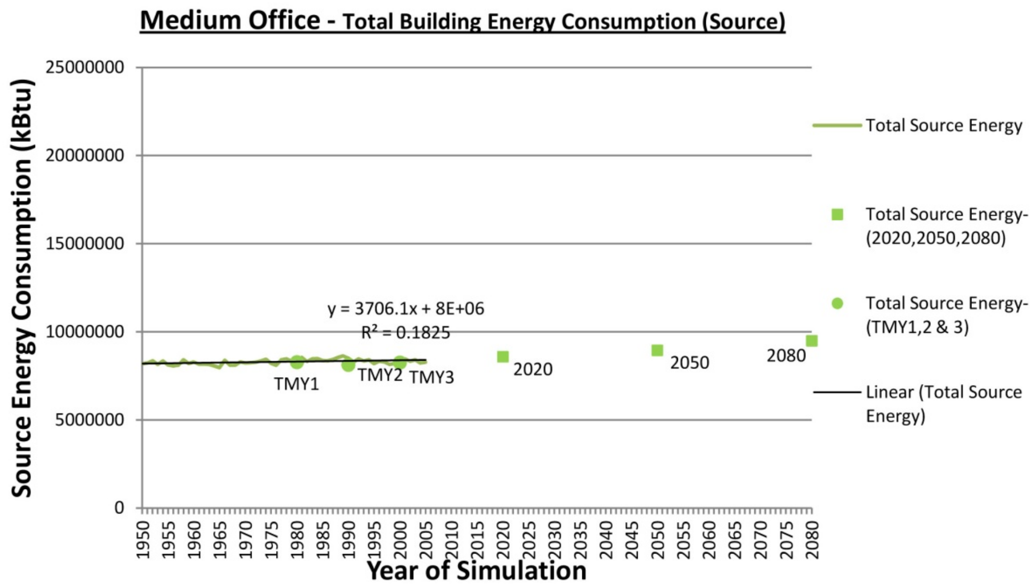


Figure 3.2.2-41: Medium Office - Total Building Energy Consumption (Source) (G-11)

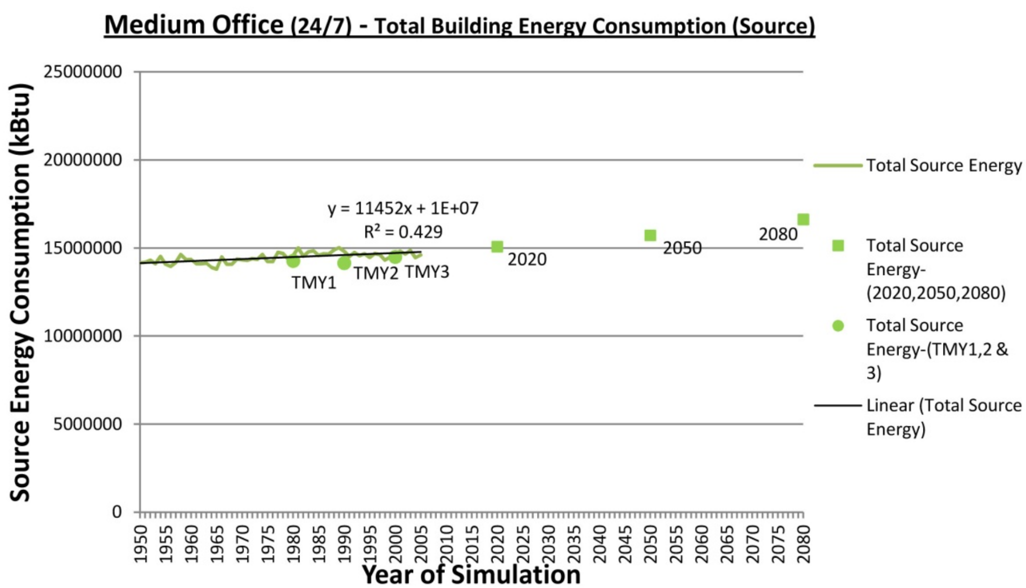


Figure 3.2.2-42: Medium Office (24/7) - Total Building Energy Consumption (Source) (G-11)

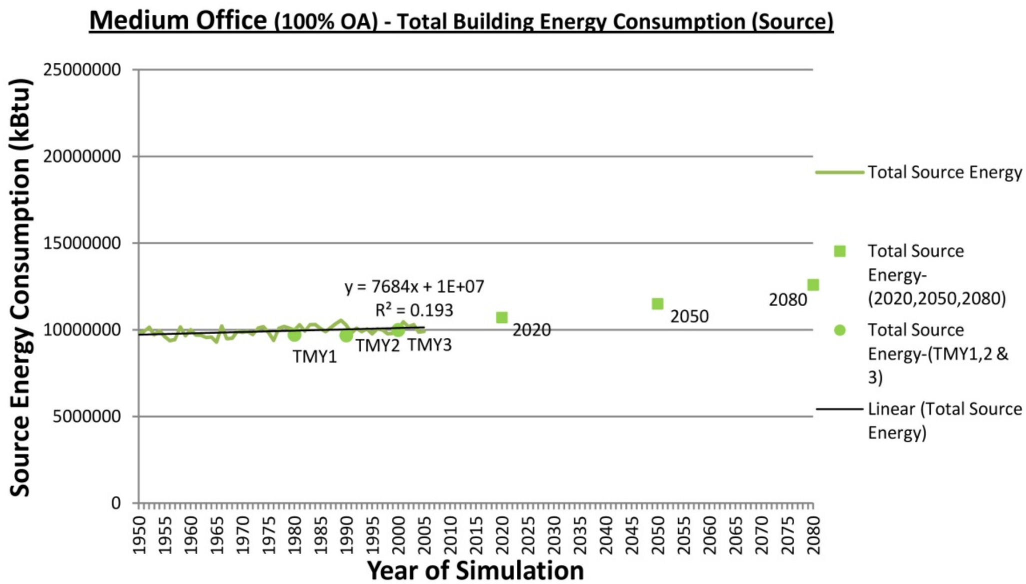


Figure 3.2.2-43: Medium Office (100% OA) - Total Building Energy Consumption (Source) (G-11)

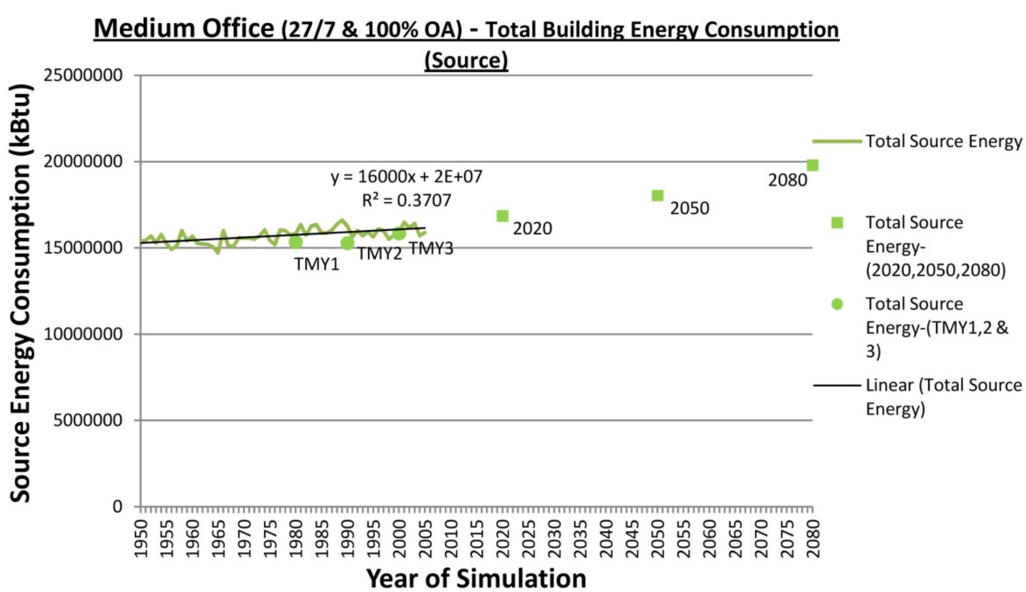


Figure 3.2.2-44: Medium Office (24/7 & 100% OA) - Total Building Energy Consumption (Source) (G-11)

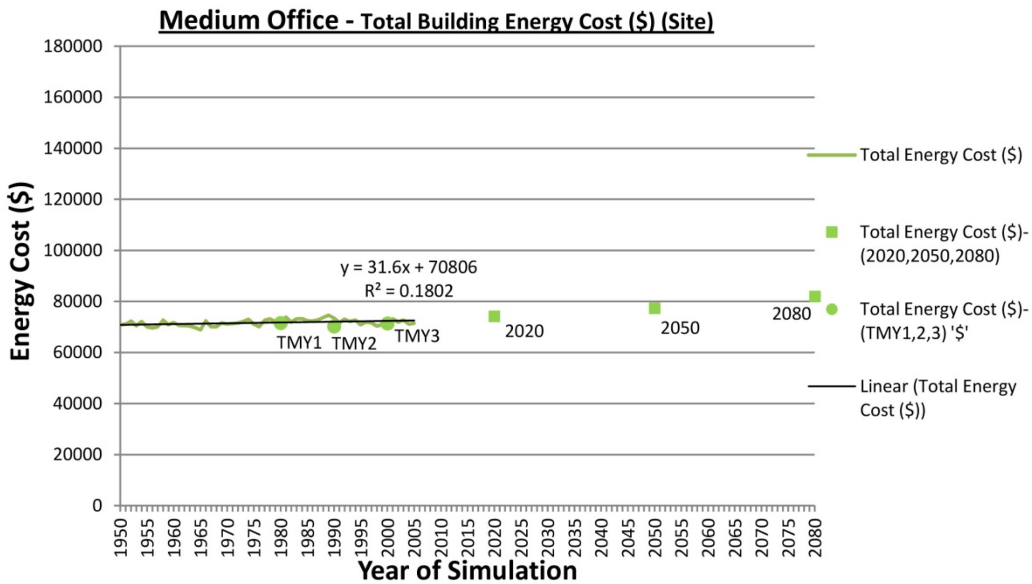


Figure 3.2.2-45: Medium Office - Total Building Energy Cost ($) (Site) (G-12)

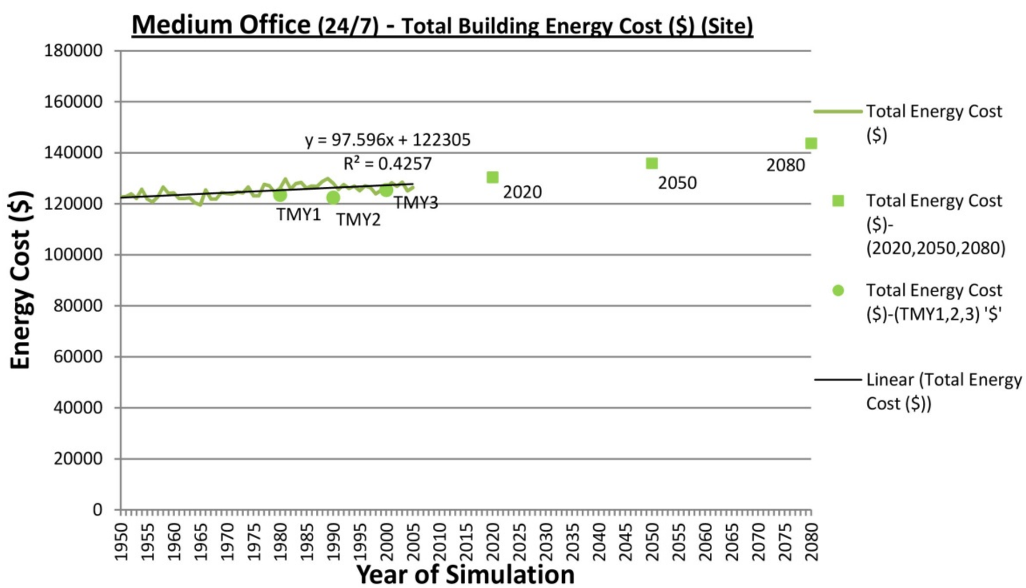


Figure 3.2.2-46: Medium Office (24/7) - Total Building Energy Cost ($) (Site) (G-12)

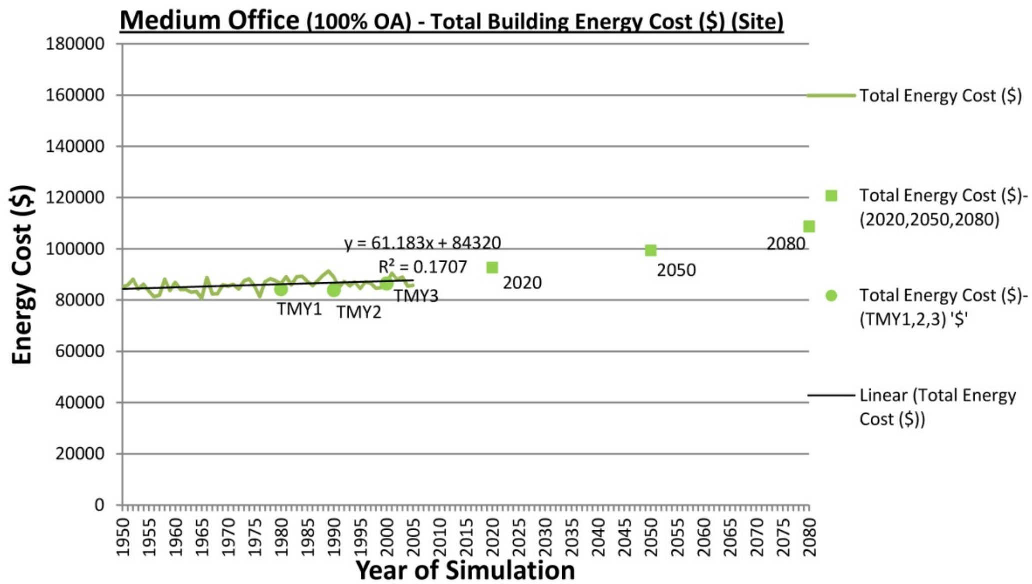


Figure 3.2.2-47: Medium Office (100% OA) - Total Building Energy Cost ($) (Site) (G-12)

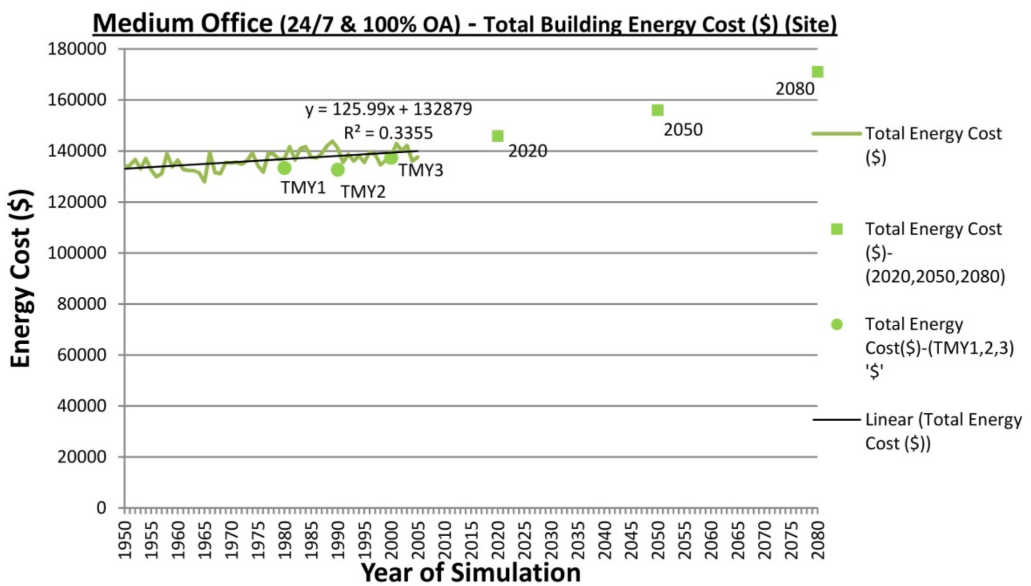


Figure 3.2.2-48: Medium Office (24/7 & 100% OA) - Total Building Energy Cost ($) (Site) (G-12)

The graphs representing the other building typologies such as the Large Office building, Retail standalone, Hospital. Warehouse, Midrise Apartment and the Single Family (detached) residential typologies are available in Appendix 'B'.

The trends, anomalies and other analysis points uncovered during the review of the results and the graphs for the other building typologies have not been discussed thoroughly in here for the lack of time. Further analysis of the data so available from the annual simulations could also be taken up at a later stage, as the enormity and the wealth of information available through this modeling and retro-annual simulation was too overwhelming to be tackled at one instance.

Chapter 4

4 CONCLUSION

The impact of the Urban Heat Island is a genuine concern and is seen to have a significant impact on the energy consumption of the various building typologies that represent the building stock that forms the fabric of the metropolitan region. Each of these building typologies is seen to have a varied influence on their energy consumption due to Urban Heat Island (UHI). It has been seen that the buildings under the study experienced a penalty in the summer months to a great extent and the swing months i.e. the Spring/Fall season to a smaller extent, as increasing temperatures during the day and specifically in the night-time due to Urban Heat Island caused an increase cooling energy consumption and this the costs to run the buildings. The winter season pays back through savings achieved by the reduced Heating energy requirements as the winter nights are getting warmer.

All the commercial building typologies showed increasing total energy consumption, expect for the hospital and the warehouse typologies. The hospital type being a highly complex building, with strict requirements for Outside Air, strict humidity and internal environment controls, is a very difficult building to generalize and associate with other building in the commercial sector.

It is beyond reasonable doubt that the increasing night-time minimum lows and daytime highs due to Urban Heat Island (UHI), has caused an increase in the energy consumed for cooling; with the four major commercial building typologies namely Small, Medium and Large offices and the Retail Standalone that weighs in at 40% of the total building stock in the hot-dry climatic zone shows increasing energy consumptions and are projected to have a rate of increase in energy consumption according to the projections as seen while simulating the projected climate change weather files. If reasonable steps are not taken to reduce the impact of Urban Heat Island (UHI), the increasing energy consumption will not only be a cause of concern for the owner of these residential and commercial buildings but also the utilities will have to ramp up the energy production due to increasing demands. The electricity demand can be predicted grow in the coming years due to the fact that more and more of the heating degree hours change to cooling degree hours causing an increasing cooling energy requirement and as electricity is the fuel of choice for meeting the cooling energy requirements. The actual increase in energy requirements for the utilities and change in consumption patterns of the building stock for the metropolitan region of Phoenix could be derived at if a statistical data base is available for weight-age for each of these building typologies in the city, lack of such specific data has limited the work of this study.

This methodology could be utilized to study the impacts of Urban Heat Island and Climate change in other cities and metropolitan regions and climatic zones. As part of further research a comparative analysis could be made between a few chosen building typologies and simulating them using weather files as obtained from the Phoenix Sky Harbor Airport (data set used in this study) representative of the micro-climate of the urban center and weather files generated from local weather stations on the edges of the cities like old airbases or any other long term weather station. This would provide us with energy savings potential for buildings that are not under the influence of the Urban Heat Island Effect prominent in the denser part of the cities and enable us to isolate global climatic changes that would impact both the locations under the study.

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APPENDIX

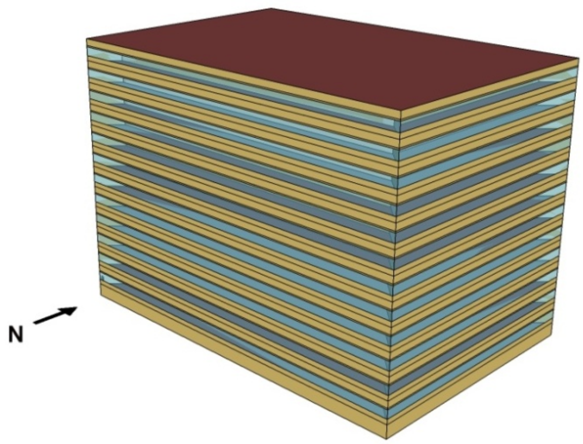
A. DETAILS OF COMMERCIAL AND RESIDENTIAL ENERGY MODELS, PART OF THE OVERALL STUDY

1. Large Office – Prototype ASHRAE 90.1

Form

- Total Floor Area (Sq Ft) - 498,600 (240 ft x 160 ft)

- Building Shape



Appendix A- 1-1: 3-D view of Large Office – Prototype ASHRAE 90.1

- Aspect Ratio - 1.5
- Number of Floors - 12 (plus Basement.)
- Window Fraction - 40% of above-grade gross walls.
  (Window-to-Wall Ratio) 37.5% of gross walls (including the below-grade walls)
- Windows Locations - Evenly distributed on all four sides
- Shading Geometry - none
- Thermal Zoning
  Perimeter zone depth -15 ft.

No. of Zones	- Each Floor has four perimeter zones, one core.
Percentages of floor area	- Perimeter 33%, Core 67%

Appendix A- 1-2: Plan of the thermal zones on each floor.

- Floor to floor Height (ft) - 13 ft
- Floor to ceiling height (ft) - 9 ft
- Glazing sill height (ft) - 3 ft

Architecture

Exterior walls

- Construction - Mass (pre-cast concrete panel): 8in. Heavy-Weight Concrete + Wall Insulation + 0.5 in. gypsum board
- U-factor and/or R-Value - ASHRAE 90.1 Requirements Non-Residential; Walls, Above-Grade, Steel-Framed

Roof

- Construction - Built-up Roof: Roof membrane + Roof Insulation + metal decking
- U-factor and/or R-Value - ASHRAE 90.1 Requirements; Non-Residential; Roofs, Insulation entirely above deck.

Window

- Dimensions - based on window fraction, location, glazing sill height, floor area and aspect ratio
- Glass-Type and frame - Hypothetical window with the exact U-factor and SHGC shown below
- U-Factor & SHGC - ASHRAE 90.1 Requirements Nonresidential;
- Visible transmittance - Hypothetical window with the exact U-factor and SHGC shown above

Foundation

- Foundation type - Basement (unconditioned)
- Construction - 8" concrete wall; 6" concrete slab, 140 lbs heavy-weight aggregate
- Thermal properties Ground Fl. **(**U-factor and/or R-value) - ASHRAE 90.1 Requirements Non-Residential; Floors, Mass

Interior Partitions

- Construction - 2 x 4 un-insulated stud wall
- Dimensions - based on floor plan and floor-to-floor height

Air barrier System

- Infiltration - Peak: 0.2016 cfm/sf of above grade exterior wall surface area (fan off)
  - Off Peak: 25% of peak infiltration rate (fan on)

<u>**HVAC**</u>

System type

- Heating type - Gas boiler
- Cooling type - Two water-cooled centrifugal chillers
- Distribution and terminal unit - VAV terminal box with damper and hot-water reheating coil. Zone control type: minimum supply air at 30% of the zone design peak supply air.

HVAC Efficiency

- Air conditioning - Various by climate location and design cooling capacity. ASHRAE 90.1 Requirements.

- Heating - Various by climate location and design heating capacity. ASHRAE 90.1 Requirements.

HVAC Control

- Thermostat Set-point - 75˚F Cooling/70˚F Heating
- Thermostat Setback - 85˚F Cooling/60˚F Heating
- Supply air temperature - Maximum 110˚F /Minimum 52˚F
- Chilled water supply Temp - 44˚F
- Hot water supply Temp - 180˚F
- Economizers - Air-side economizer
- Ventilation - .085 cfm/ft^2 (ASHRAE Ventilation Standard 62.1)
- Demand Control Ventilation - No
- Energy Recovery - No

Service Water Heating

- SWH type - Storage Tank
- Fuel type - Natural Gas
- Thermal efficiency (%) - 80%
- Tank Volume (gal) - 260 gallons
- Water temperature set-point - 180˚F

Lighting

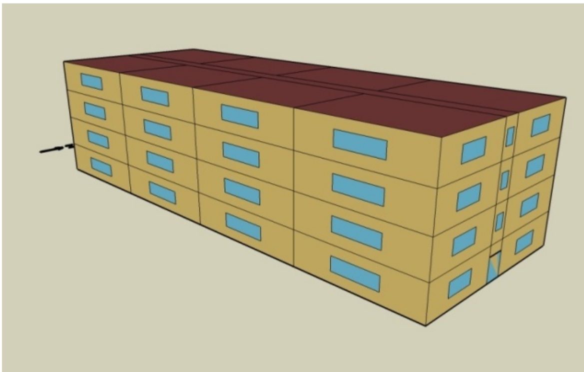
- Average power density(W/ft2) - ASHRAE 90.1; LPD using the Building-Area Method

- Daylighting Controls - ASHRAE 90.1 Requirements
- Occupancy Sensors - ASHRAE 90.1 Requirements

2. Mid Rise Apartment – Prototype ASHRAE 90.1

Form

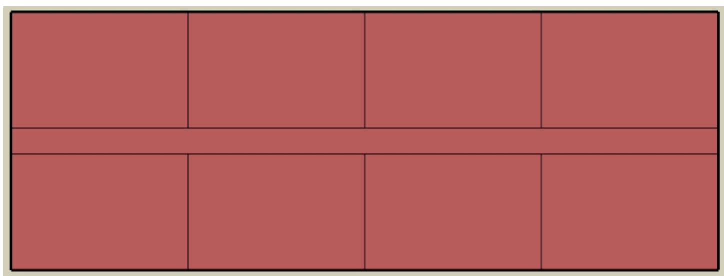
- Total Floor Area (Sq Ft) - 33,700 (152 ft x 55.5 ft)
- Building Shape



Appendix A- 2-1: 3-D view of Mid Rise Apartment – Prototype ASHRAE 90.1

- Aspect Ratio - 2.74
- Number of Floors - 4 nos.
- Window Fraction (Window-to-Wall Ratio) - South: 14.7%, East: 16.3%, North: 14.7%, West: 15.1% Average Total: 15.0%
- Windows Locations - according to design
- Shading Geometry - none
- Thermal Zoning

No. of Zones	- Each floor has 8 apartments except ground floor (7 apartments and 1 lobby with equivalent apartment area) Total 8 apartments per floor with corridor in center.
Perimeter zone depth	- Zone depth is 25 ft for each apartment from side walls and each apt is 25' x 38' (950 ft^2)



Appendix A- 2-2: Plan of the thermal zones.

- Floor to floor Height (ft) - 10 ft
- Floor to ceiling height (ft) - 10 ft
- Glazing sill height (ft) - 3 ft (14 ft wide x 4 ft high)

Architecture

Exterior walls

- Construction - Steel-Frame Walls (2X4 16IN OC) 0.4 in. Stucco+5/8 in. gypsum board + wall Insulation+5/8 in.

- U-factor and/or R-Value - ASHRAE 90.1 Requirements; Residential; Walls, above grade, Steel Frame

Roof

- Construction - Built-up Roof: Roof membrane + Roof Insulation + metal decking
- U-factor and/or R-Value - ASHRAE 90.1 Requirements Residential; Roofs, Insulation entirely above deck

Window

- Dimensions - based on window fraction, location, glazing sill height, floor area and aspect ratio
- Glass-Type and frame - Hypothetical window with the exact U-factor and SHGC shown below
- U-Factor & SHGC - ASHRAE 90.1 Requirements Residential; Vertical Glazing, 10.1-20%
- Visible transmittance - Hypothetical window with the exact U-factor and SHGC shown above

Foundation

- Foundation type - Slab-on-grade floors (unheated)

- Construction - 8" concrete slab poured directly on to the earth
- Slab on grade floor insulation Level - ASHRAE 90.1 Requirements Non-Residential; Slab-on-Grade, Floor unheated

Interior Partitions

- Construction - 2 x 4 un-insulated stud wall
- Dimensions - based on floor plan and floor-to-floor height

Air barrier System

- Infiltration - 0.2016 cfm/ft² of gross exterior wall area at all times (at 10 mph wind speed)

<u>HVAC</u>

System type

- Heating type - Gas Furnace
- Cooling type - Split system DX (1 per apt)
- Distribution and terminal unit - Constant volume

HVAC Efficiency

- Air conditioning - ASHRAE 90.1 Requirements Minimum Equipment Efficiency for Air Conditioners and Condensing Units

- Heating - ASHRAE 90.1 Requirements Minimum Equipment Efficiency for Warm Air Furnaces

HVAC Control

- Thermostat Setpoint - 75˚F Cooling/70˚F Heating
- Thermostat Setback - No Setback for apartments
- Supply air temperature - Maximum 110˚F /Minimum 52˚F
- Chilled water supply Temp - NA
- Hot water supply Temp - NA
- Economizers - ASHRAE 90.1 Requirements
- Ventilation - .085 cfm/ft^2 (ASHRAE Ventilation Standard 62.1)
- Demand Control Ventilation - ASHRAE 90.1 Requirements
- Energy Recovery - ASHRAE 90.1 Requirements

Service Water Heating

- SWH type - Storage Tank
- Fuel type - Natural Gas
- Thermal efficiency (%) - ASHRAE 90.1 Requirements;
- Tank Volume (gal) - 20 gallons
- Water temperature set-point - 120˚F

Lighting

- Average power density (W/ft2)- Apartment units: 0.36 w/ft^2 (daily peak for hard-wired lighting). Other space types: meet maximum allowed LPD by ASHRAE 90.1, using Space-by-Space Method

- Daylighting Controls - ASHRAE 90.1 Requirements
- Occupancy Sensors - ASHRAE 90.1 Requirements

3. Single Family Detached Residential – Prototype ASHRAE 90.1

Form

- Total Floor Area (Sq Ft) - 2500 ft x 150 ft)
- Building Shape
- Aspect Ratio - 1.5
- Number of Floors - 1 nos
- Window Fraction (Window-to-Wall Ratio) - South: 14.7%, East: 16.3%, North: 14.7%, West: 15.1% Average Total: 15.0%
- Windows Locations - according to design
- Shading Geometry - none
- Thermal Zoning

  No. of Zones - Living areas (conditioned), Garage (unconditioned)
- Floor to floor Height (ft) - NA
- Floor to ceiling height (ft) - 10Ft

- Glazing sill height (ft) - 3 ft (top of the window is 8 ft high with 5 ft high glass)

Architecture

Exterior walls

- Construction - Stucco 1in. + Building paper felt + sheathing consol layer + OSB 5/8in. + wall consol layer + Drywall 1/2in.
- U-factor and/or R-Value - ASHRAE 90.1 Requirements; Residential; Walls, above grade, Steel Frame

Roof

- Construction - Asphalt shingles + OSB 1/2in.; Attic floor – ceiling consol layer + Drywall 1/2in.
- U-factor and/or R-Value - ASHRAE 90.1 Requirements Residential; Roofs, Insulation entirely above deck

Window

- Dimensions - based on window fraction, location, glazing sill height, floor area and aspect ratio

- Glass-Type and frame - Hypothetical window with the exact U-factor and SHGC shown below
- U-Factor & SHGC - ASHRAE 90.1 Requirements Residential; Vertical Glazing, 10.1-20%
- Visible transmittance - Hypothetical window with the exact U-factor and SHGC shown above

Foundation

- Foundation type - Slab-on-grade floors (unheated)
- Construction - 4" concrete slab poured directly on to the earth
- Slab on grade floor insulation Level - ASHRAE 90.1 Requirements Residential; Slab-on-Grade, Floor unheated

Interior Partitions

- Construction - Drywall 1/2in. + Air gap 4in. + Drywall 1/2in.
- Dimensions - based on floor plan and floor-to-floor height

Air barrier System

- Infiltration - Infiltration through building asper standards, Natural Ventilation –

controlled, during spring/fall seasons

HVAC

System type

- Heating type - Gas Furnace
- Cooling type - DX Cooling Coil (1 per apt)
- Distribution and terminal unit - Constant volume

HVAC Efficiency

- Air conditioning - ASHRAE 90.1 Requirements Minimum Equipment Efficiency for Air Conditioners and Condensing Units
- Heating - ASHRAE 90.1 Requirements Minimum Equipment Efficiency for Warm Air Furnaces

HVAC Control

- Thermostat Setpoint - 75˚F Cooling/70˚F Heating
- Thermostat Setback - No Setback for apartments
- Supply air temperature - Maximum 110˚F /Minimum 52˚F
- Chilled water supply Temp - NA
- Hot water supply Temp - NA
- Economizers - ASHRAE 90.1 Requirements

- Ventilation - .085 cfm/ft^2 + natural ventilation during spring/fall season (ASHRAE Ventilation Standard 62.1)
- Demand Control Ventilation - ASHRAE 90.1 Requirements
- Energy Recovery - ASHRAE 90.1 Requirements

Service Water Heating

- SWH type - Storage Tank
- Fuel type - Natural Gas
- Thermal efficiency (%) - ASHRAE 90.1 Requirements;
- Tank Volume (gal) - 10 gallons
- Water temperature set-point - 120˚F

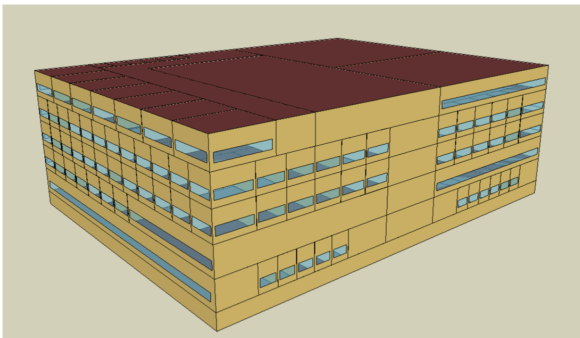
Lighting

- Average power density (W/ft2)- Meet maximum allowed LPD by ASHRAE 90.1, using Space-by-Space Method
- Daylighting Controls - ASHRAE 90.1 Requirements
- Occupancy Sensors - ASHRAE 90.1 Requirements

4. Hospital – Prototype ASHRAE 90.1

Form

- Total Floor Area (Sq Ft) - 24,695 (178 ft x 139 ft)
- Building Shape



Appendix A- 4-1: 3-D view of Hospital – Prototype ASHRAE 90.1

- Aspect Ratio - 1.31
- Number of Floors - 5 nos (plus basement)
- Window Fraction - North: 12%, East: 13%, South: 15%, (Window-to-Wall Ratio) West: 24%, Average Total: 16%
- Windows Locations - according to design
- Shading Geometry - none
- Thermal Zoning

  No. of Zones - separate thermal zone layouts exist including Emergency Room, Office, Lobby, Nurse Station, Operating Room, Patient Room, Physical Therapy, Lab, Radiology, Dining, Kitchen, and Corridors. Percentages

	of floor area: Clinic 25%, Core/Public 35%, Perimeter (patient rooms and offices) 15%, Kitchen 5%, Lobby/Hallway 20%
• Floor to floor Height (ft)	- 14 ft above ground, 8 ft basement
• Floor to ceiling height (ft)	- No ceiling plenum is modeled
• Glazing sill height (ft)	- 3 ft (4 ft high windows)

<u>Architecture</u>

Exterior walls

• Construction	- Mass (concrete blocks): 8 in. HW Concrete + Wall Insulation + 0.5 in. Gym
• U-factor and/or R-Value	- 1st, 2nd and 5th floors: Use nonresidential envelop requirement. 3rd and 4th floors: Use residential envelop requirement since most of the spaces in the perimeter zones are patient rooms, which are residential spaces based on 90.1's definitions.

Roof

• Construction	- Built-up Roof: Roof membrane + Roof Insulation + metal decking

- U-factor and/or R-Value - ASHRAE 90.1 Requirements. Non-Residential; Roofs, Insulation entirely above deck.

Window

- Dimensions - based on window fraction, location, glazing sill height, floor area and aspect ratio
- Glass-Type and frame - Hypothetical window with the exact U-factor and SHGC shown below
- U-Factor & SHGC - ASHRAE 90.1 Requirements Residential; Vertical Glazing, 10.1-20%
- Visible transmittance - Hypothetical window with the exact U-factor and SHGC shown above

Foundation

- Foundation type - Basement (conditioned)
- Construction - 6" concrete slab poured directly on to the earth with carpet
- Thermal properties Ground Fl. (U-factor and/or R-value) - ASHRAE 90.1 Requirements Non-Residential; Slab-on-Grade, Floor unheated

Interior Partitions

- Construction - 2 x 4 un-insulated stud wall

- Dimensions - based on floor plan and floor-to-floor height

Air barrier System

- Infiltration - Peak: 0.2016 cfm/sf of above grade exterior wall surface area (fan off)
  - Off Peak: 25% of peak infiltration rate (fan on)

<u>HVAC</u>

System type

- Heating type - Gas boiler.
- Cooling type - Water cooled centrifugal chiller
- Distribution and terminal unit - Medical critical zones: five variable air volume (VAV) systems with hot water reheating and electric stream humidifiers. Non-critical zones: two VAV systems for general zones and one constant air volume (CAV) system for kitchen zone: VAV terminal box with damper and hot water reheating coil; minimum supply air at 30% of the zone design peak supply air.

HVAC Efficiency

- Air conditioning - Various by climate location and design cooling capacity. ASHRAE 90.1 Requirements. Two water-cooled screw chillers, for each chiller with normal cooling capacity
- Heating - Various by climate location and design heating capacity. ASHRAE 90.1 Requirements. Minimum equipment efficiency for hot water boiler

HVAC Control

- Thermostat Setpoint - 75˚F Cooling/70˚F Heating
- Thermostat Setback - No Setback
- Supply air temperature - Maximum 110˚F /Minimum 52˚F
- Chilled water supply Temp - 44˚F
- Hot water supply Temp - 180˚F
- Economizers - No economizer
- Ventilation - Both OA and TSA design air flow rate are derived from two sources:
  1. Minimum OA and TSA air requirements specified by AIA Guidelines for Design and

Construction of Health Care Facilities and

2. ASHRAE Standard 62.1-2004

- Demand Control Ventilation - ASHRAE 90.1 Requirements
- Energy Recovery - ASHRAE 90.1 Requirements

Service Water Heating

- SWH type - Storage Tank
- Fuel type - Natural Gas
- Thermal efficiency (%) - ASHRAE 90.1 Requirements; Water Heating Equipment, Gas storage water heaters, >75,000 Btu/h input
- Tank Volume (gal) - 800 gallons
- Water temperature set-point - 140˚F

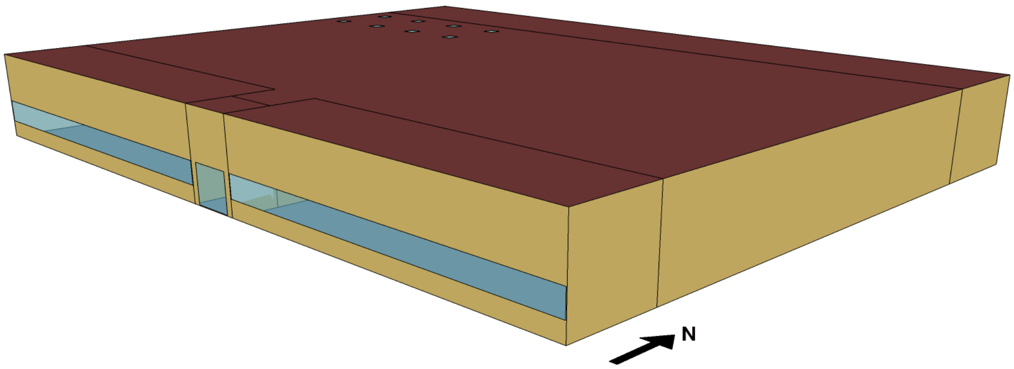
Lighting

- Average power density(W/ft2) - ASHRAE 90.1; LPD using the Building-Area Method
- Daylighting Controls - ASHRAE 90.1 Requirements
- Occupancy Sensors - ASHRAE 90.1 Requirements

5. Retail Standalone – Prototype ASHRAE 90.1

Form

- Total Floor Area (Sq Ft) - 24,695 (178 ft x 139 ft)
- Building Shape

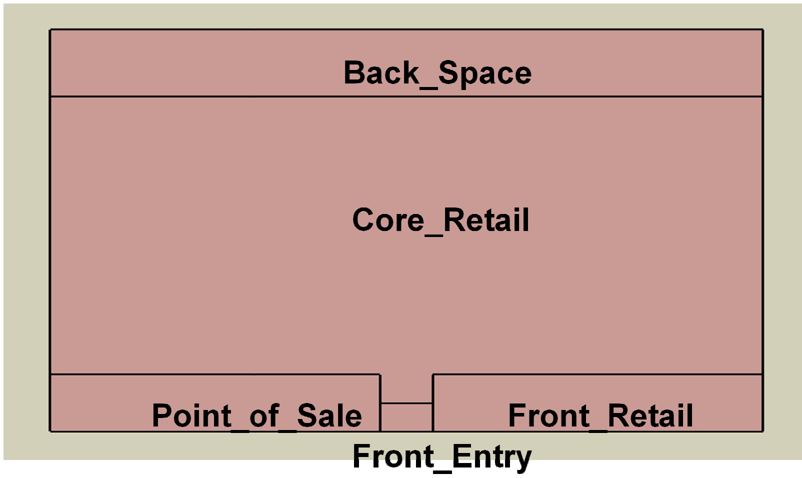


Appendix A- 5-1: 3-D view of Retail Standalone – Prototype ASHRAE 90.1

- Aspect Ratio - 1.28
- Number of Floors - 1 nos
- Window Fraction - 7.1%

  (Window-to-Wall Ratio) (Window Dimension: 82.136 ft x 5ft, 9.843 ft x 8.563 ft and 82.136 ft x 5 on the street facing facade)
- Windows Locations - Windows only on the street facing façade (25.4% WWR)
- Shading Geometry - none
- Thermal Zoning

  No. of Zones - Five thermal zones



Appendix A- 5-2: Plan of the thermal zones.

- Floor to floor Height (ft) - NA
- Floor to ceiling height (ft) - 20 ft
- Glazing sill height (ft) - 5 ft (top of the window is 8.74ft high with 3.74 high glass)

Architecture

Exterior walls

- Construction - Concrete Block Wall: 8 in. CMU + Wall Insulation + 0.5 in. gypsum board
- U-factor and/or R-Value - ASHRAE 90.1 Requirements Non-Residential; Walls, Above-Grade, Mass

Roof

- Construction - Built-up Roof: Roof membrane + Roof Insulation + metal decking

- U-factor and/or R-Value - ASHRAE 90.1 Requirements; Non-Residential; Roofs, Insulation entirely above deck.

Window

- Dimensions - based on window fraction, location, glazing sill height, floor area and aspect ratio
- Glass-Type and frame - Hypothetical window with the exact U-factor and SHGC shown below
- U-Factor & SHGC - ASHRAE 90.1 Requirements Nonresidential; Nonresidential; Skylight with Curb, Glass
- Visible transmittance - Hypothetical window with the exact U-factor and SHGC shown above

Foundation

- Foundation type - Slab-on-grade floors (unheated)
- Construction - 6" concrete slab poured directly on to the earth with carpet
- Thermal properties Ground Fl. **(**U-factor and/or R-value) - ASHRAE 90.1 Requirements Non-Residential; Slab-on-Grade, Floor unheated

Interior Partitions

- Construction - 0.5 in gypsum board + 0.5 in gypsum board
- Dimensions - based on floor plan and floor-to-floor height

Air barrier System

- Infiltration - Peak: 0.2016 cfm/sf of above grade exterior wall surface area (fan off)
  - Off Peak: 25% of peak infiltration rate (fan on)

<u>HVAC</u>

System type

- Heating type - Gas furnace inside the packaged air conditioning unit for back-space, core-retail, point-of-sale, and front-retail. Standalone gas furnace for front entry.
- Cooling type - Packaged air conditioning unit for back-space, core-retail, point-of-sale, and front-retail; No cooling for front entry.
- Distribution and terminal unit - Constant air volume air distribution 4 single-zone roof top units serving

four thermal zones (back-space, core-retail, point-of-sale, and front-retail)

HVAC Efficiency

- Air conditioning - Various by climate location and design cooling capacity. ASHRAE 90.1 Requirements. Minimum equipment efficiency for Air Conditioners and Condensing Units
- Heating - Various by climate location and design heating capacity. ASHRAE 90.1 Requirements. Minimum equipment efficiency for Warm Air Furnaces

HVAC Control

- Thermostat Setpoint - 75˚F Cooling/70˚F Heating
- Thermostat Setback - 85˚F Cooling/60˚F Heating
- Supply air temperature - Maximum 104˚F /Minimum 55˚F
- Chilled water supply Temp - NA
- Hot water supply Temp - NA
- Economizers - Various by climate location and cooling capacity. Control type: differential dry bulb

- Ventilation - 0.12 cfm/ft^2 for Storage rooms, 0.23 cfm/ft^2 Sales Zones (ASHRAE Ventilation Standard 62.1)
- Demand Control Ventilation - ASHRAE 90.1 Requirements

  Energy Recovery - ASHRAE 90.1 Requirements

Service Water Heating

- SWH type - Storage Tank
- Fuel type - Natural Gas
- Thermal efficiency (%) - ASHRAE 90.1 Requirements; Water Heating Equipment, Gas storage water heaters, >75,000 Btu/h input
- Tank Volume (gal) - 40 gallons
- Water temperature set-point - 120˚F

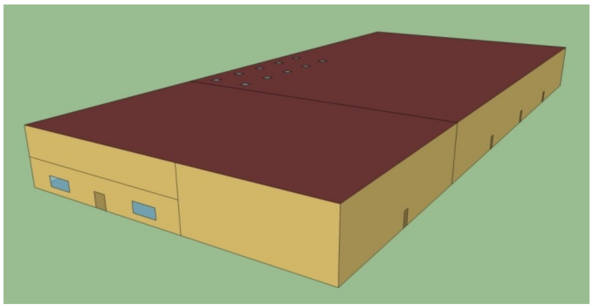
<u>Lighting</u>

- Average power density(W/ft2) - ASHRAE 90.1; LPD using the Building-Area Method
- Daylighting Controls - ASHRAE 90.1 Requirements
- Occupancy Sensors - ASHRAE 90.1 Requirements

6. Non-refrigerated warehouse – Prototype ASHRAE 90.1

Form

- Total Floor Area (Sq Ft) - 49,495 (330 ft x 150 ft)
- Building Shape

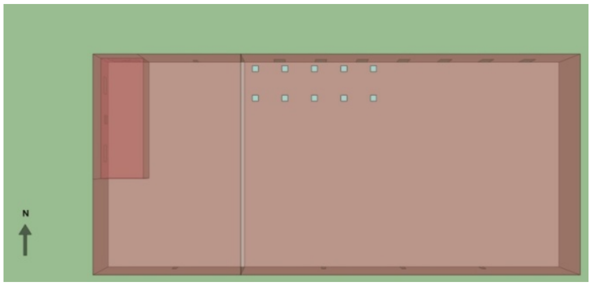


Appendix A- 6-1: 3-D view of Non-refrigerated warehouse – Prototype ASHRAE 90.1

- Aspect Ratio - 2.2
- Number of Floors - 1 nos
- Window Fraction - 0.71%

  (Window-to-Wall Ratio) Punched windows in Office Space
- Windows Locations - Only for Office Space
- Shading Geometry - none
- Thermal Zoning

  No. of Zones - Three zones: Bulk Storage, Fine Storage, and Office. The Office zone is enclosed on two sides and at the top by the Fine Storage zone.



Appendix A- 6-2: Plan of the thermal zones.

- Floor to floor Height (ft) - 28 ft
- Floor to ceiling height (ft) - 14ft (Office)
- Glazing sill height (ft) - 3 ft (top of the window is 8 ft high with 5 ft high glass)

Architecture

Exterior walls

- Construction - Metal Building Wall: Metal Surface + Wall Insulation + Gypsum Board
- U-factor and/or R-Value - ASHRAE 90.1 Requirements; Nonresidential; Walls, Above-Grade, Metal Building
  Semi heated; Walls, Above-Grade, Metal Building

Roof

- Construction - Metal Building Roof: Metal Surface + Roof Insulation
- U-factor and/or R-Value - ASHRAE 90.1 Requirements Non-residential; Roofs, Metal Building

Semi heated; Roofs, Metal Building

Window

- Dimensions - based on window fraction, location, glazing sill height, floor area and aspect ratio
- Glass-Type and frame - Hypothetical window with no frame and meeting ASHRAE 90.1 Requirements
- U-Factor & SHGC - ASHRAE 90.1 Requirements Non-residential; Vertical Glazing, 0-10%, U_fixed
- Visible transmittance - Hypothetical window with no frame and meeting ASHRAE 90.1 Requirements

Foundation

- Foundation type - Slab-on-Grade
- Construction - 6" concrete slab
- Thermal properties Ground Fl. **(**U-factor and/or R-value) - ASHRAE 90.1 Requirements Non-residential; Slab-on-Grade Floors, unheated. Semi heated; Slab-on-Grade Floors, unheated

Interior Partitions

- Construction - 2 x 4 un-insulated stud wall

- Dimensions - based on floor plan and floor-to-floor height

Air barrier System

- Infiltration - Office: 0.043346 cfm/ft2 of exterior surface area.
  Fine storage: 0.044442 cfm/ft2 of exterior surface area
  bulk storage: 3265 cfm (fixed)

<u>HVAC</u>

System type

- Heating type - Gas furnace inside the packaged air conditioning unit.
- Cooling type - Packaged air conditioning unit
- Distribution and terminal unit - Direct, uncontrolled air

HVAC Efficiency

- Air conditioning - Various by climate location and design cooling capacity. ASHRAE 90.1 Requirements. Minimum equipment efficiency for Air Conditioners and Condensing Units
- Heating - Various by climate location and design heating capacity. ASHRAE 90.1 Requirements. Minimum

equipment efficiency for Warm Air Furnaces

HVAC Control

- Thermostat Setpoint - Fine storage: 80℉ Cooling/ 6 0℉ Heating; Office Area: 75℉ Cooling/ 70℉ Heating; Bulk Storage: 50℉ Heating;
- Thermostat Setback - 85℉ Cooling/60℉ Heating
- Supply air temperature - Maximum 110˚F /Minimum 55˚F
- Chilled water supply Temp - NA
- Hot water supply Temp - NA
- Economizers - Various by climate location and cooling capacity; Control type: differential dry bulb
- Ventilation - .085 cfm/ft^2 (ASHRAE Ventilation Standard 62.1)
- Demand Control Ventilation - ASHRAE 90.1 Requirements
- Energy Recovery - ASHRAE 90.1 Requirements

Service Water Heating

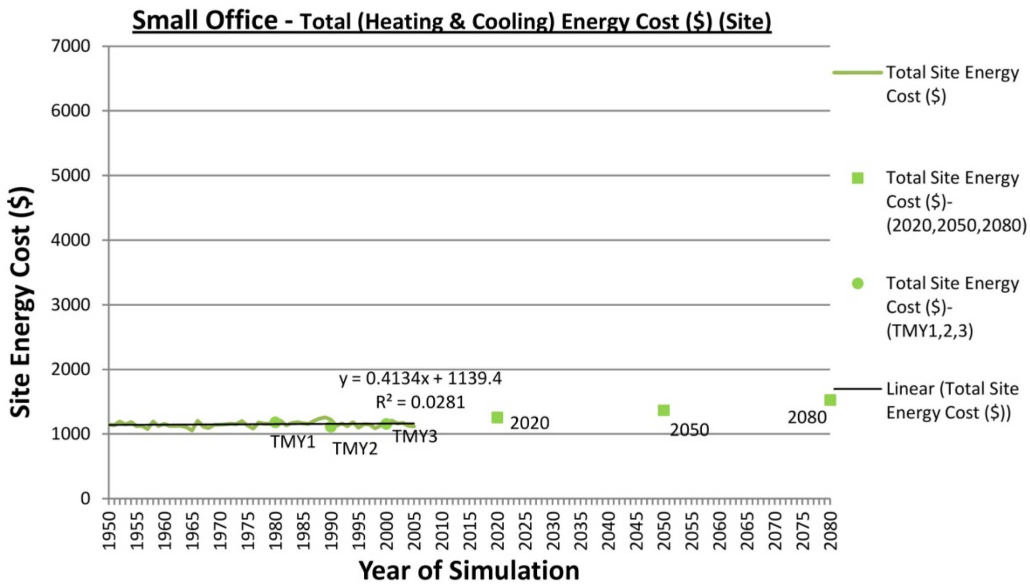
- SWH type - Electric storage water heater
- Fuel type - Electricity
- Thermal efficiency (%) - ____
- Tank Volume (gal) - 20 gallons

- Water temperature set-point - 120˚F

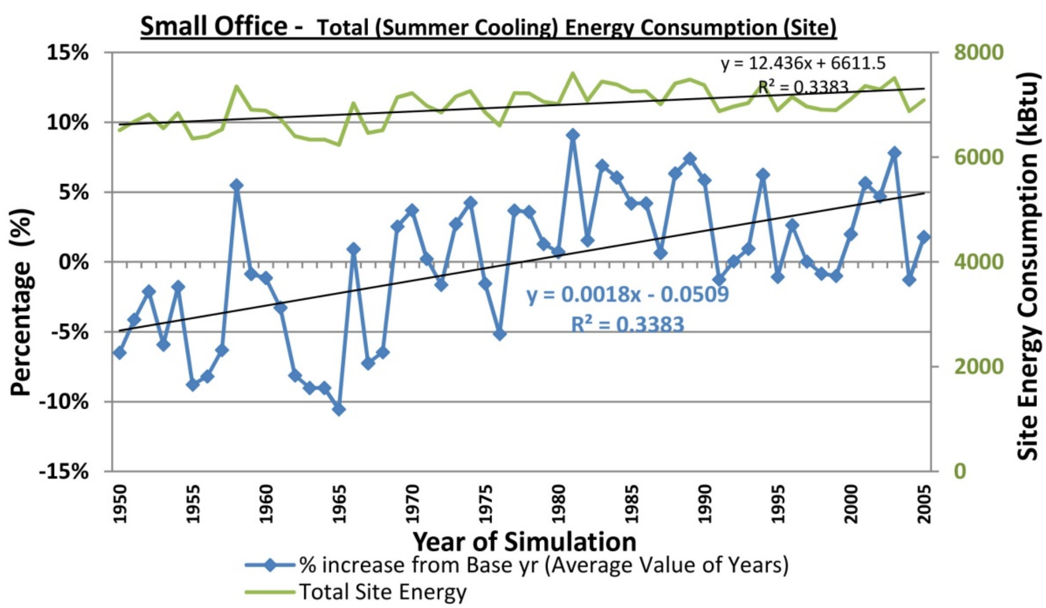
Lighting

- Average power density(W/ft2) - ASHRAE 90.1; LPD Using the Space-By-Space Method
- Daylighting Controls - ASHRAE 90.1 Requirements
- Occupancy Sensors - ASHRAE 90.1 Requirements

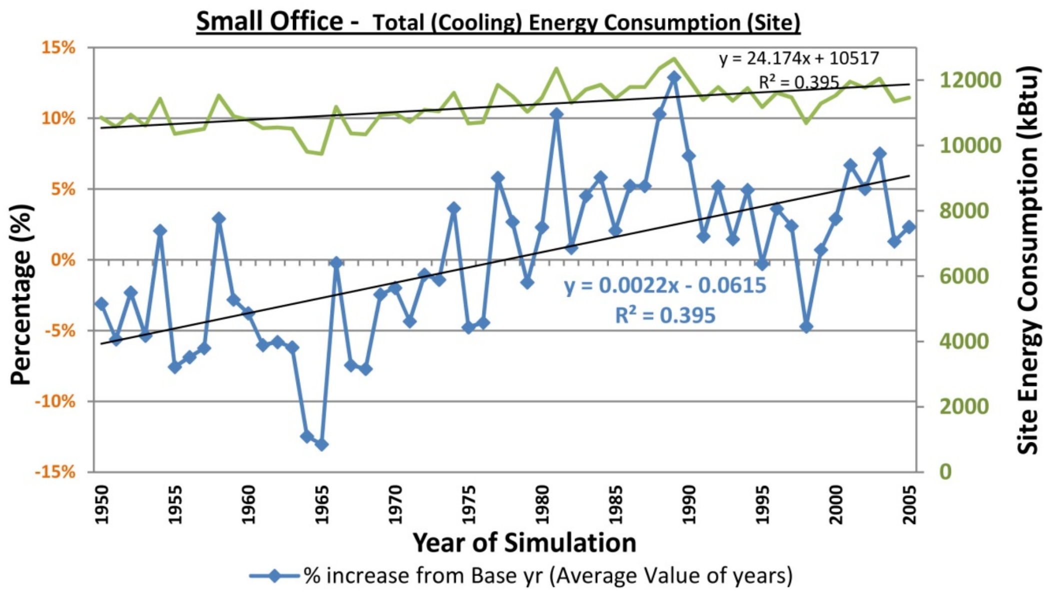
B. GRAPHS REPRESENTING ANNUAL SIMULATION RUNS OF SMALL OFFICE BUILDING TYPE)



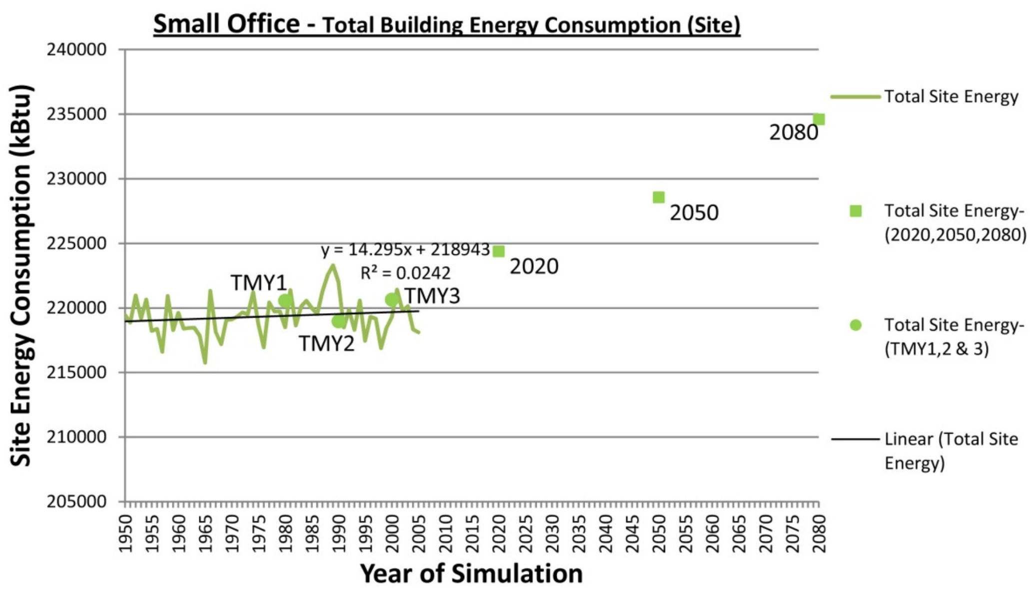
Appendix B- 1: Small Office - Total (Heating & Cooling) Energy Consumption (Site) (G-7)



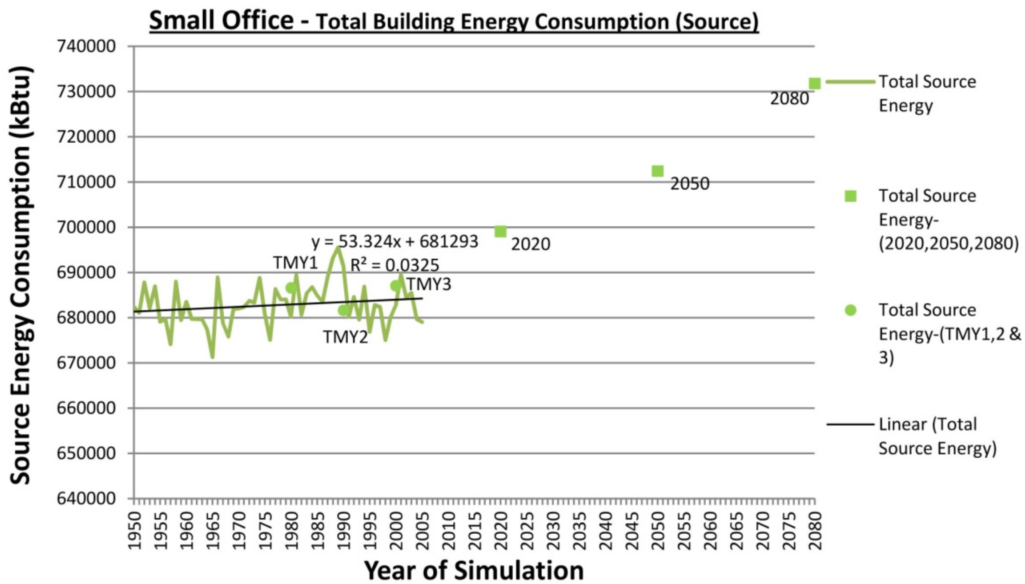
Appendix B- 2: Small Office - Total (Summer Cooling) Energy Consumption (Site) (G-8)



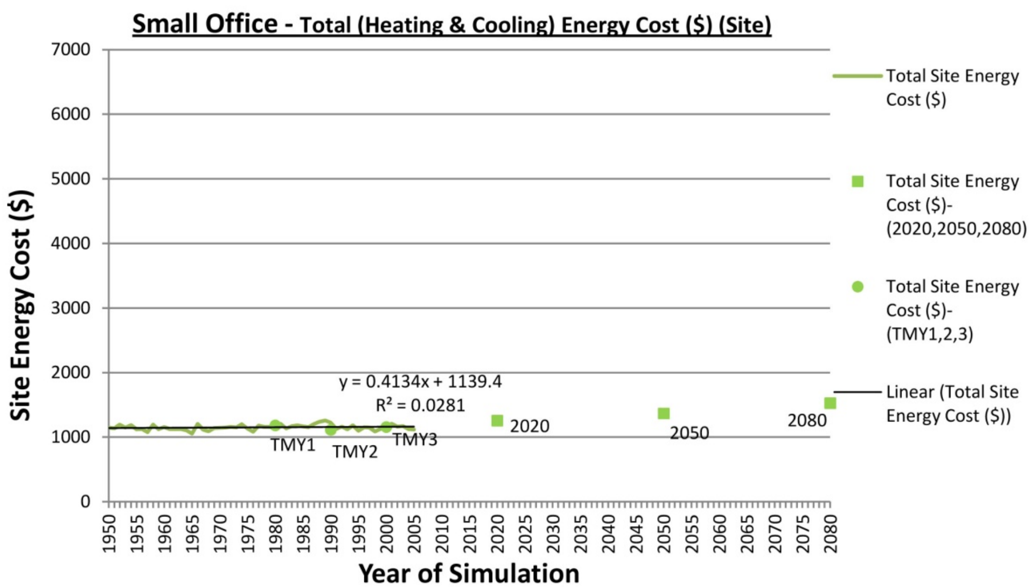
Appendix B- 3: Small Office - Total (Cooling) Energy Consumption (Site) (G-9)



Appendix B- 4: Small Office - Total (Heating & Cooling) Energy Consumption (Site) (G-10)



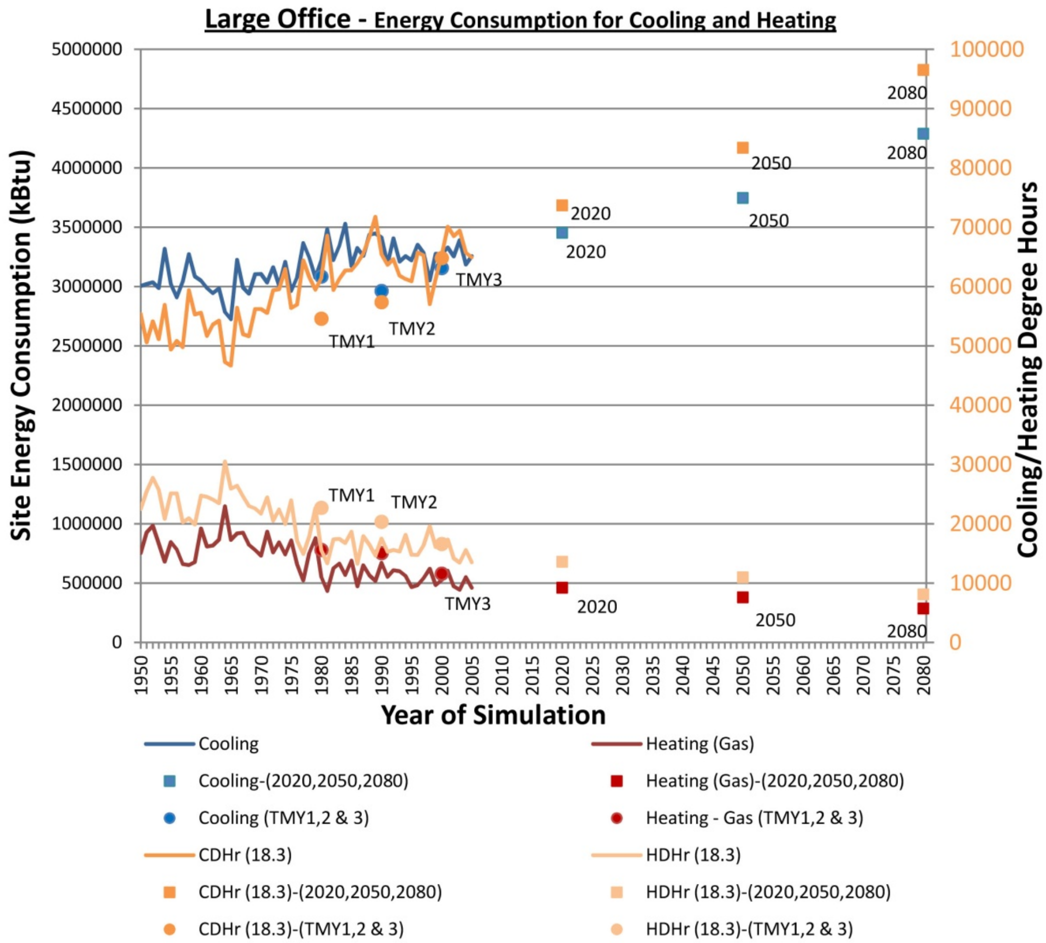
Appendix B- 5: Small Office - Total Building Energy Consumption (Source) (G-11)



Appendix B- 6: Small Office - Small Office - Total Building Energy Cost ($) (Site) (G-12)

C. GRAPHS REPRESENTING ANNUAL SIMULATION RUNS OF ALL BUILDING TYPOLOGIES UNDER STUDY

1. Large Office – Prototype ASHRAE 90.1



Appendix C- 1-1: Large Office - Energy Consumption for Cooling and Heating (G-1)

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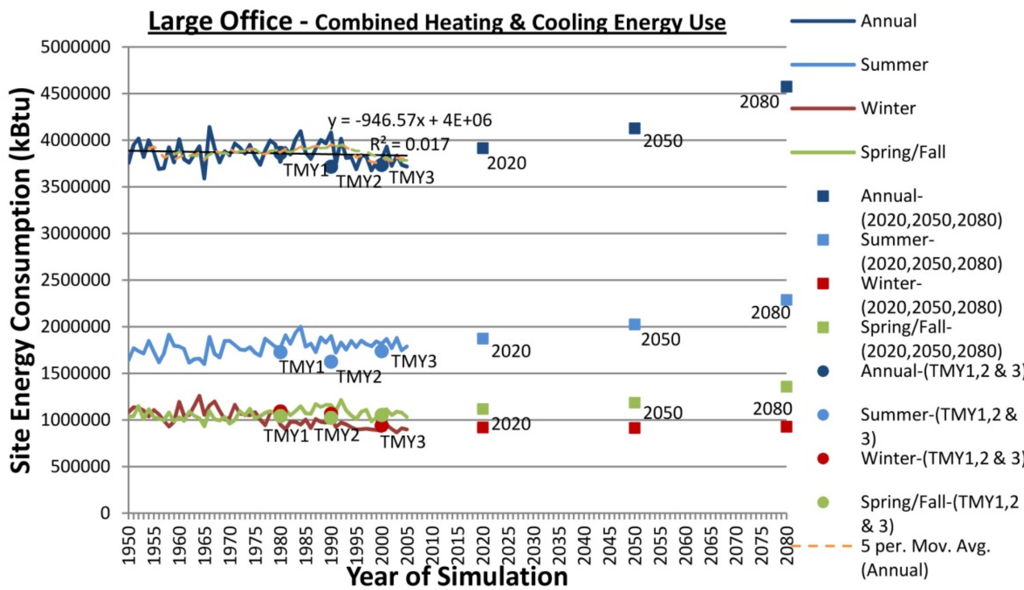
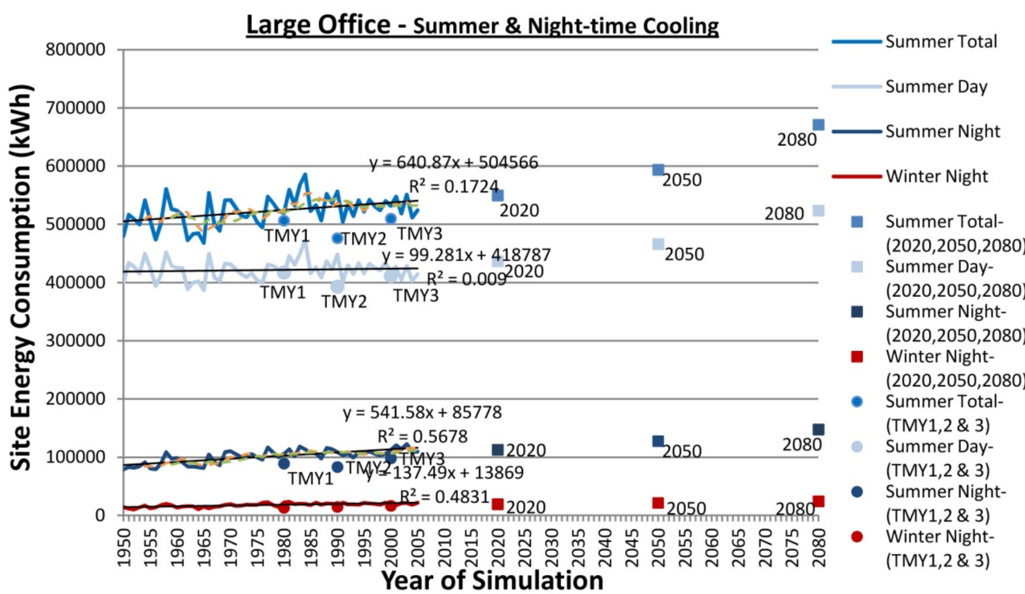
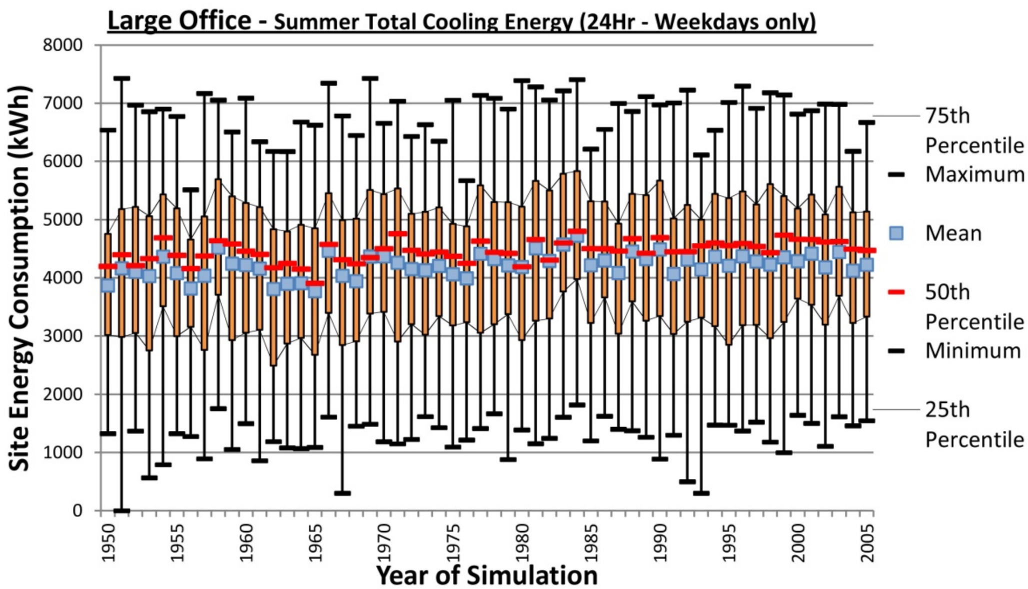


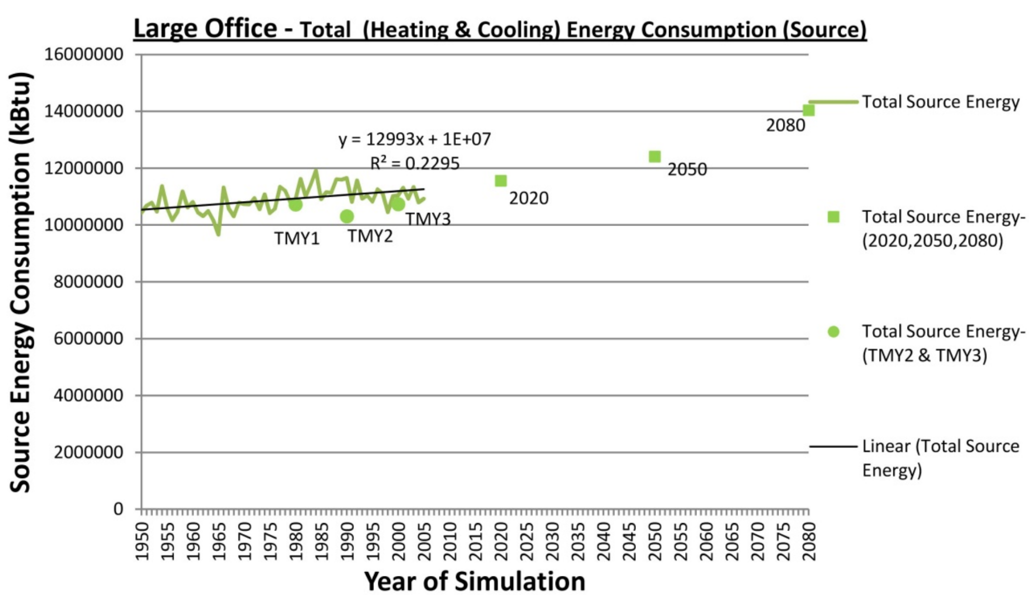
Appendix C- 1-2: Large Office - Heating and Cooling Energy Use (G-2)



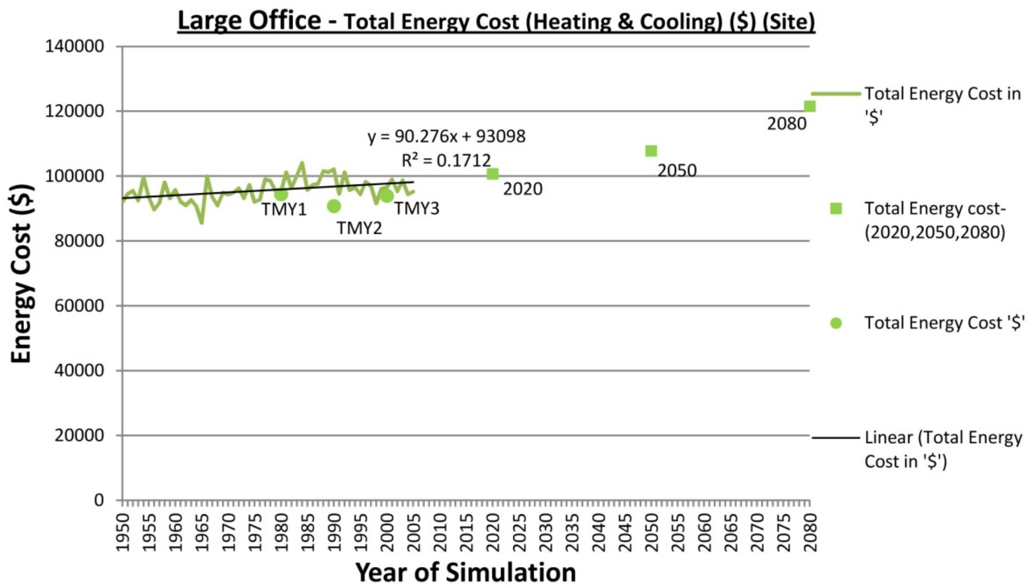
Appendix C- 1-3: Large Office - Summer & Night-time Cooling (G-3)



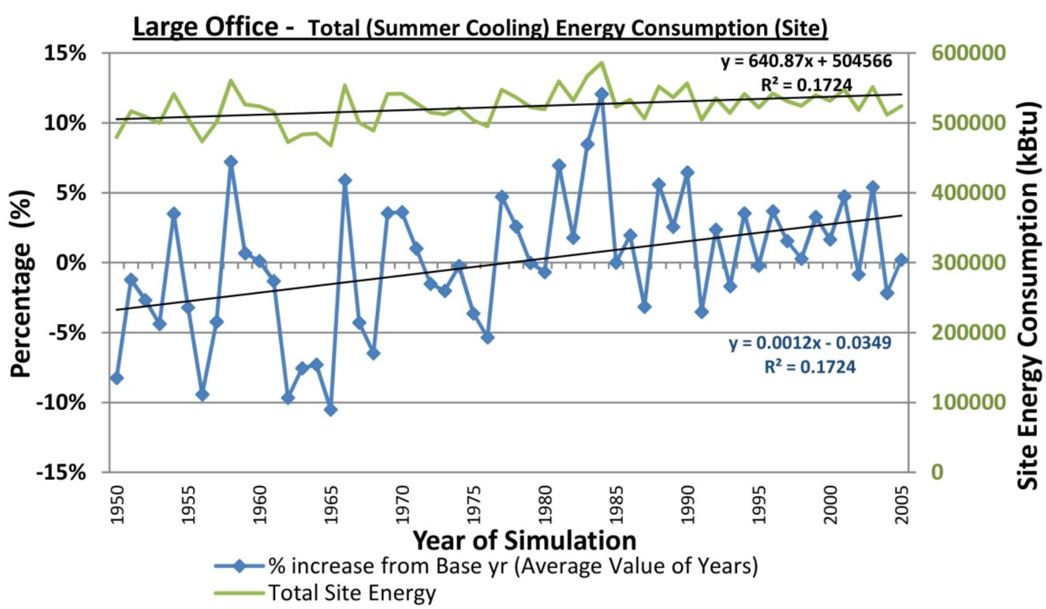
Appendix C- 1-4: Large Office - Summer Total Cooling Energy (24hr - Weekdays only) (G-4)



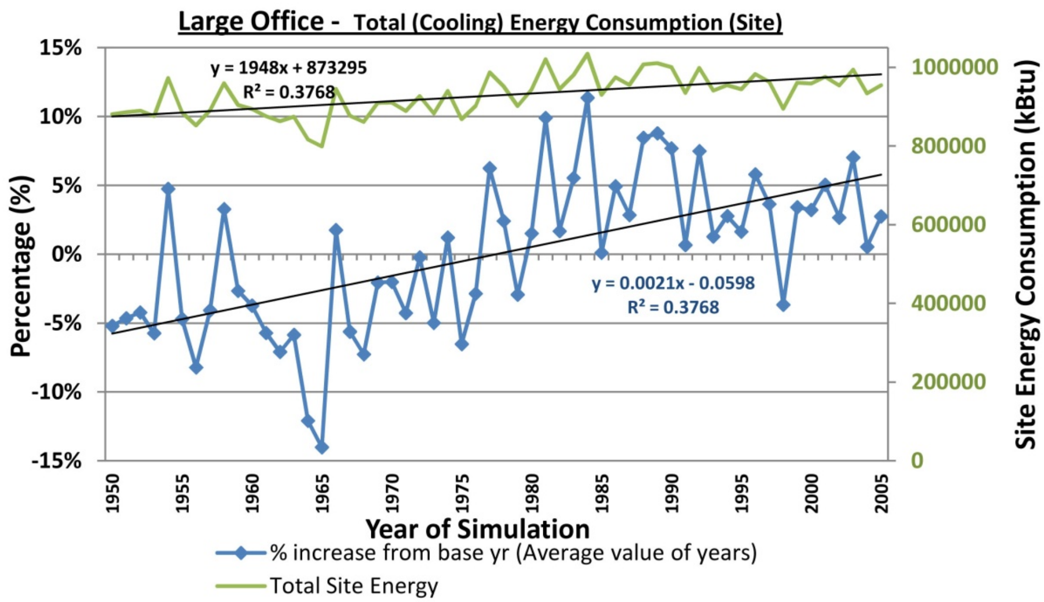
Appendix C- 1-5: Large Office - Total (Heating & Cooling) Energy Consumption (Source) (G-6)



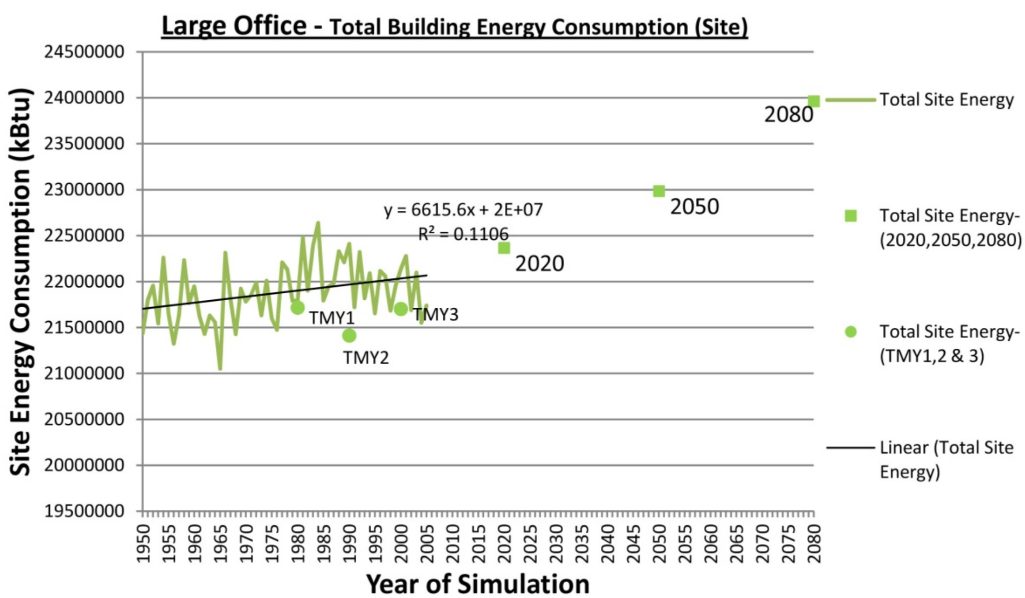
Appendix C- 1-6: Large Office - Total Energy Cost (Heating & Cooling) ($) (Site) (G-7)



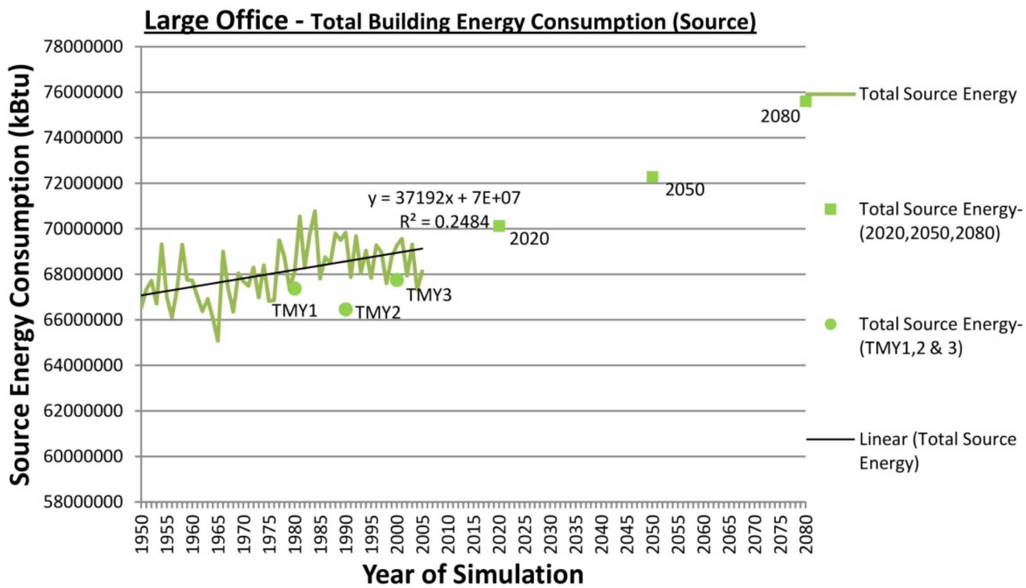
Appendix C- 1-7: Large Office - Total (Summer Cooling) Energy Consumption (Site) (G-8)



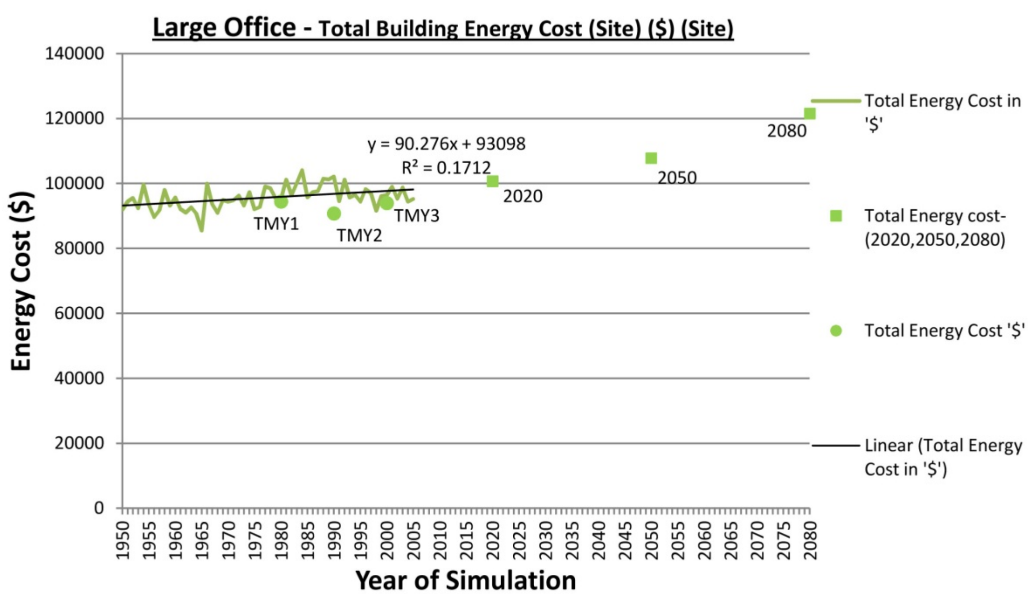
Appendix C- 1-8: Large Office - Total (Cooling) Energy Consumption (Site) (G-9)



Appendix C- 1-9: Large Office - Total Building Energy Consumption (Site) (G-10)

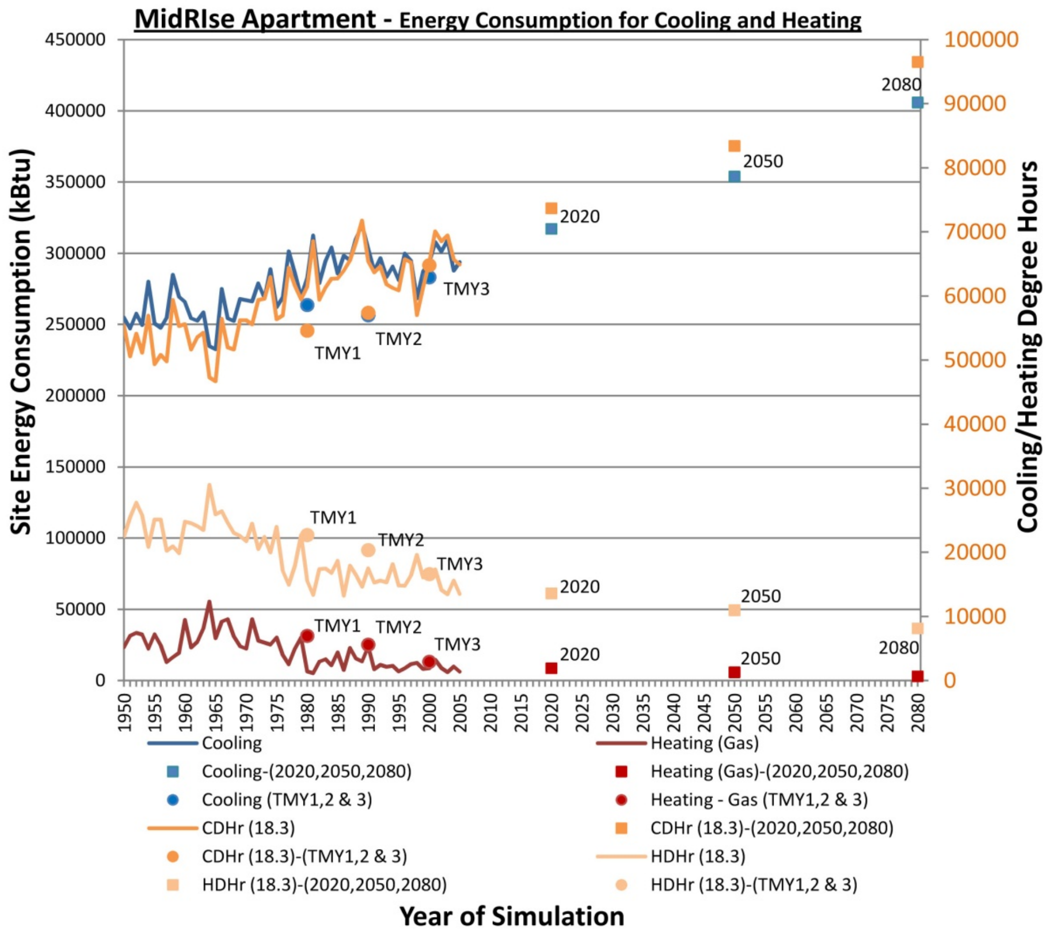


Appendix C- 1-10: Large Office - Total Building Energy Consumption (Source) (G-11)

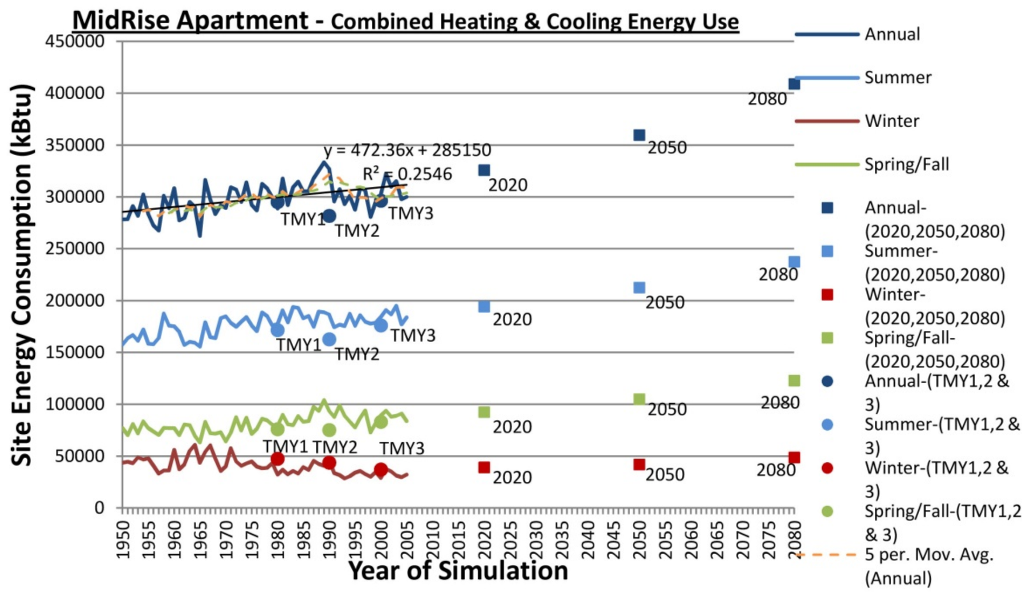


Appendix C- 1-11: Large Office - Total Building Energy Cost (Site) ($) (Site) (G-12)

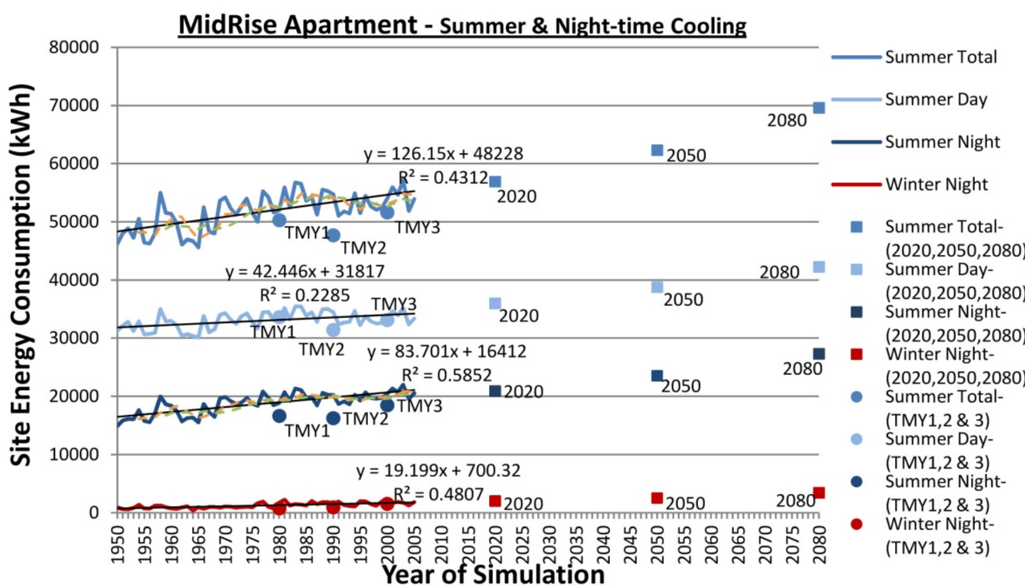
2. Mid Rise Apartment – Prototype ASHRAE 90.1



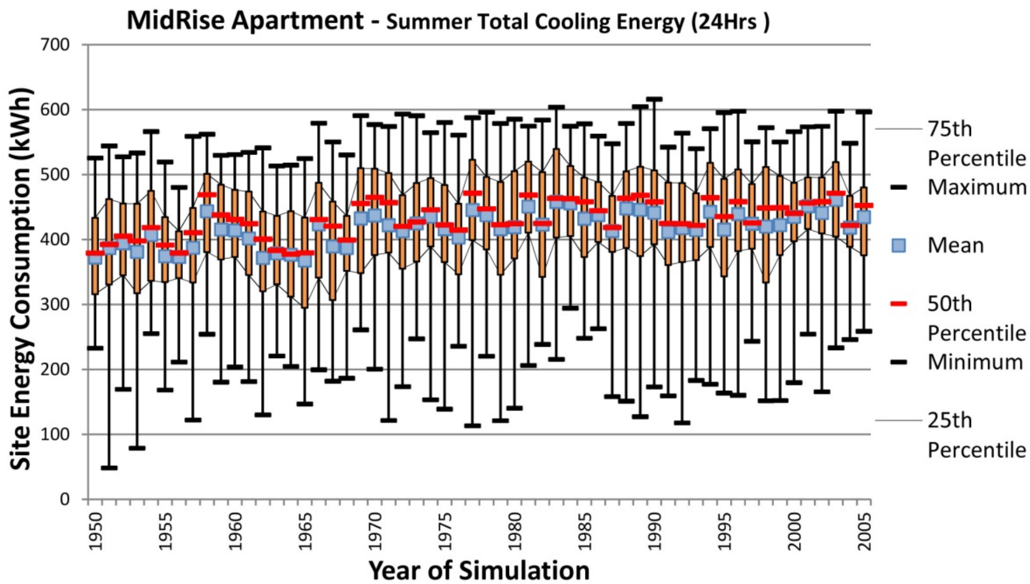
Appendix C- 2-1: MidRIse Apartment - Energy Consumption for Cooling and Heating (G-1)



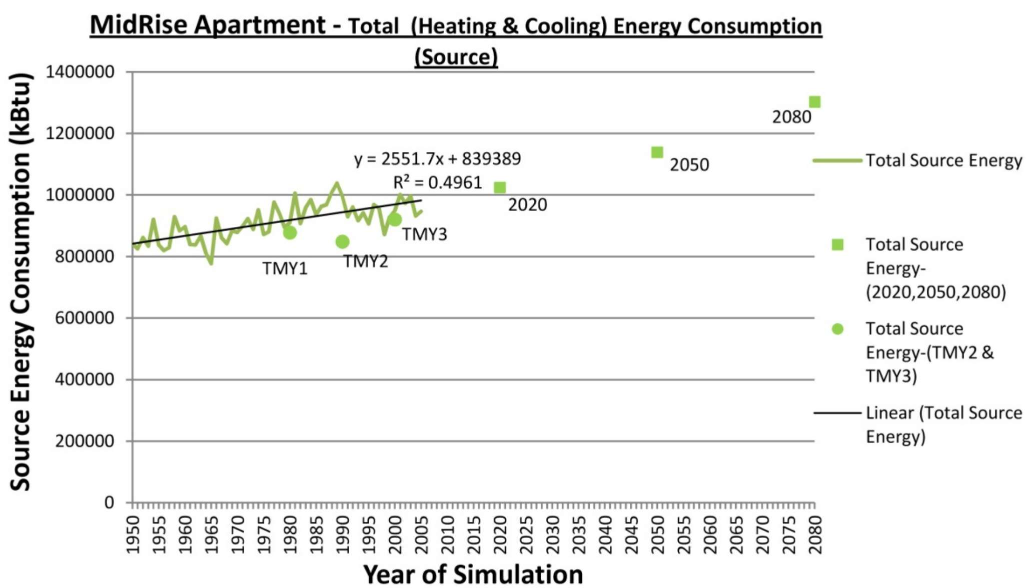
Appendix C- 2-2: MidRIse Apartment - Combined Heating and Cooling Energy Use (G-2



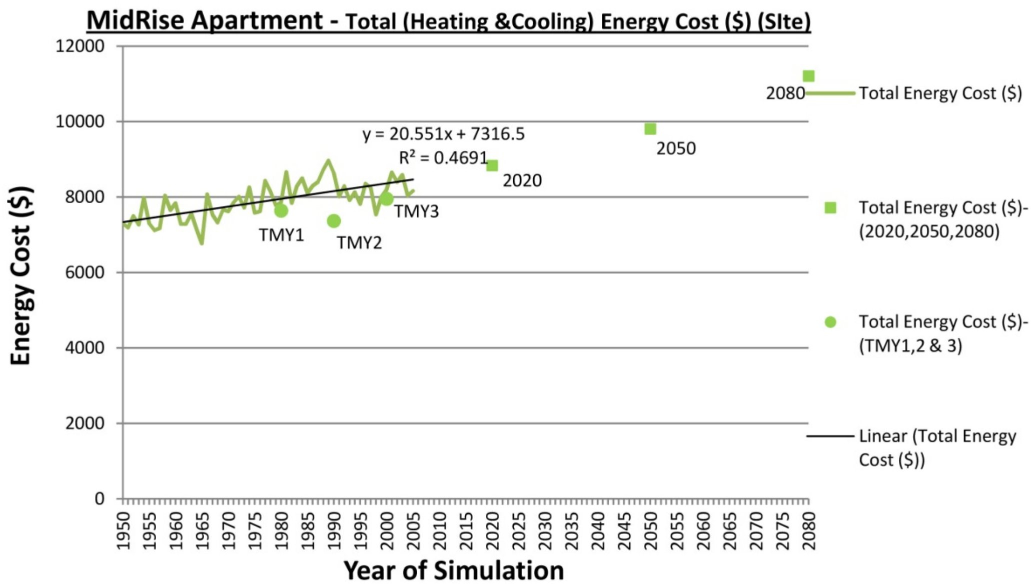
Appendix C- 2-3: MidRise Apartment - Summer & Night-time Cooling (G-3)



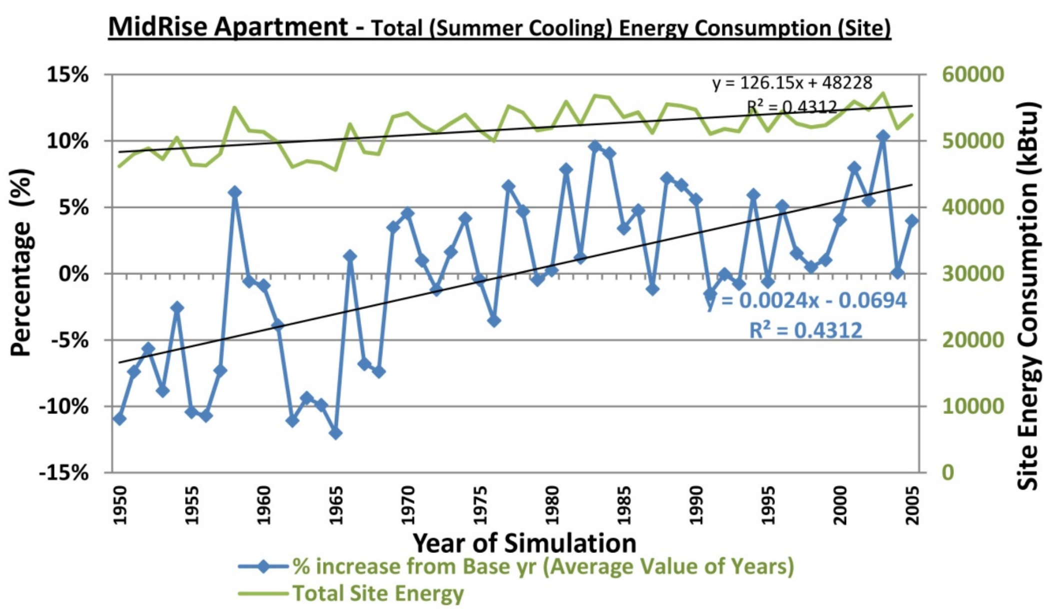
Appendix C- 2-4: MidRise Apartment - Summer Total Cooling Energy (24Hrs) (G-4)



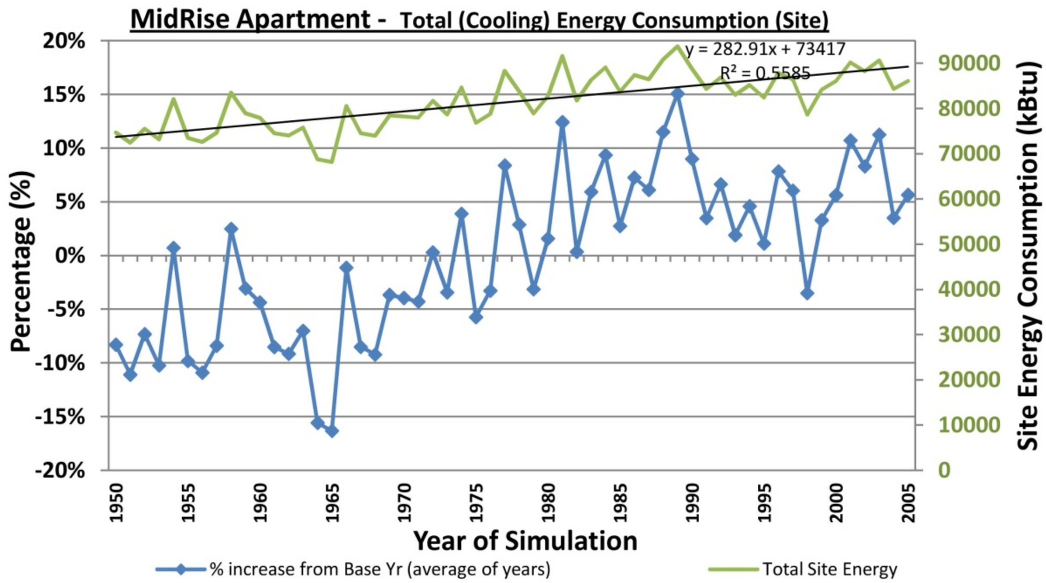
Appendix C- 2-5: MidRise Apartment - Total (Heating & Cooling) Energy Consumption (Source) (G-6)



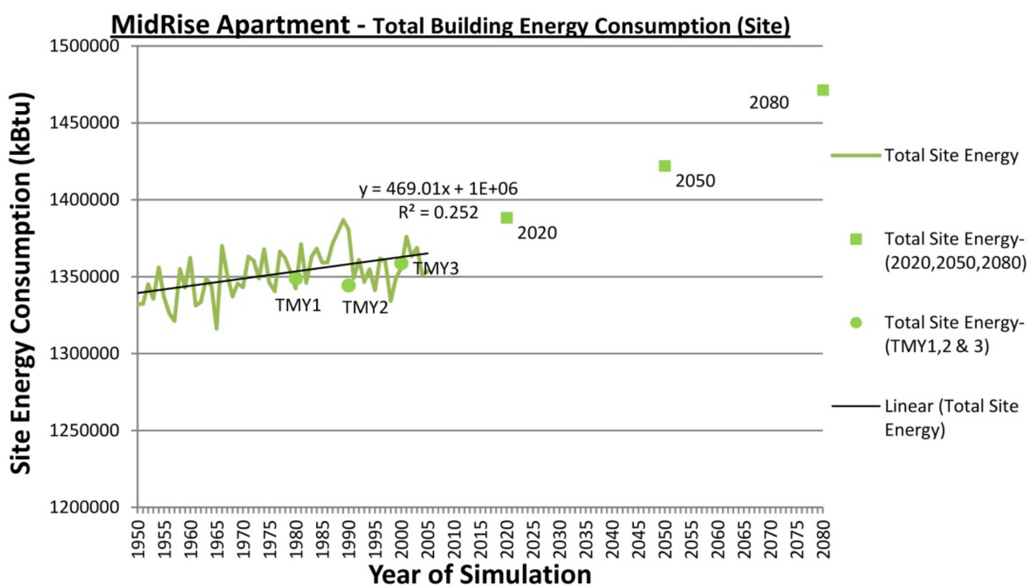
Appendix C- 2-6: MidRise Apartment - Total (Heating & Cooling) Energy Cost ($) (Site) (G-7)



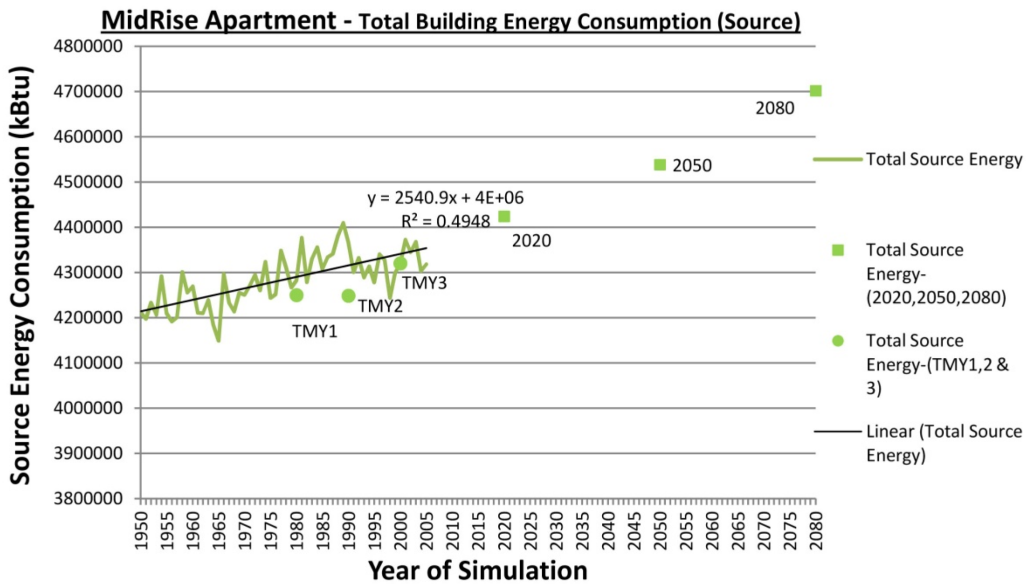
Appendix C- 2-7: MidRise Apartment - Total (Summer Cooling) Energy Consumption (Site) (G-8)



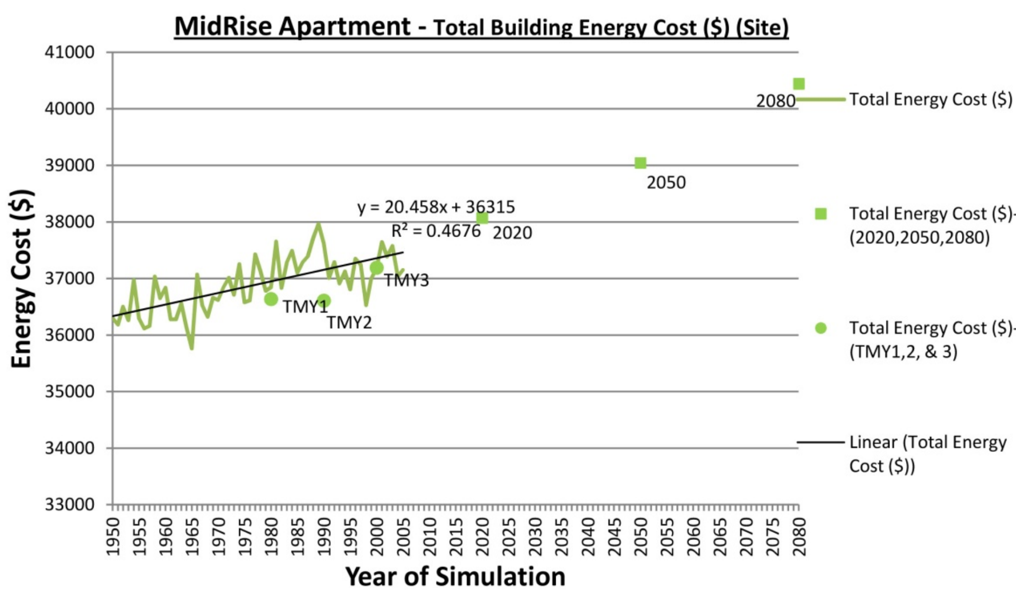
Appendix C- 2-8: MidRise Apartment - Total (Cooling) Energy Consumption (Site) (G-9)



Appendix C- 2-9: MidRise Apartment - Total BuildingEnergy Consumption (Site) (G-10)

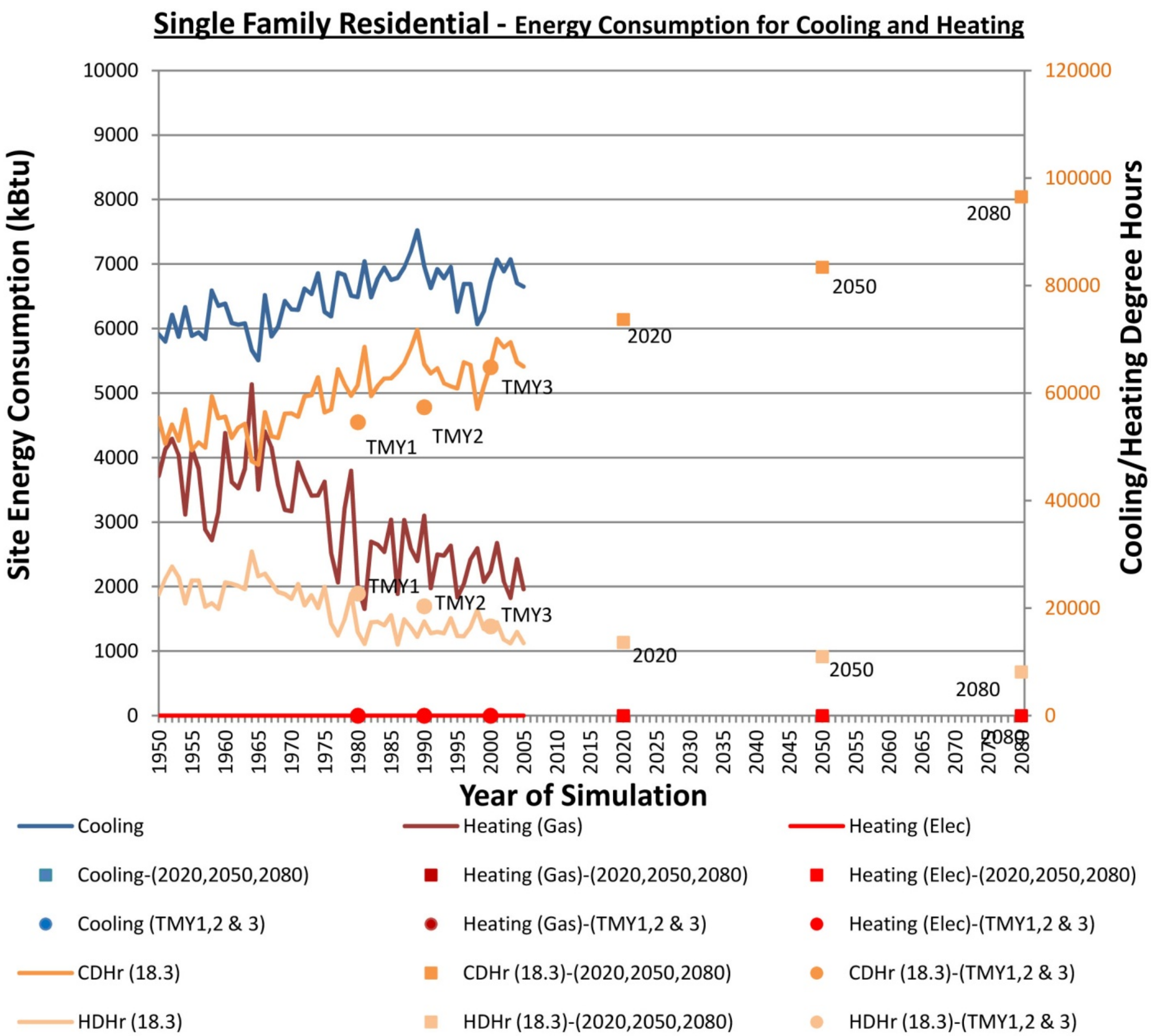


Appendix C- 2-10: MidRise Apartment - Total Building Energy Consumption (Source) (G-11)

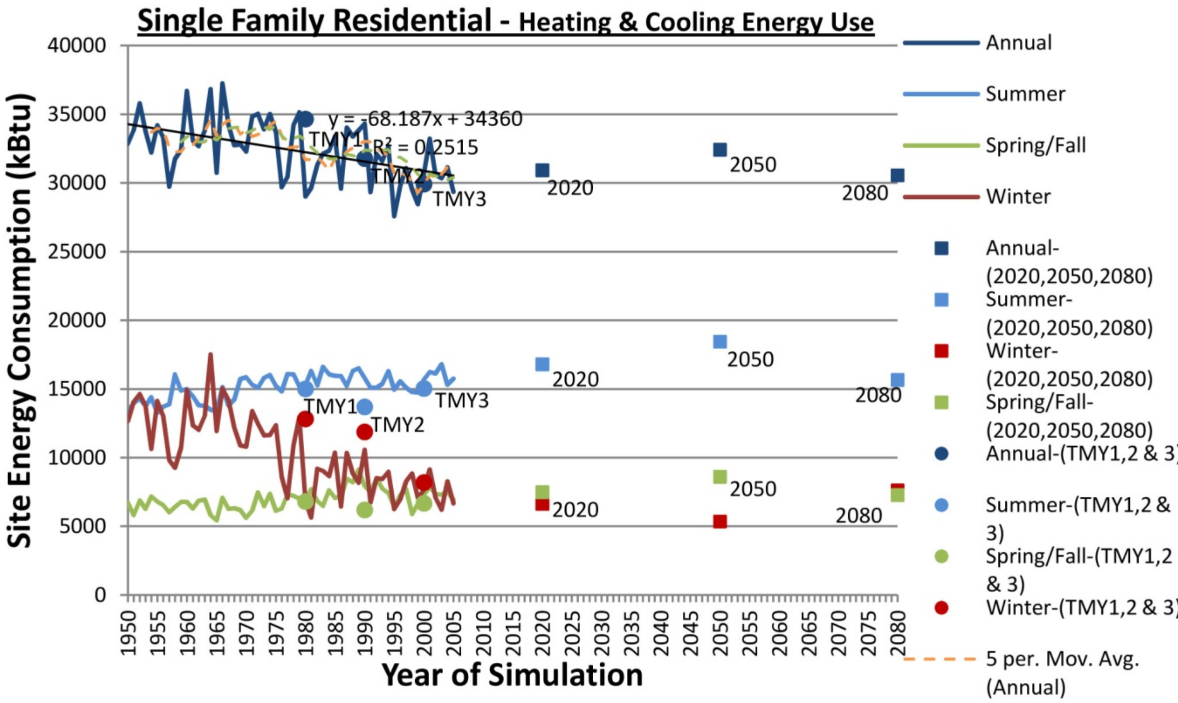


Appendix C- 2-11: MidRise Apartment - Total Building Energy Cost ($) (Site) (G-12)

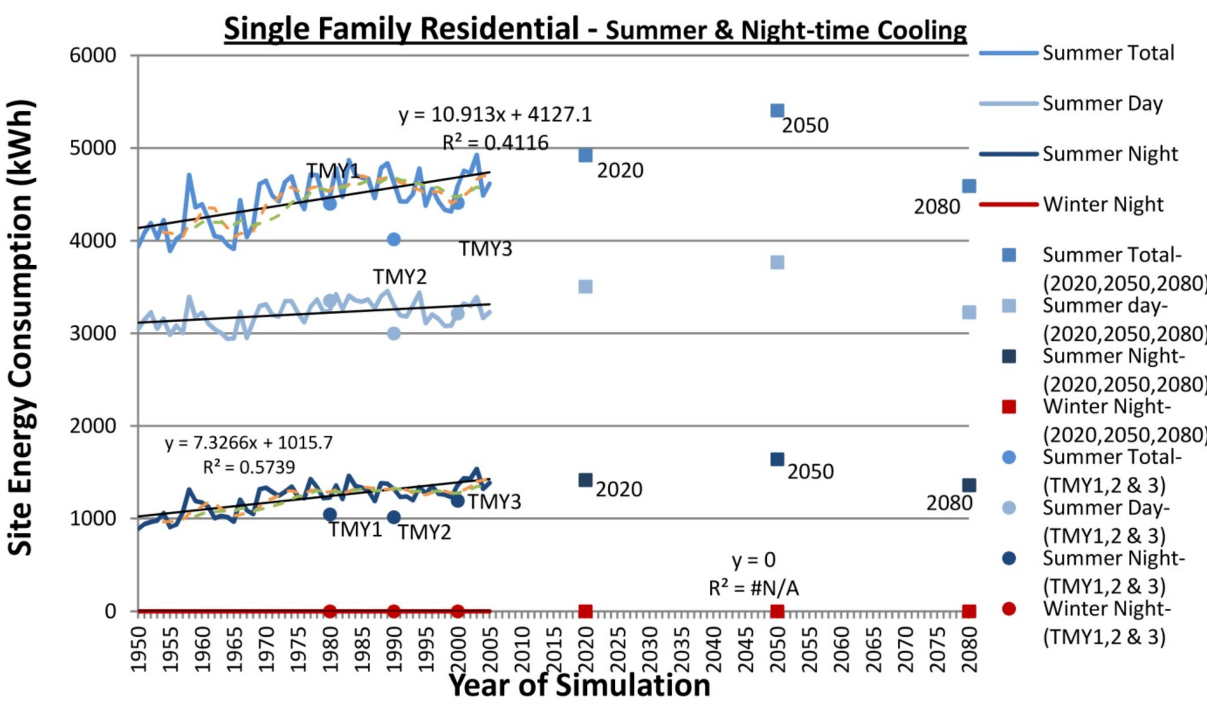
3. Single Family Detached Residential – Prototype ASHRAE 90.1



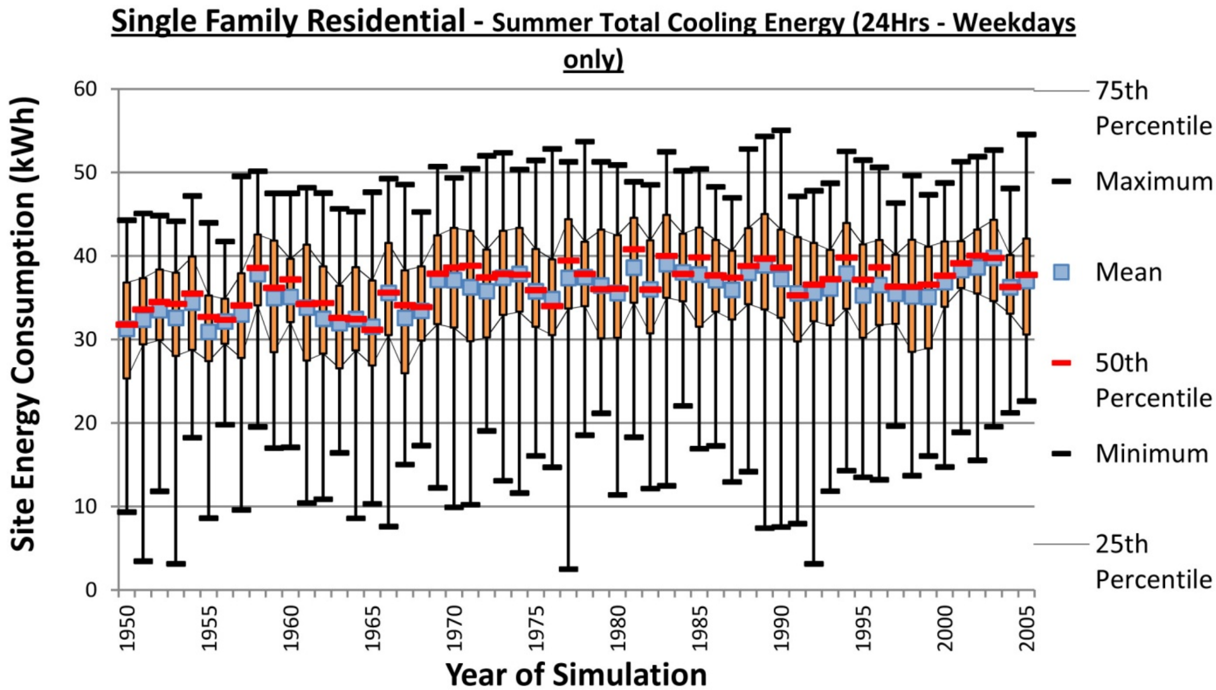
Appendix C- 3-1: Small Office - Energy Consumption for Cooling and Heating (G-1)



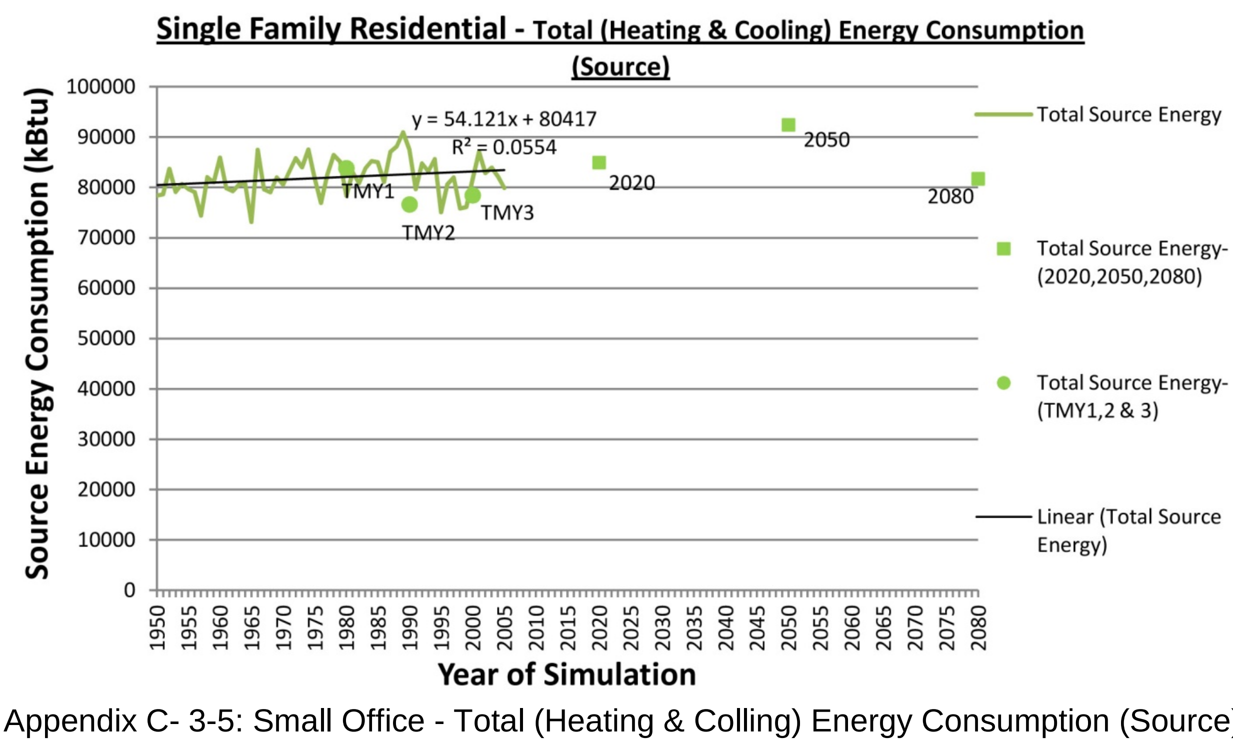
Appendix C- 3-2: Small Office – Combined Heating & Cooling Energy Use (G-2)



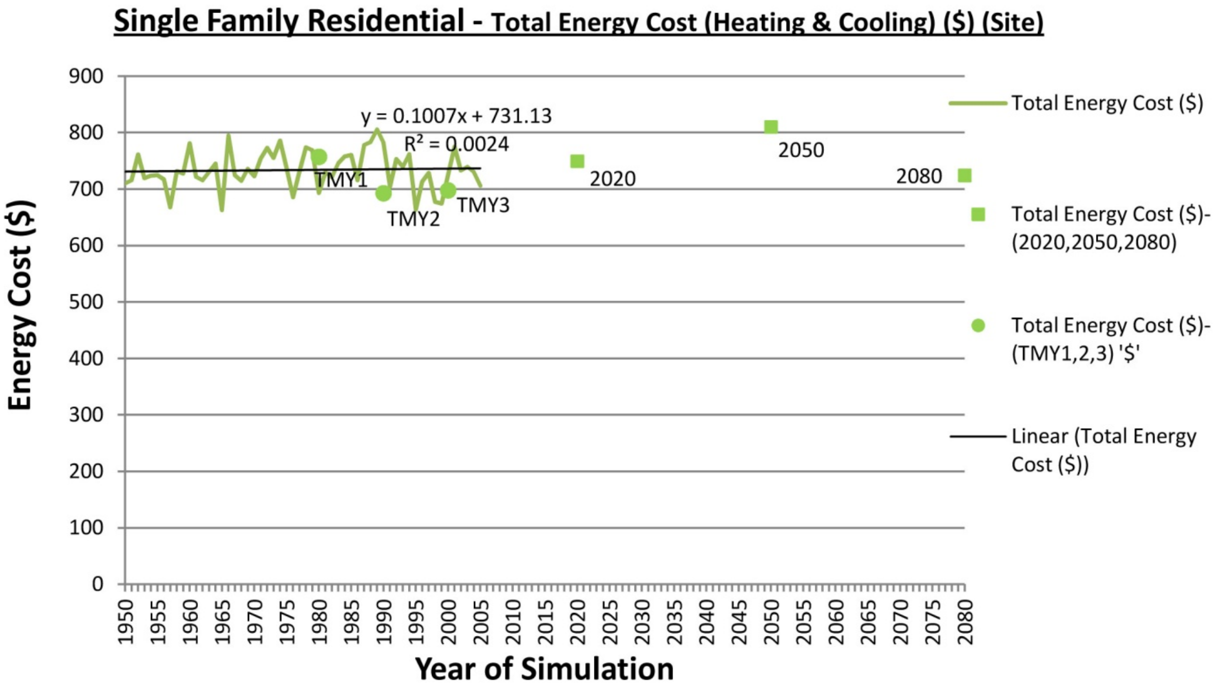
Appendix C- 3-3: Small Office - Summer & Night-time Cooling (G-3)



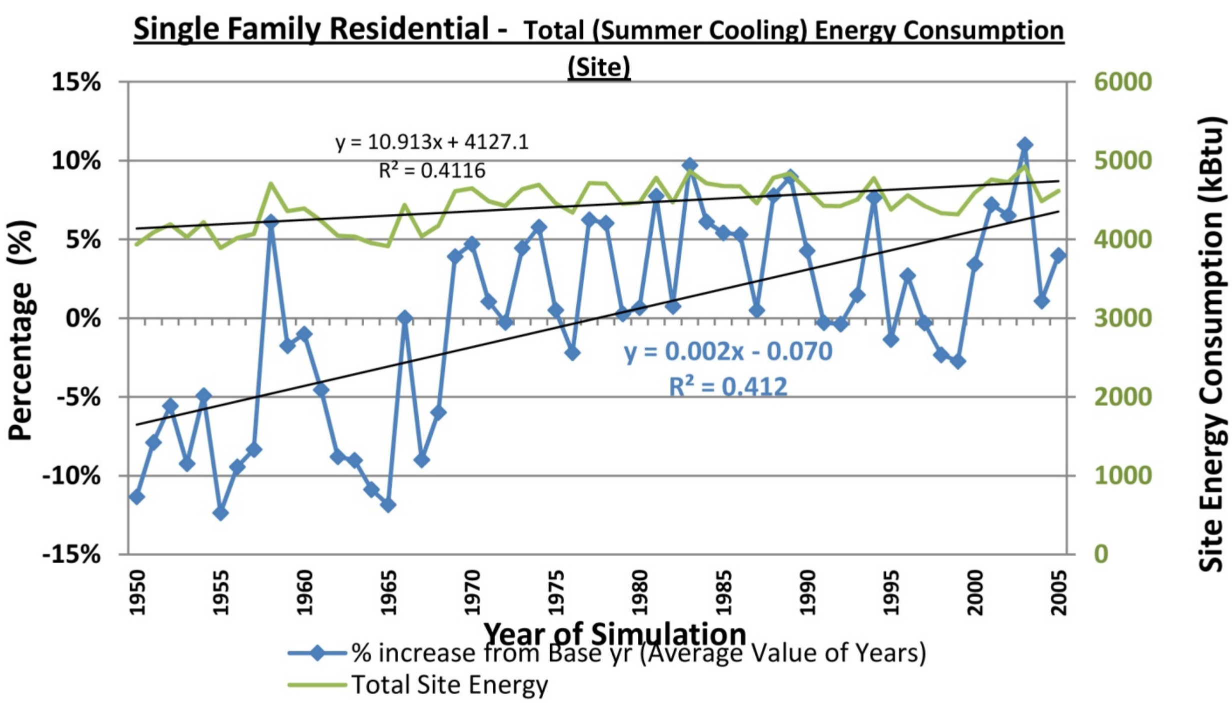
Appendix C- 3-4: Small Office - Summer Daily Cooling Energy (24Hrs - Weekdays only) (G-4)



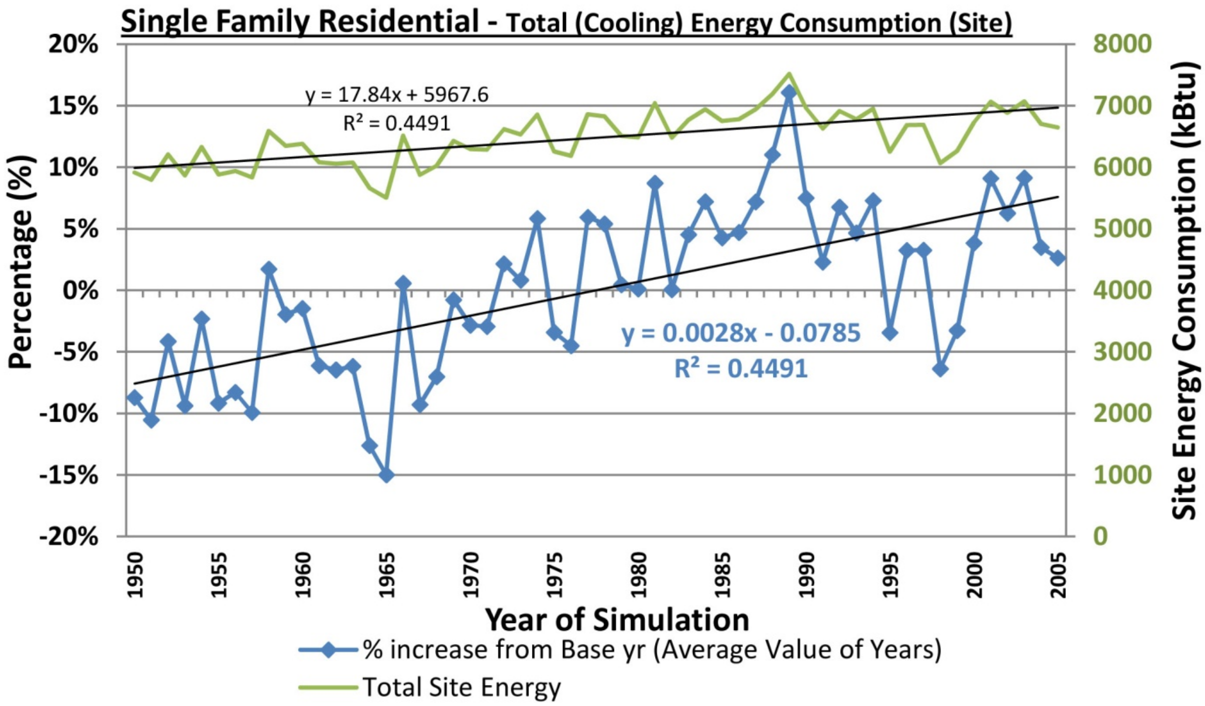
Appendix C- 3-5: Small Office - Total (Heating & Colling) Energy Consumption (Source) (G-6)



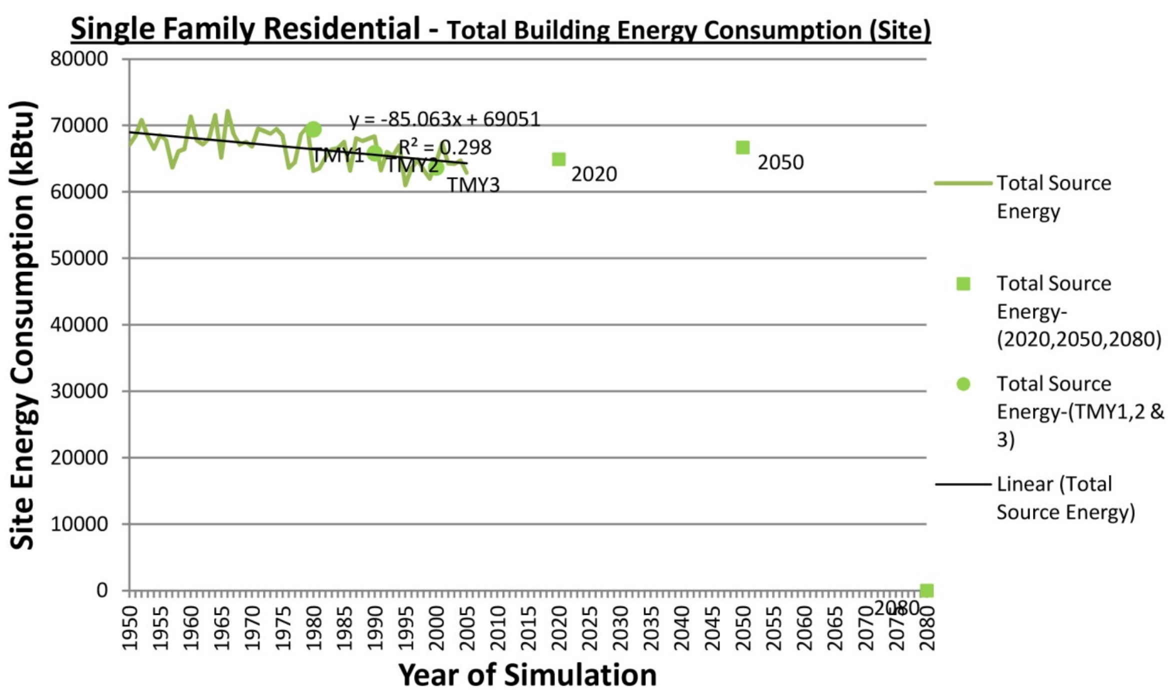
Appendix C- 3-6: Small Office - Total (Summer Cooling) Energy Cost (Site) (G-7)



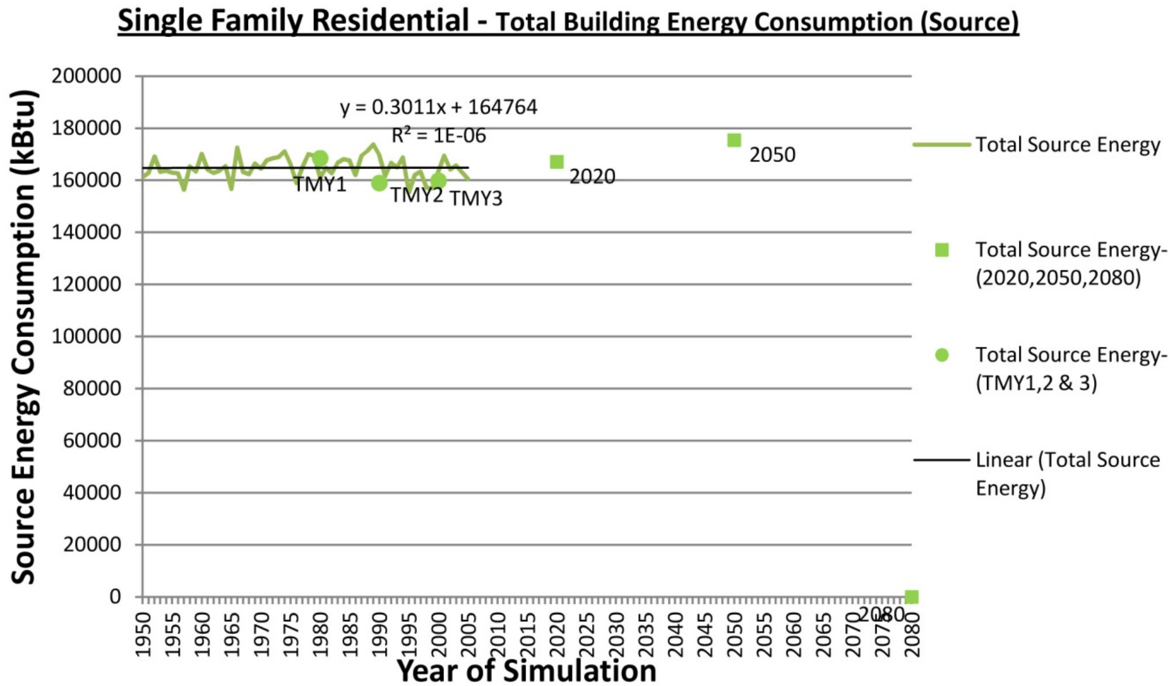
Appendix C- 3-7: Small Office - Total (Summer Cooling) Energy Consumption (Site) (G-8)



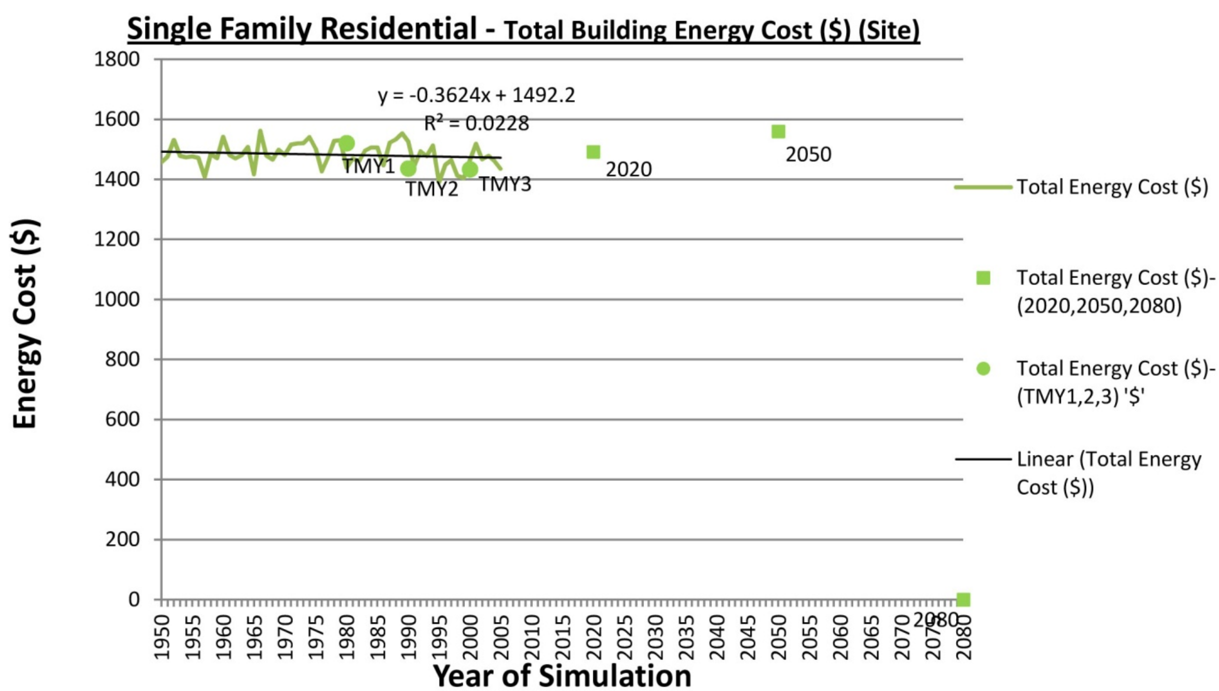
Appendix C- 3-8: Small Office - Total (Cooling) Energy Consumption (Site) (G-9)



Appendix C- 3-9: Small Office - Total Building Energy Consumption (Site) (G-10)

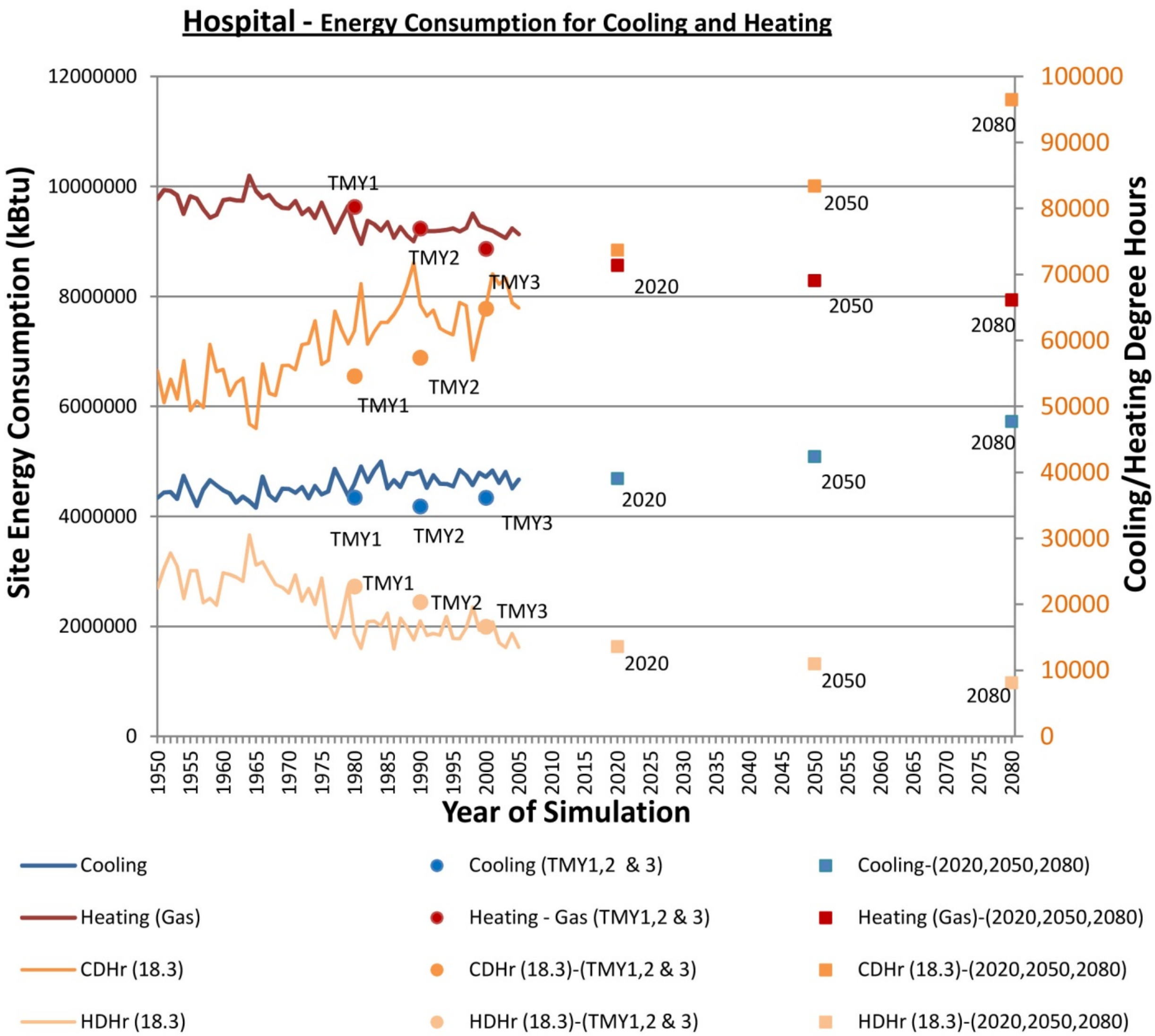


Appendix C- 3-10: Small Office - Small Office - Total Building Energy Consumption (Source) (G-11)

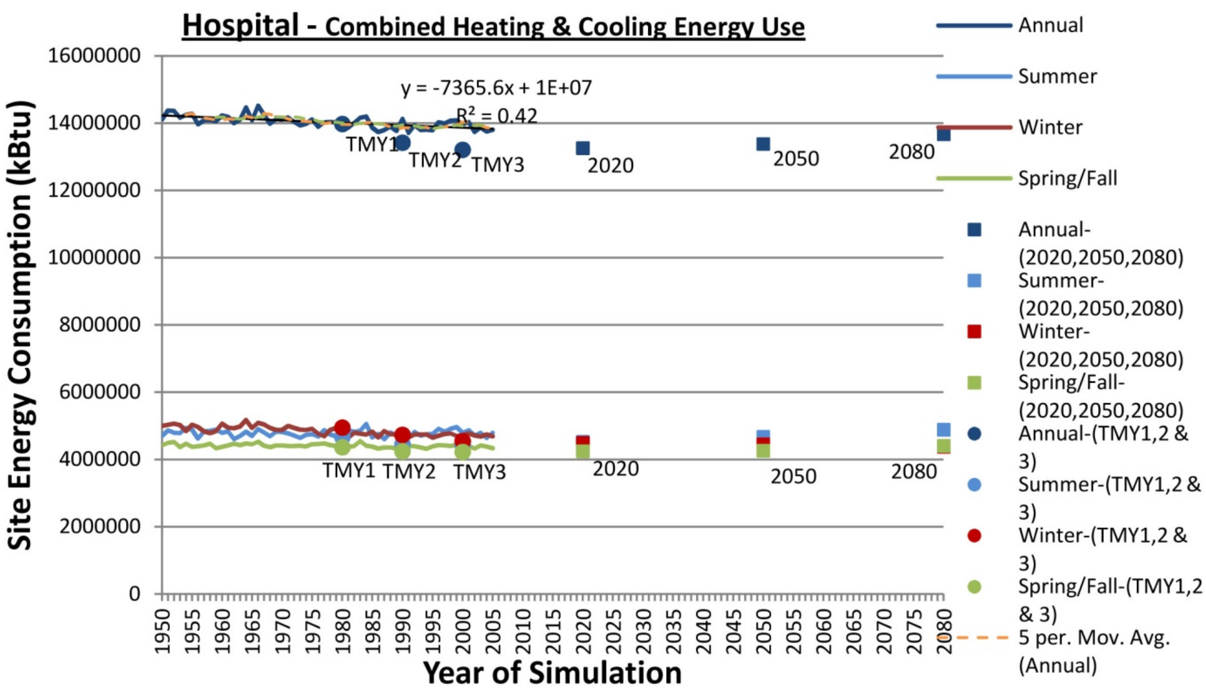


Appendix C- 3-11: Small Office - Total Building Energy Consumption (Source) (G-12)

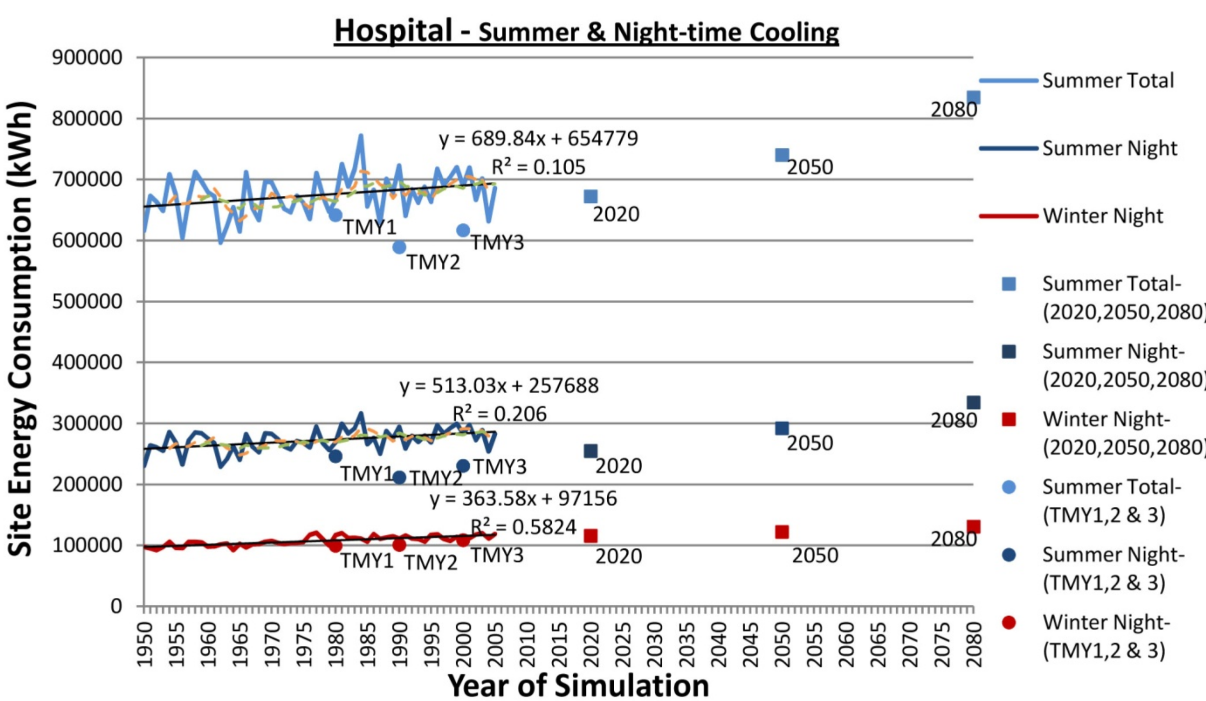
4. Hospital – Prototype ASHRAE 90.1



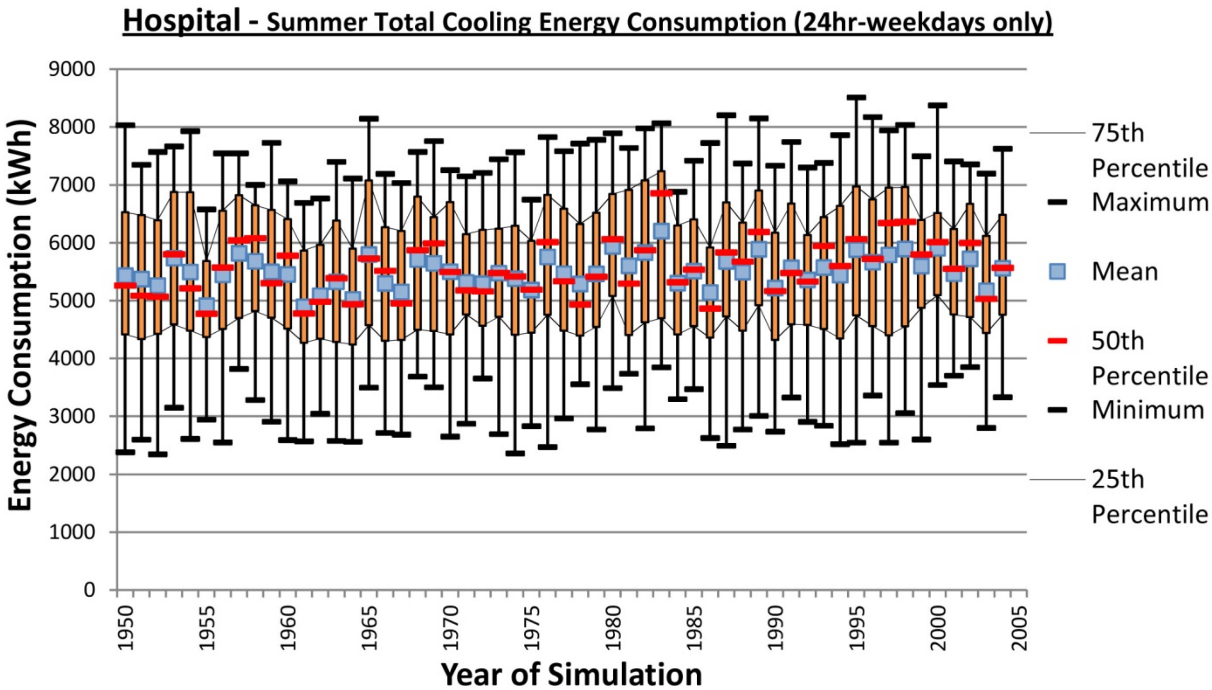
Appendix C- 4-1: Hospital - Energy Consumption for Cooling and Heating (G-1)



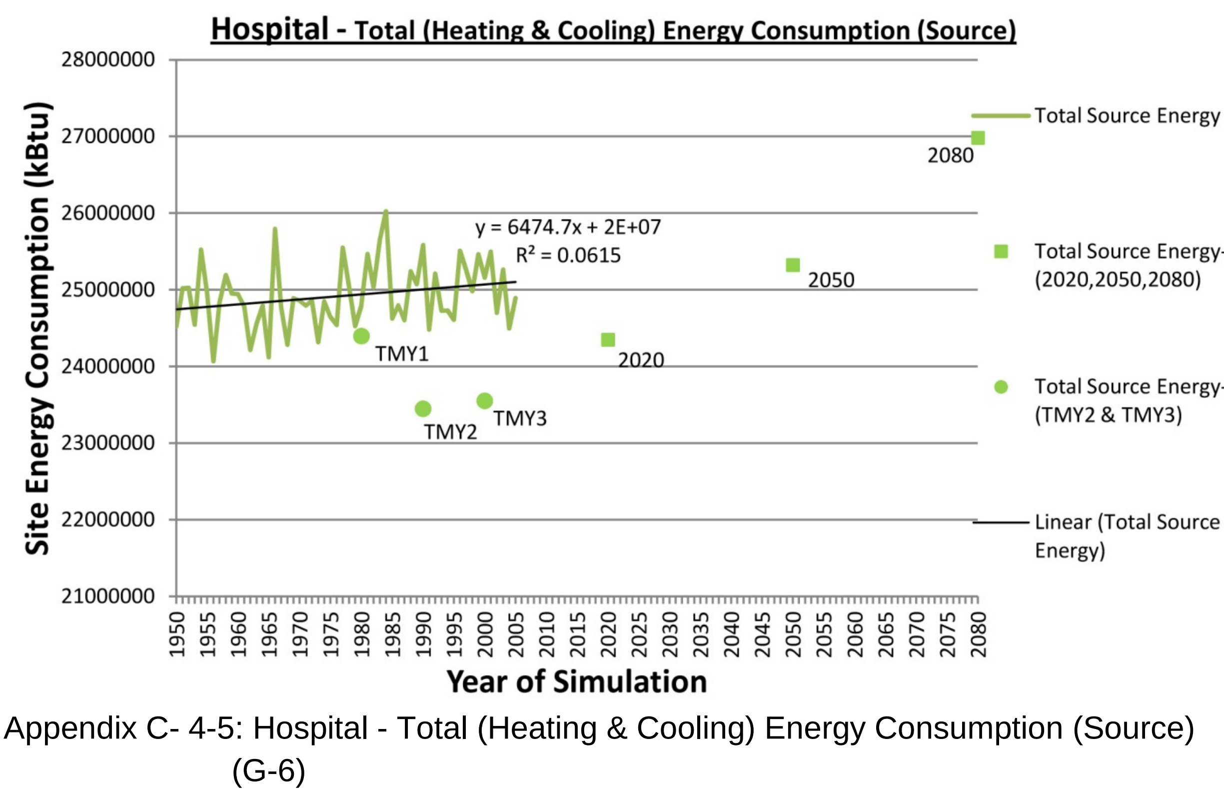
Appendix C- 4-2: Hospital - Energy Consumption for Heating & Cooling Energy Use (G-2)



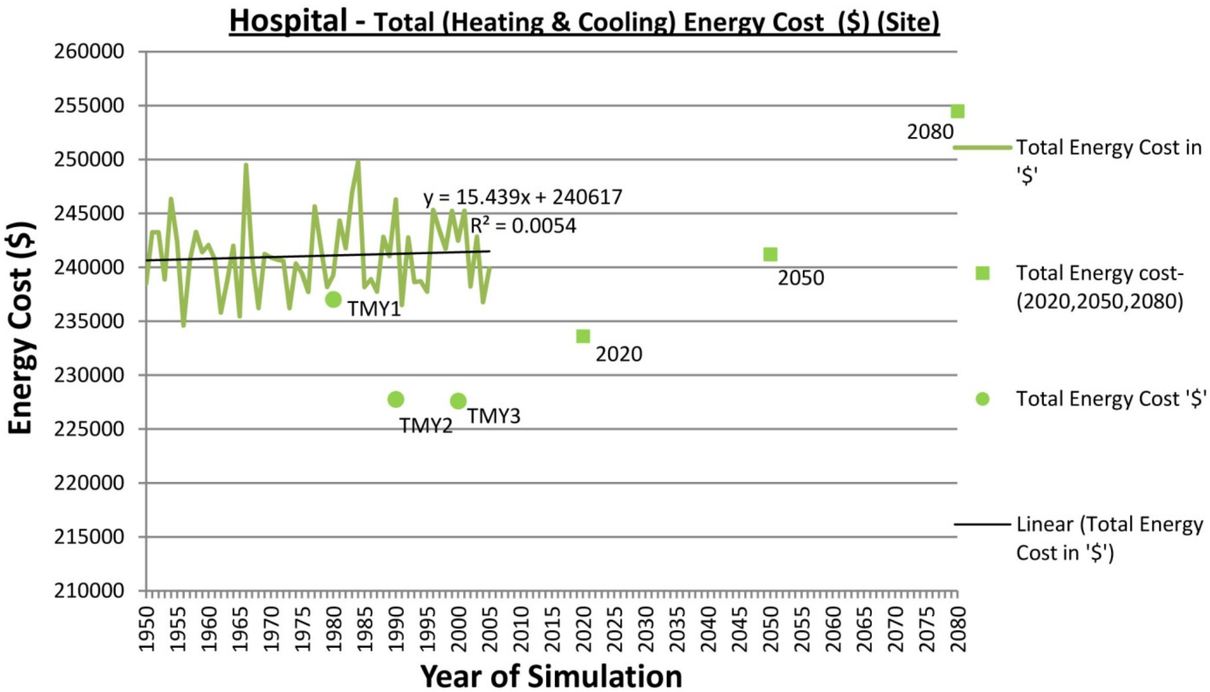
Appendix C- 4-3: Hospital - Summer & Night-time Cooling (G-3)



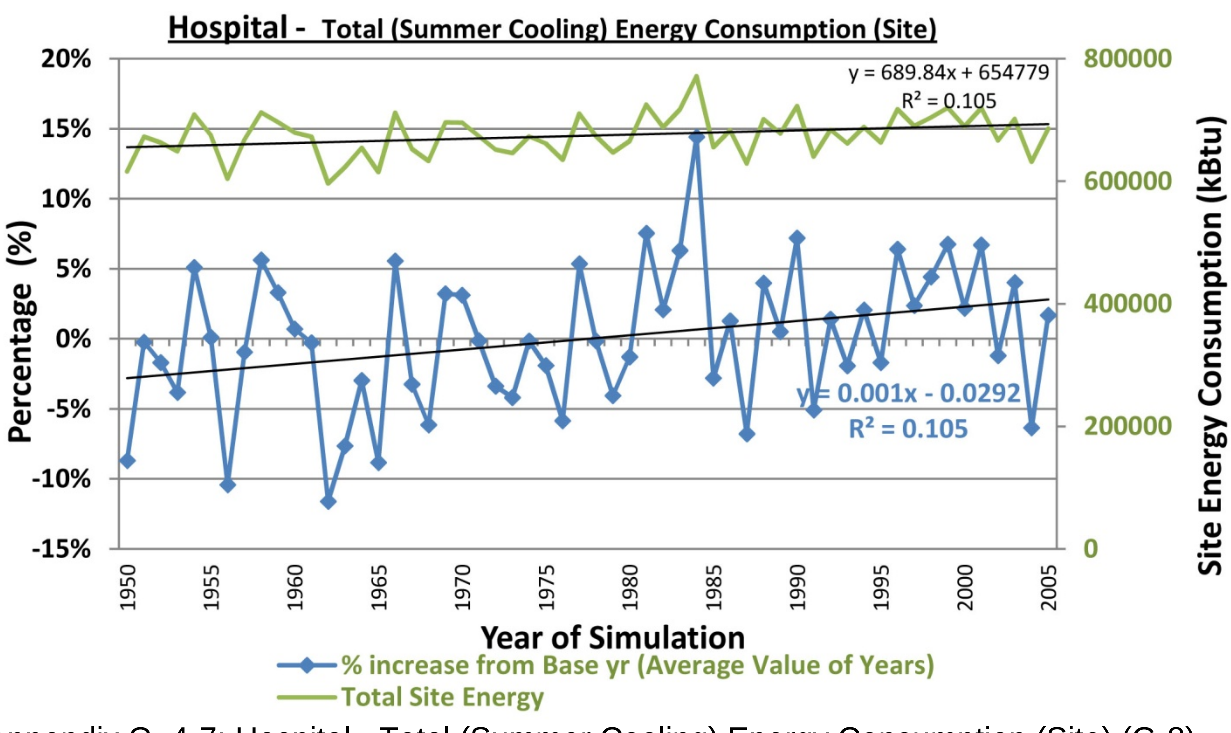
Appendix C- 4-4: Hospital - Summer Total Cooling Energy COnsumption (24Hr - weekdays only) (G-4)



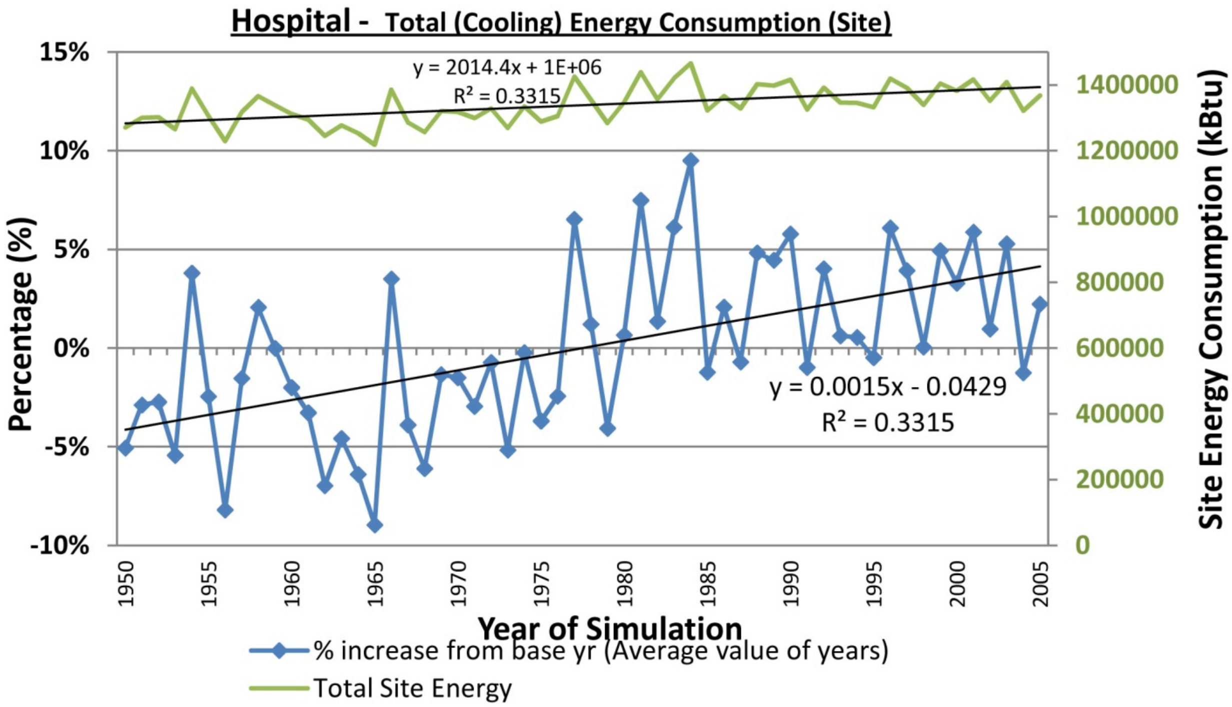
Appendix C- 4-5: Hospital - Total (Heating & Cooling) Energy Consumption (Source) (G-6)



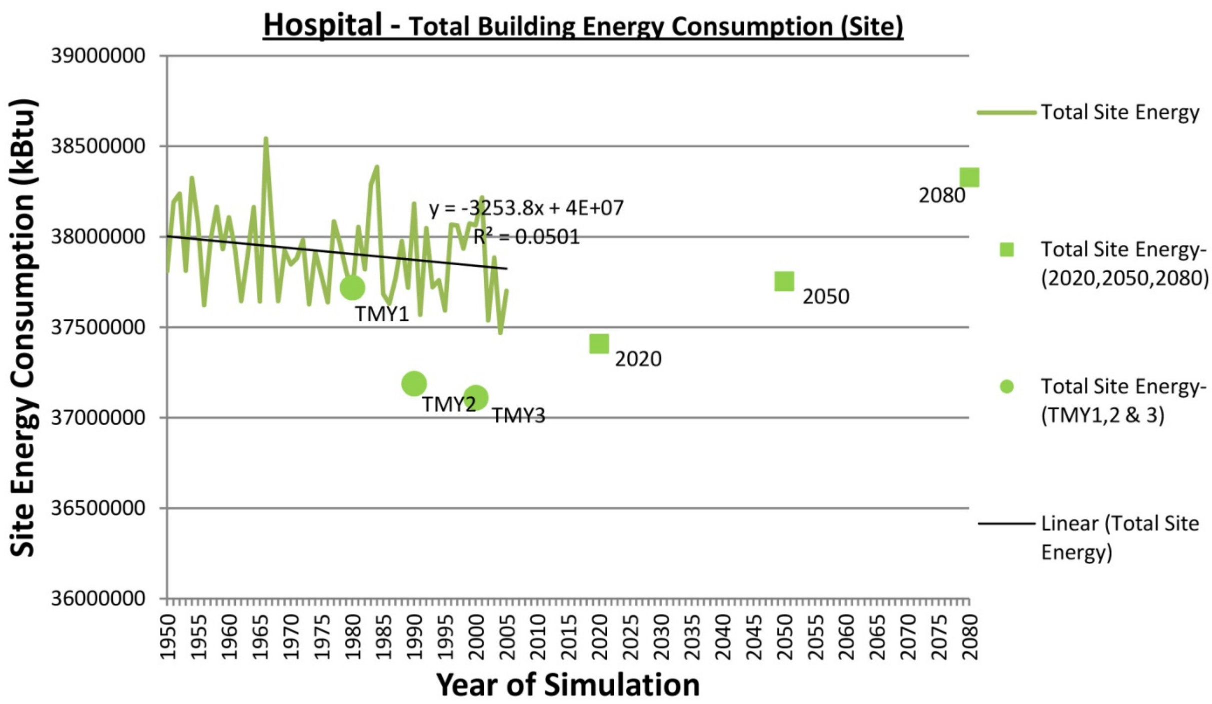
Appendix C- 4-6: Hospital - Total (Heating & Cooling) Energy Cost ($) (Site) (G-7)



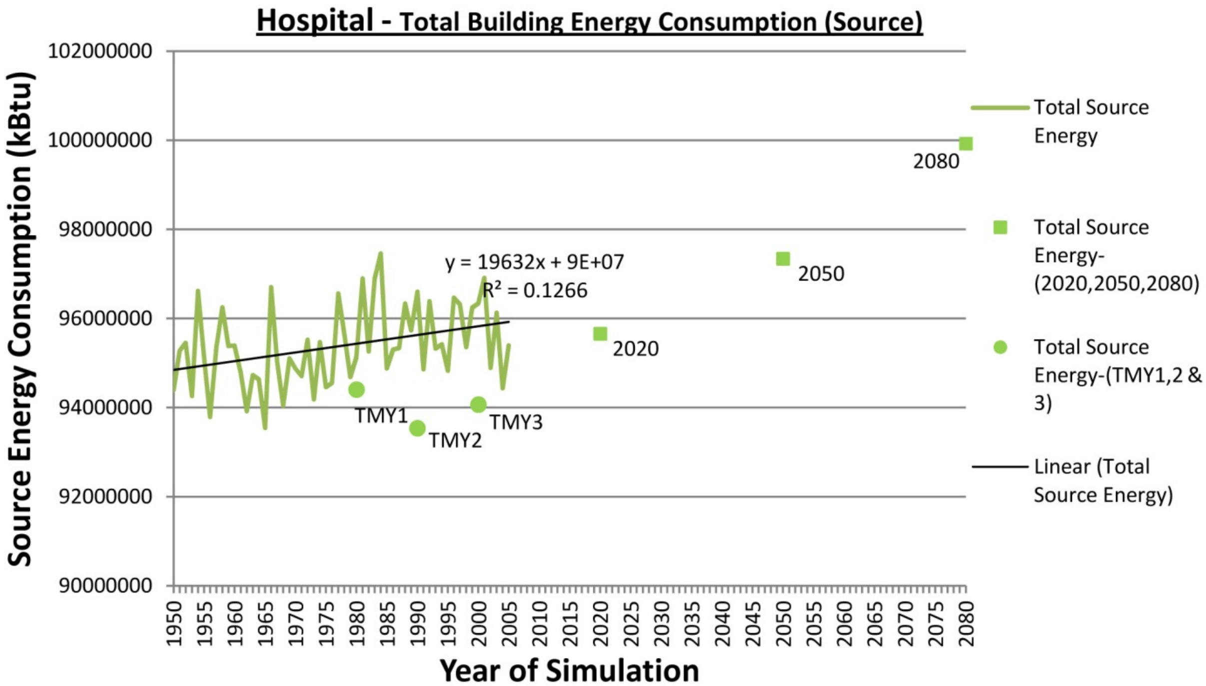
Appendix C- 4-7: Hospital - Total (Summer Cooling) Energy Consumption (Site) (G-8)



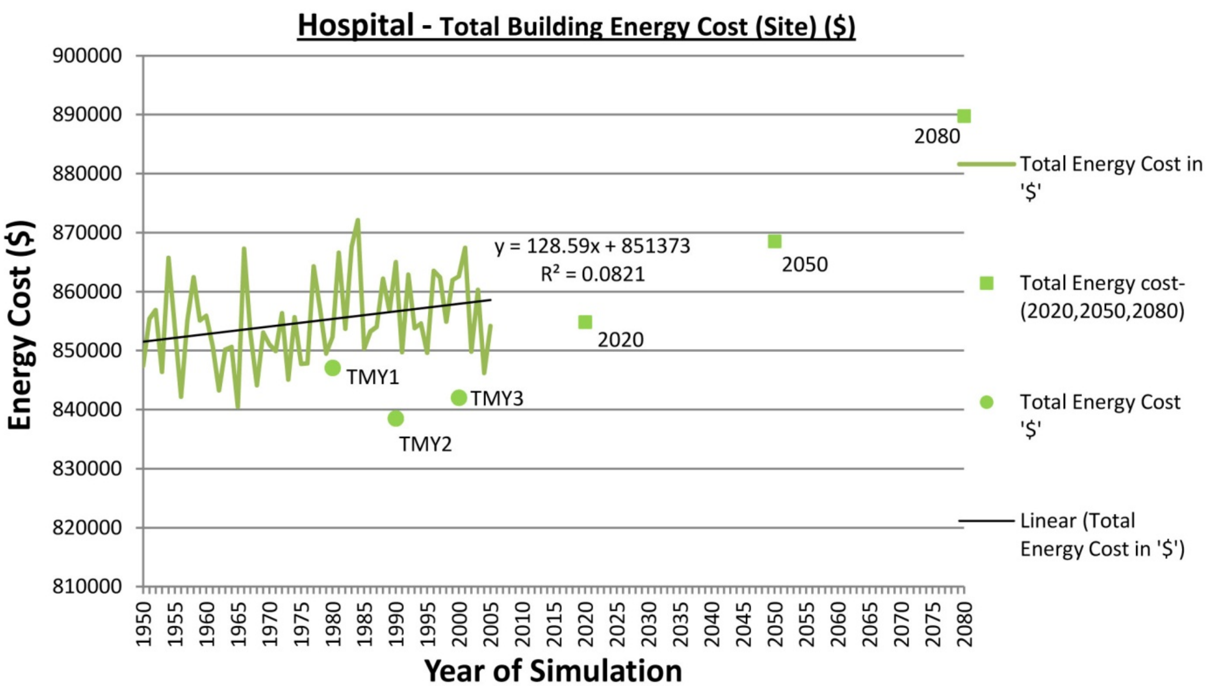
Appendix C- 4-8: Hospital - Total (Cooling) Energy Consumption (Site) (G-9)



Appendix C- 4-9: Hospital - Total Building Energy Consumption (Site) (G-10)

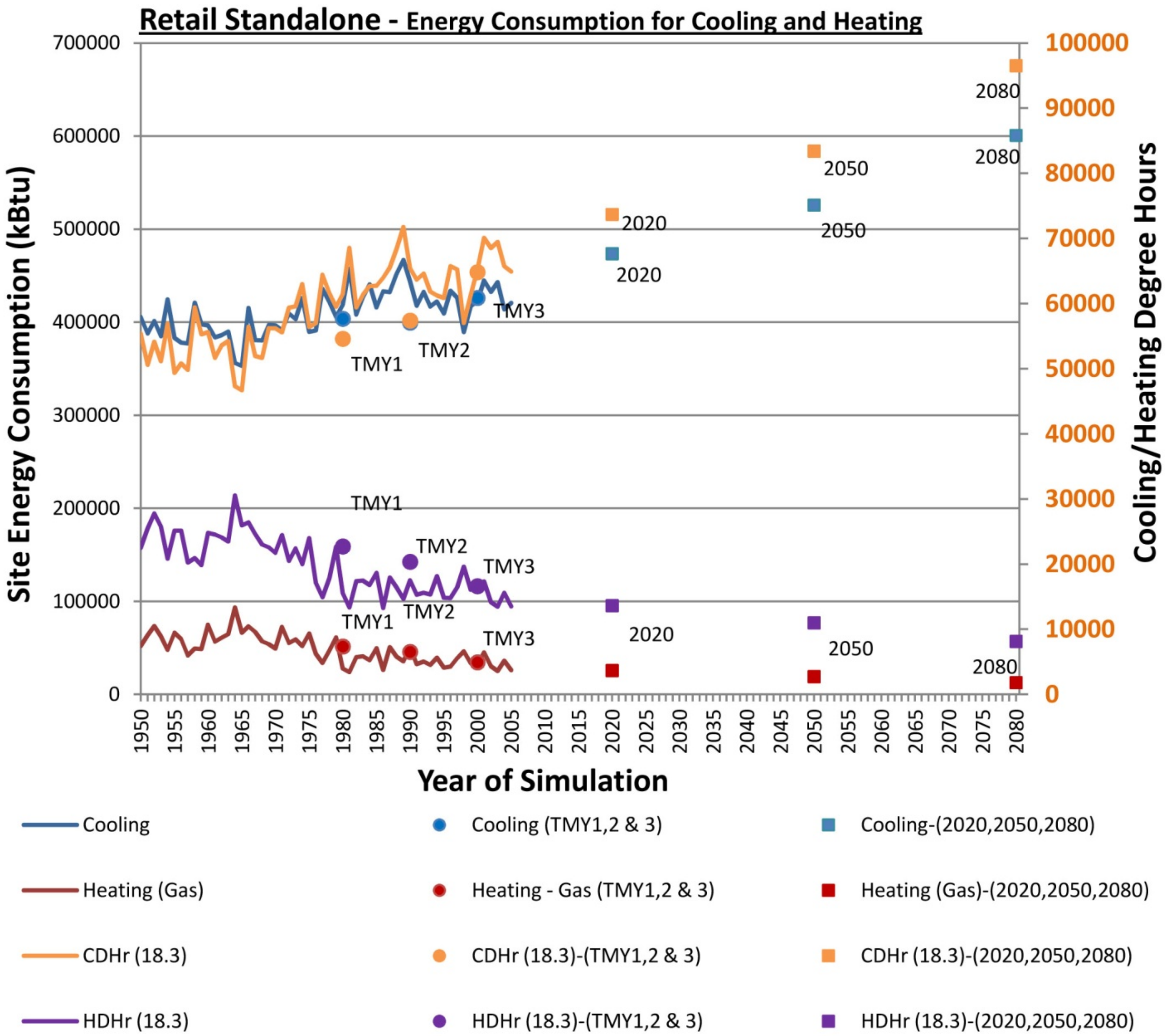


Appendix C- 4-10: Hospital - Total Building Energy Consumption (Source) (G-11)

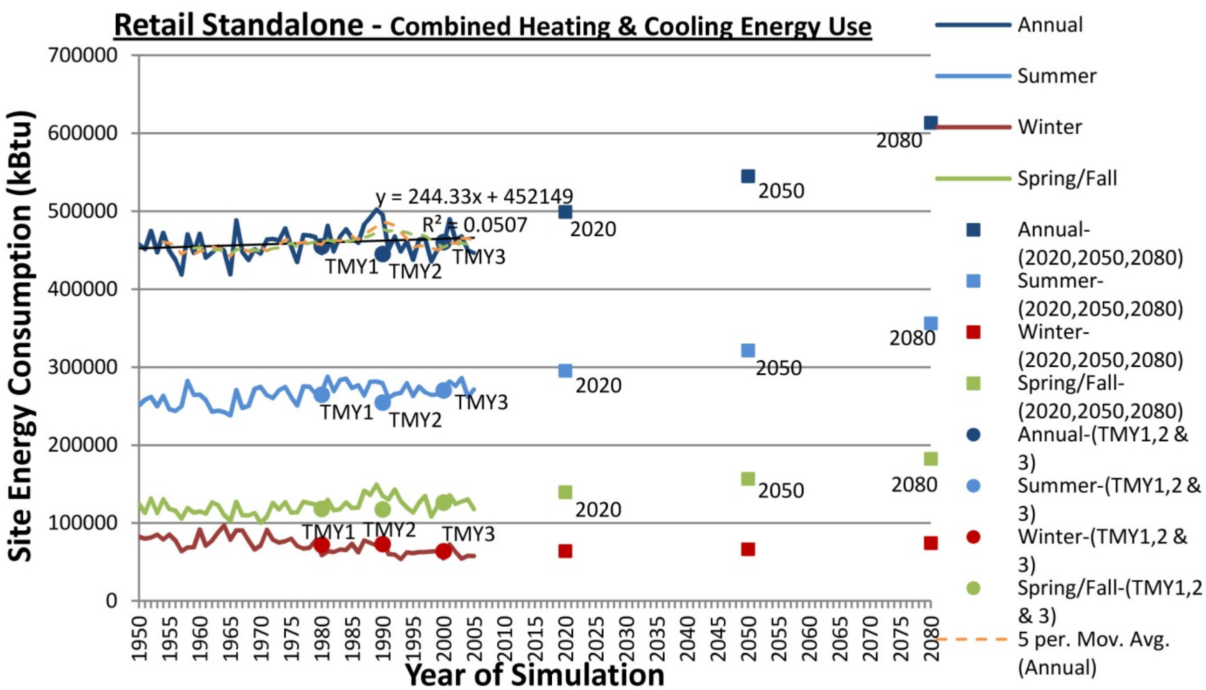


Appendix C- 4-11: Hospital - Total Building Energy Cost (Site) ($) (G-12)

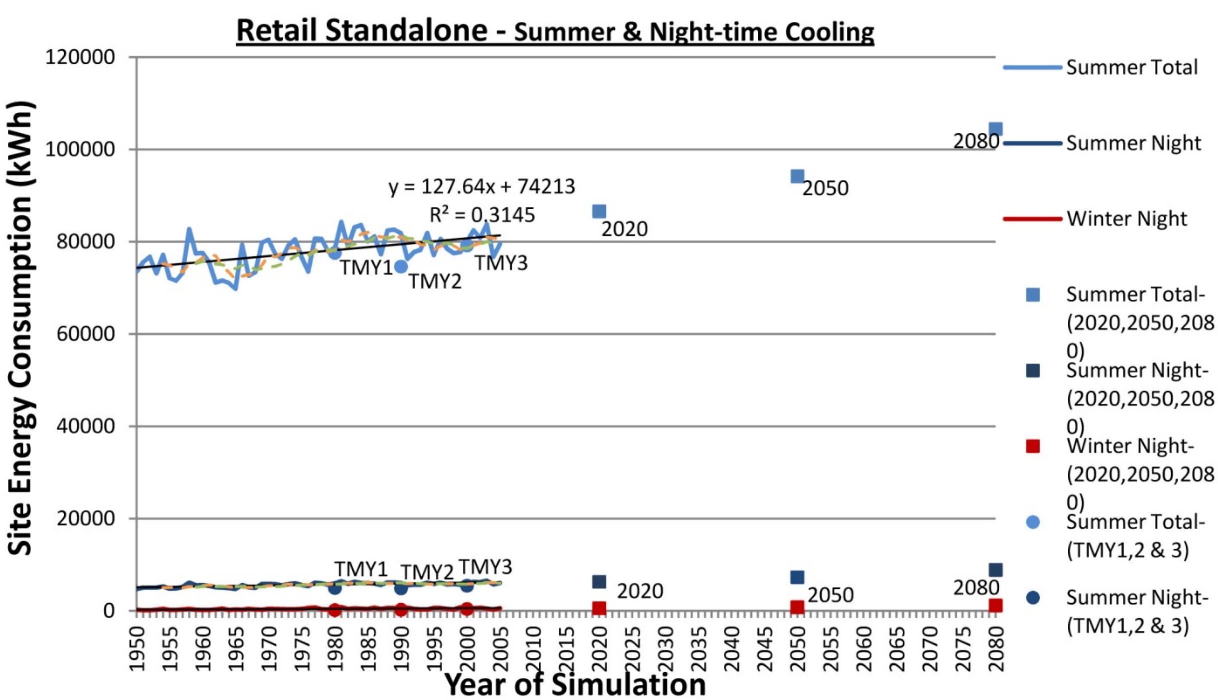
5. Retail Standalone – Prototype ASHRAE 90.1



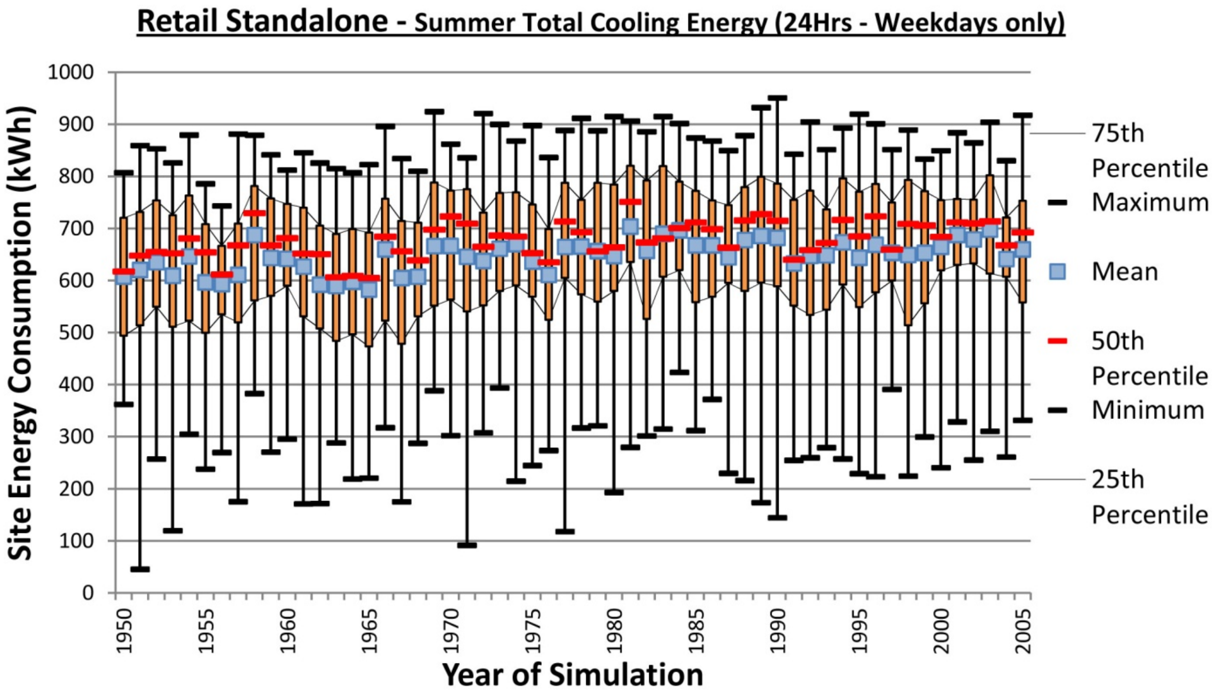
Appendix C- 5-1: Retail Standalone - Energy Consumption for Cooling and Heating (G-1)



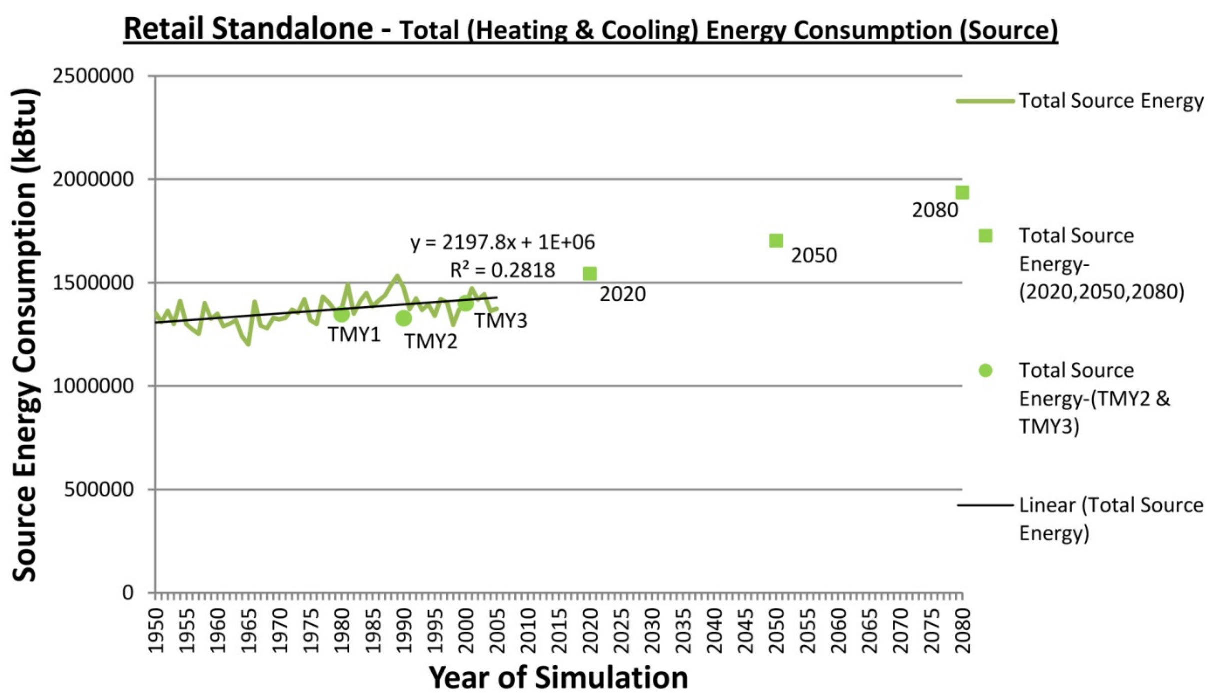
Appendix C- 5-2: Retail Standalone - Combined Heating & Cooling Energy Use (G-2)



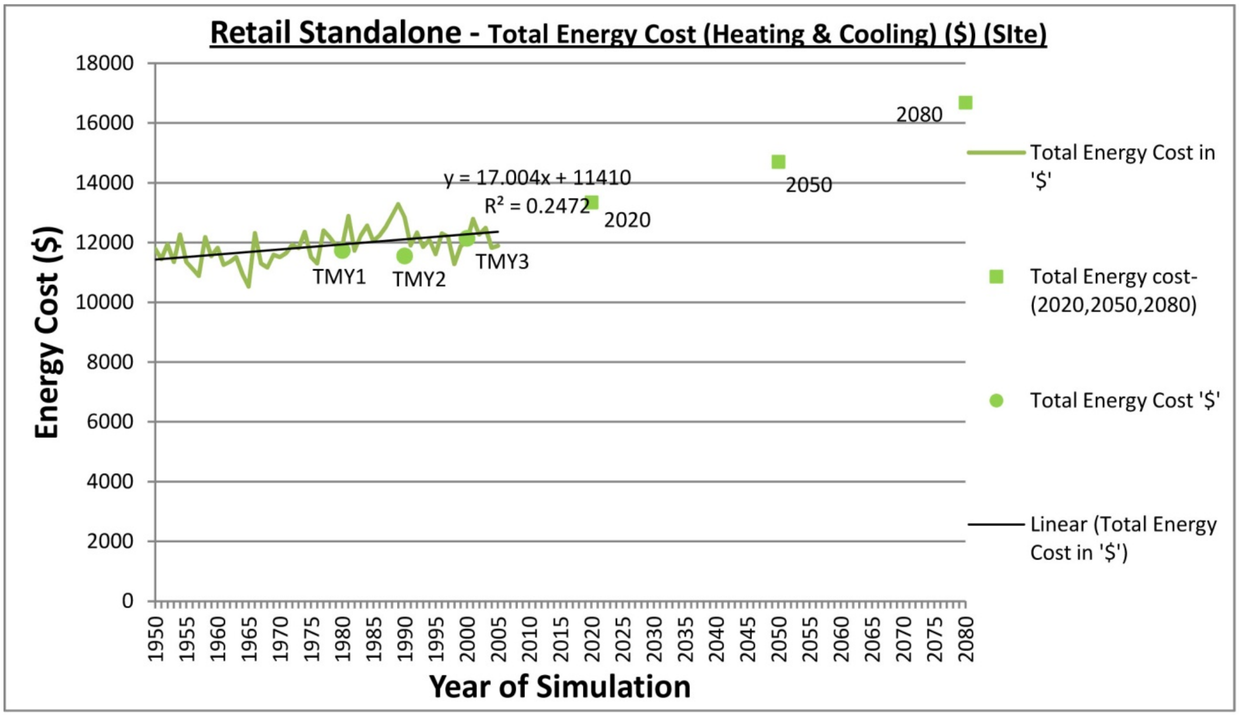
Appendix C- 5-3: Retail Standalone - Summer & Night-time Cooling (G-3)



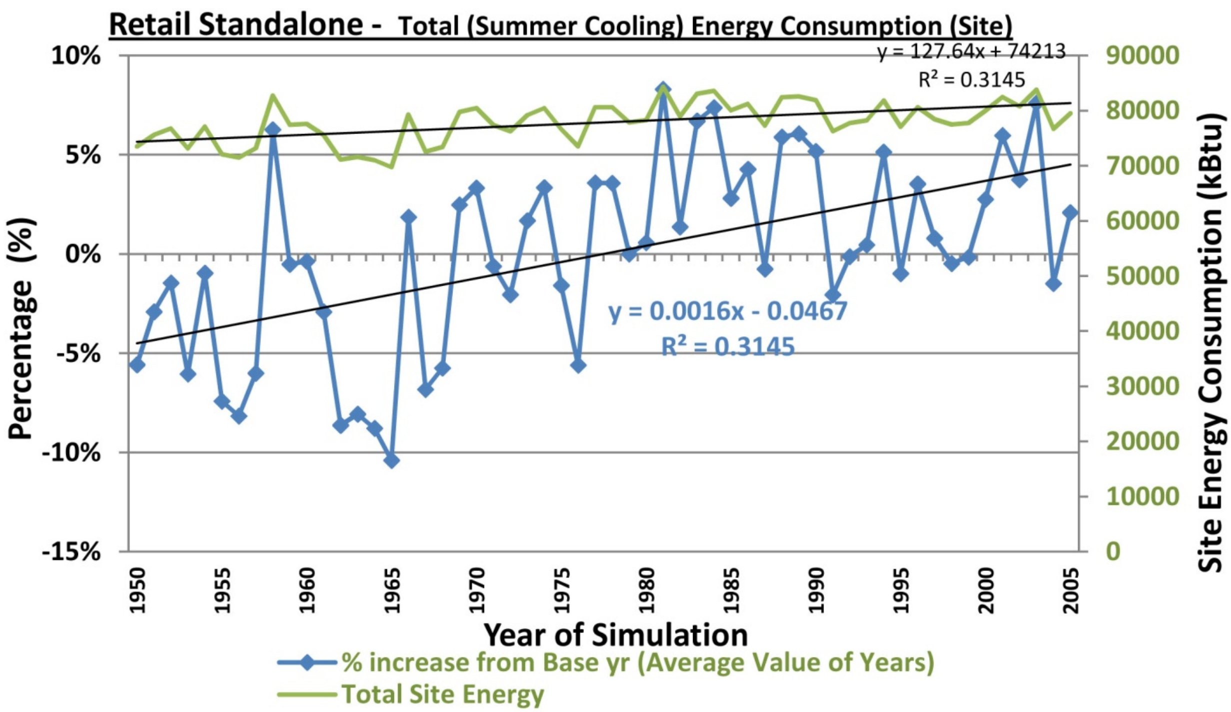
Appendix C- 5-4: Retail Standalone - Summer Total Cooling Energy (24Hrs - Weekdays only) (G-4)



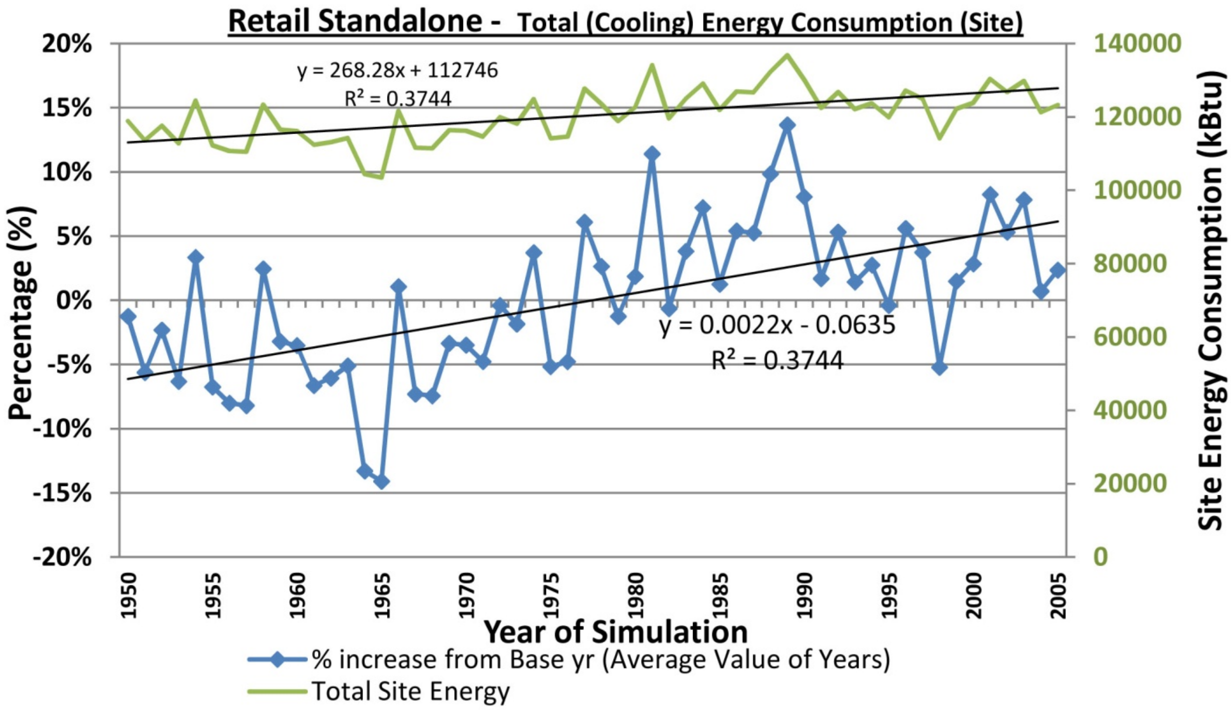
Appendix C- 5-5: Retail Standalone - Total (Heating & Cooling) Energy Consumption (Source) (G-6)



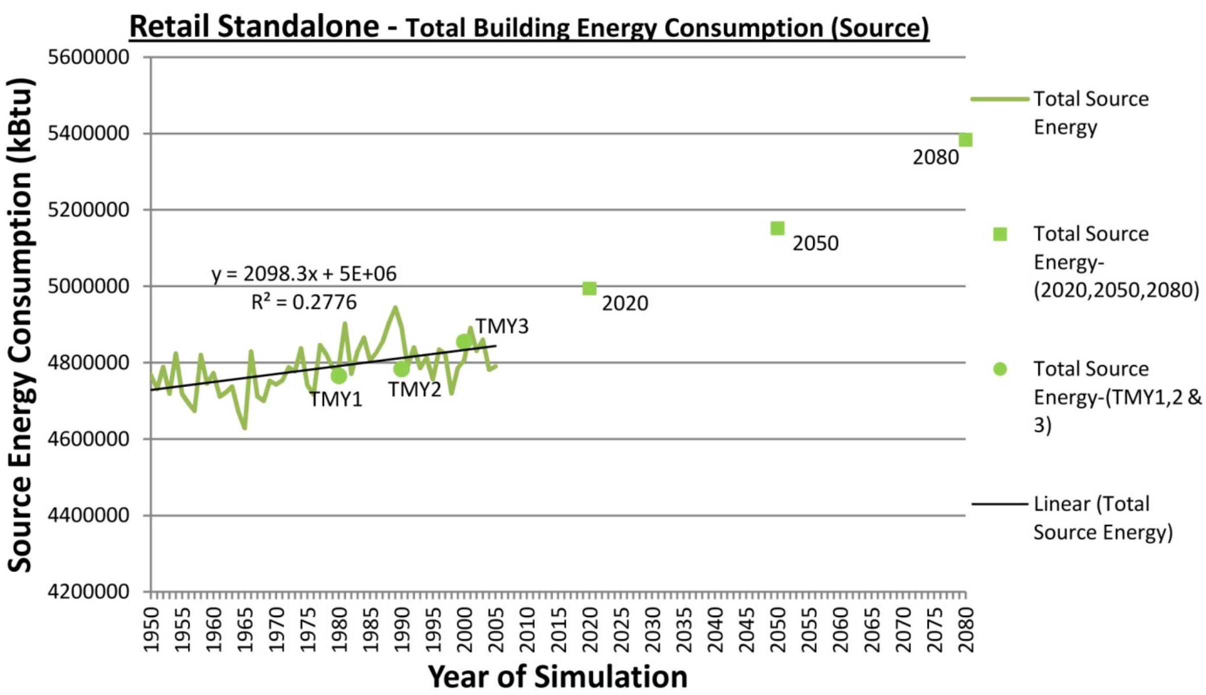
Appendix C- 5-6: Retail Standalone - Total Energy Cost (Heating & Cooling) ($) (Site) (G-7)



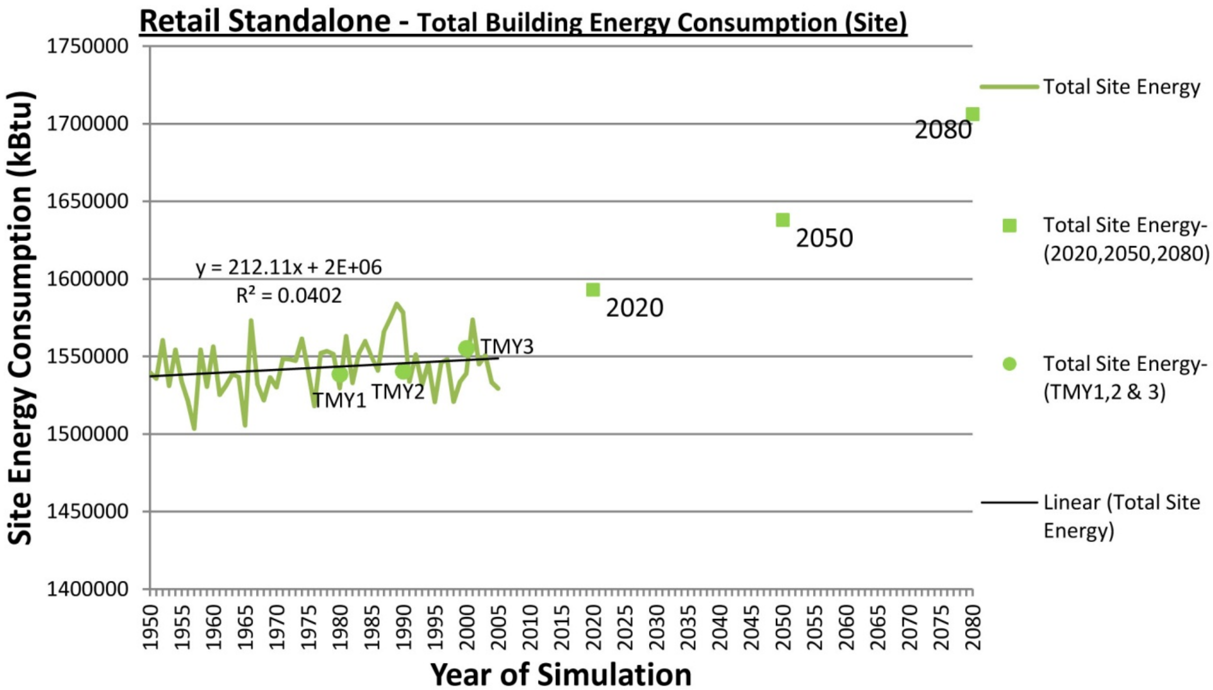
Appendix C- 5-7: Retail Standalone - Total (Summer Cooling) Energy Consumption (Site) (G-8)



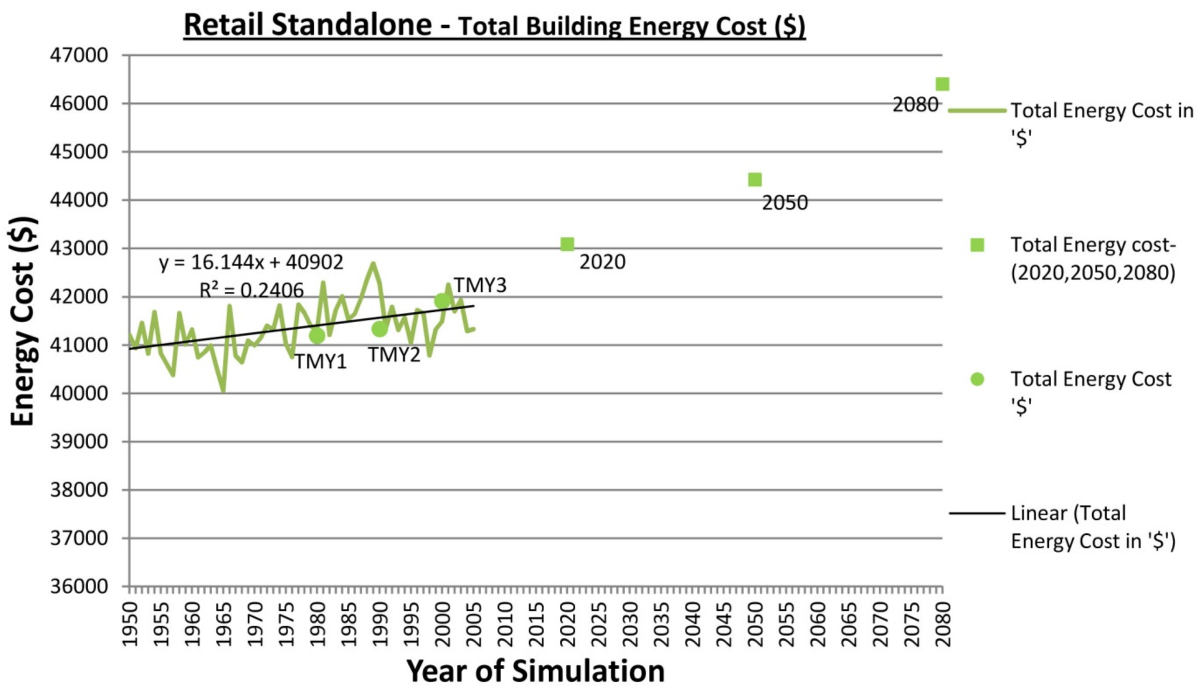
Appendix C- 5-8: Retail Standalone - Total (Cooling) Energy Consumption (Site) (G-9)



Appendix C- 5-9: Retail Standalone - Total Building Energy Consumption (Source) (G-10)

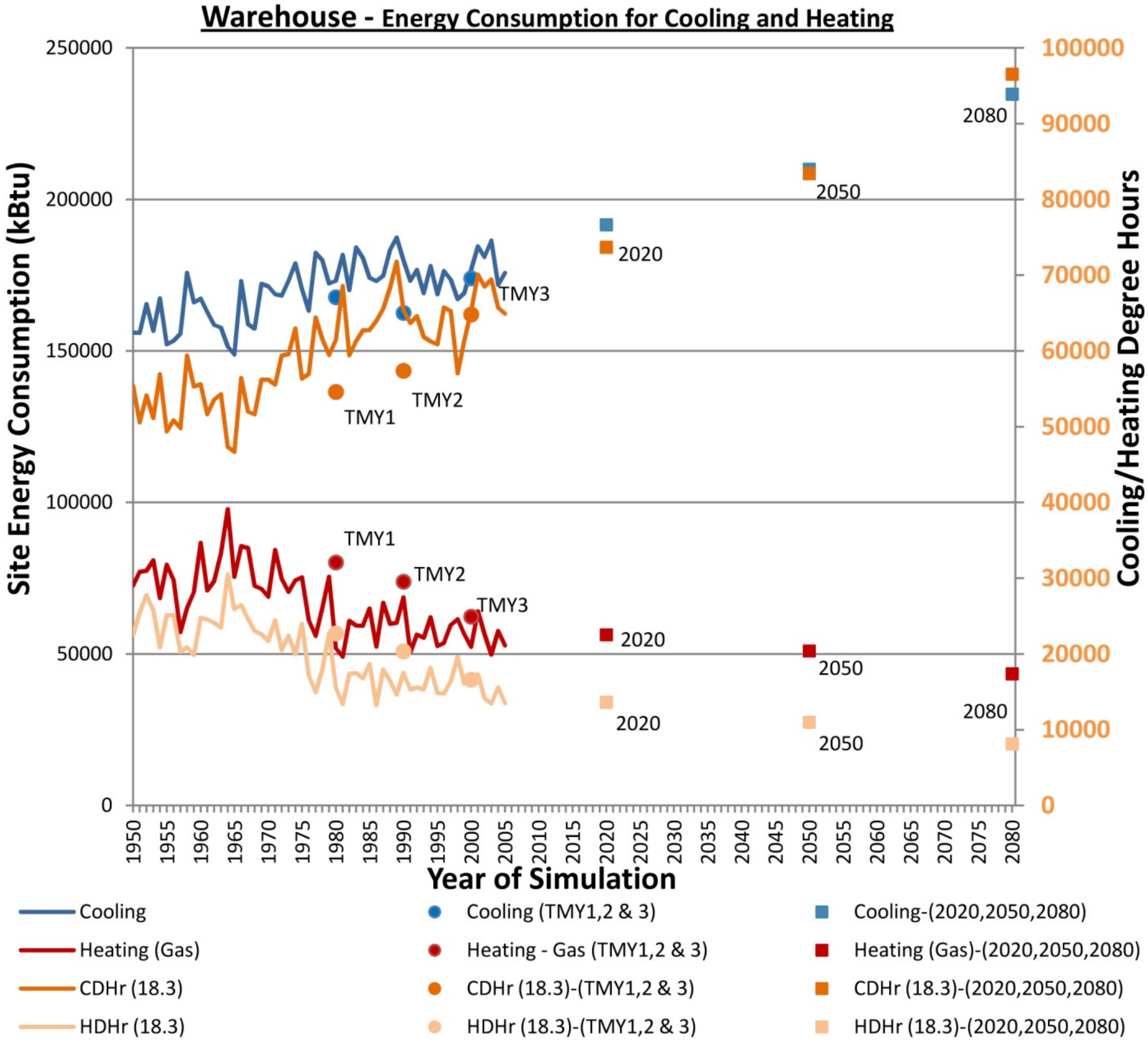


Appendix C- 5-10: Retail Standalone - Total Building Energy Consumption (Site) (G-11)

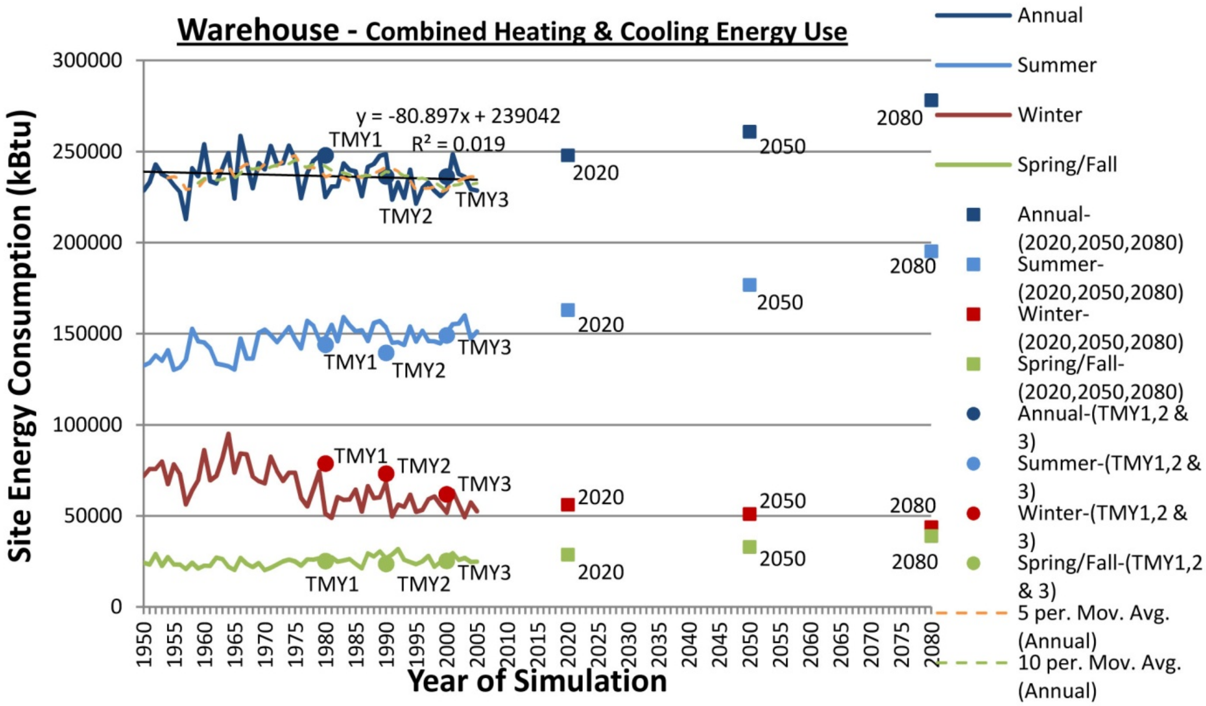


Appendix C- 5-11: Retail Standalone - Total Building Energy Cost ($) (G-12)

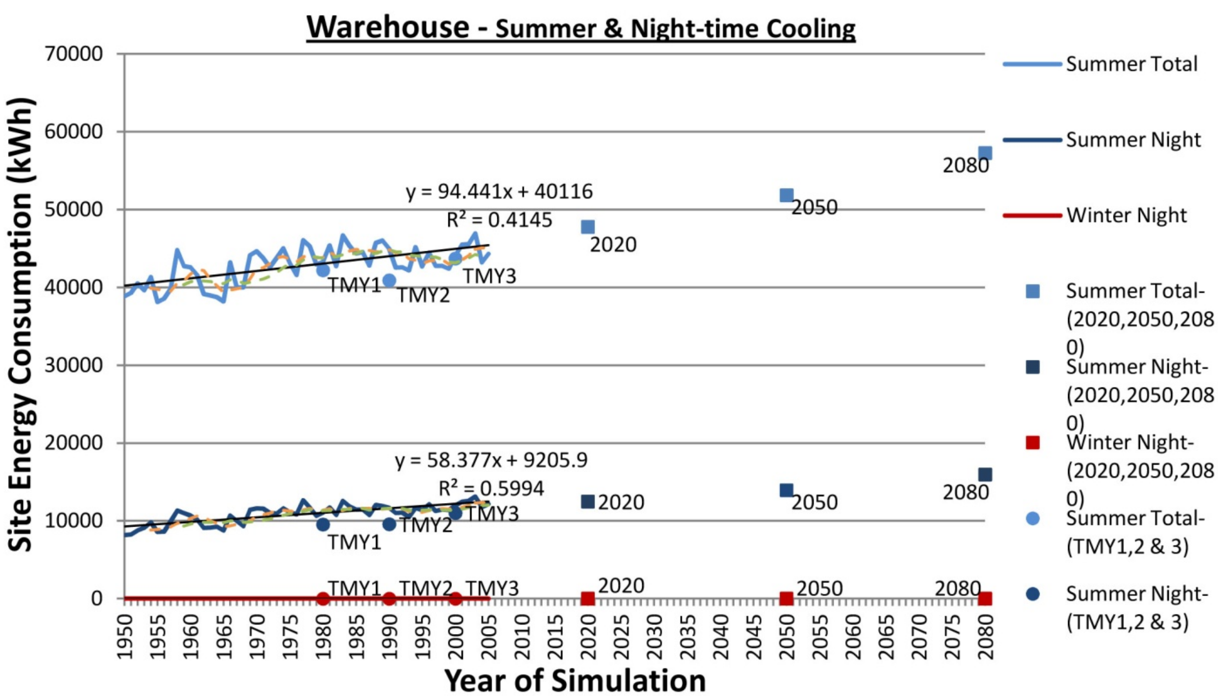
6. Non-Refrigerated Warehouse – Prototype ASHRAE 90.1



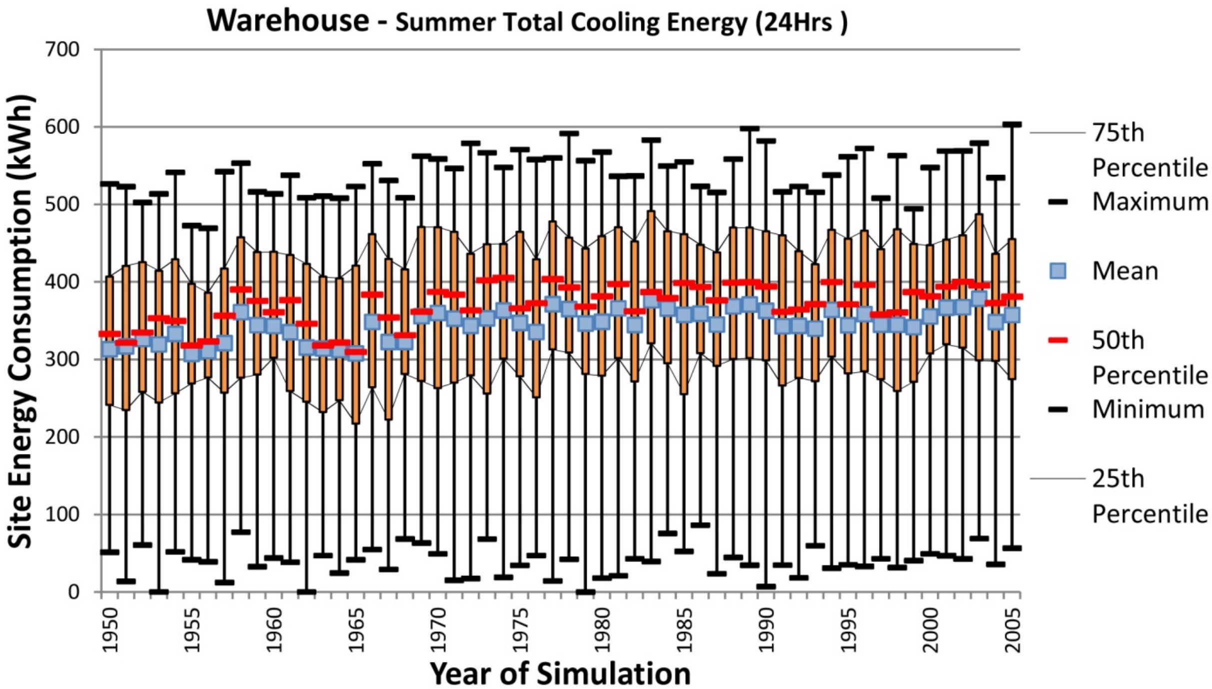
Appendix C- 6-11: Warehouse - Energy Consumption for Cooling and Heating (G-1)



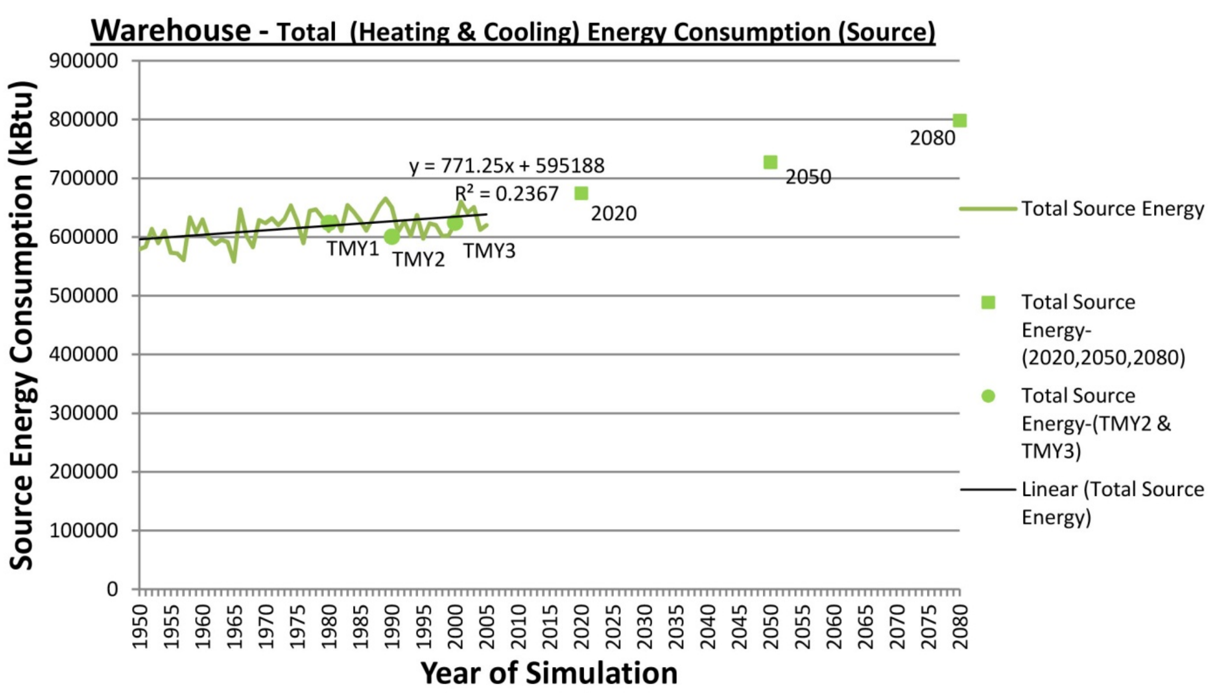
Appendix C- 6-2: Warehouse - Combined Heating & Cooling Energy Use (G-2)



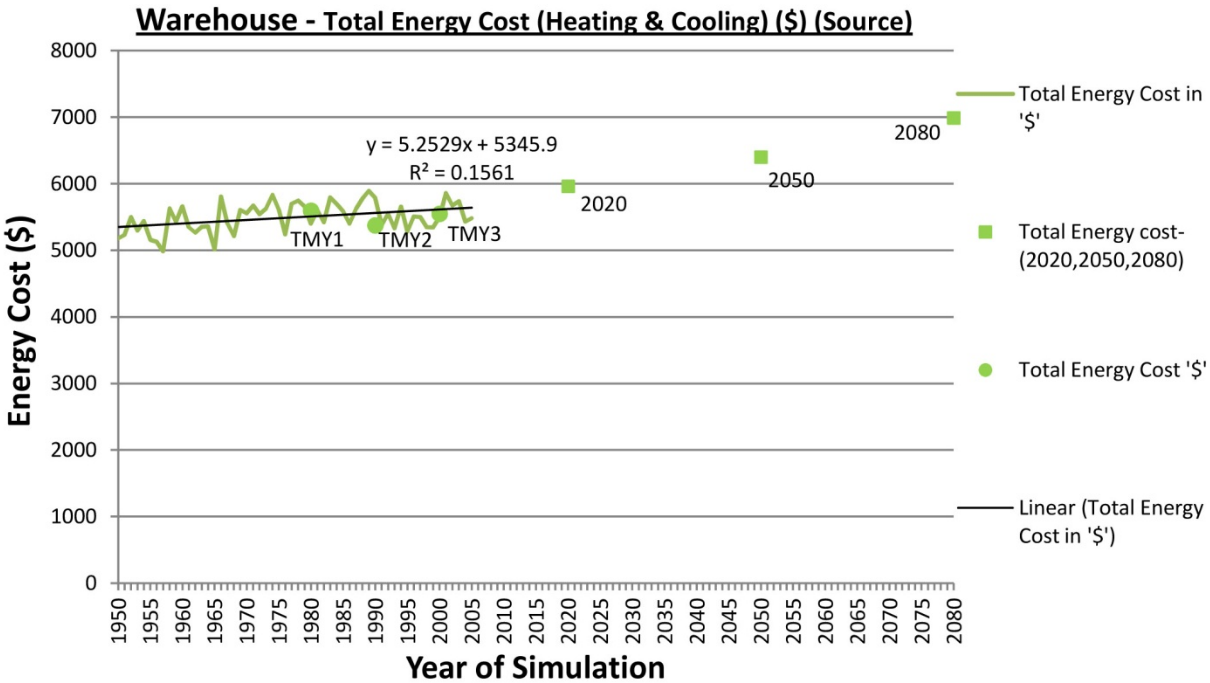
Appendix C- 6-3: Warehouse - Summer & Night-time Cooling (G-3)



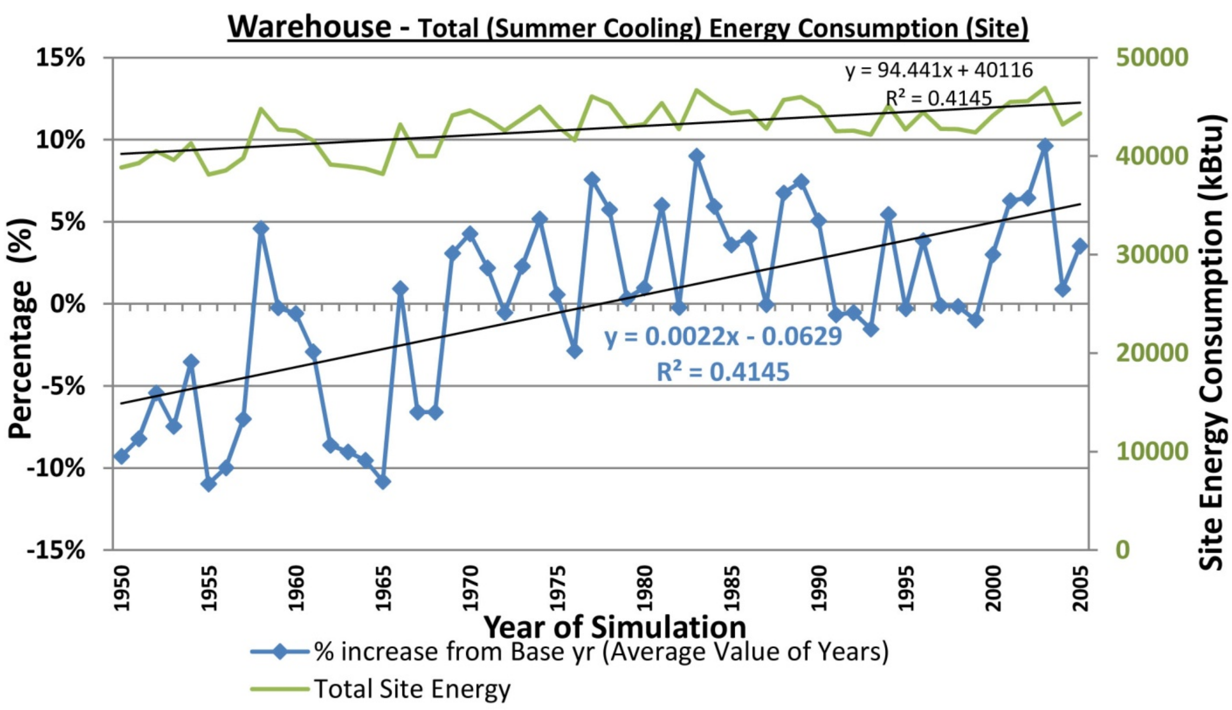
Appendix C- 6-4: Warehouse - Summer Total Cooling Energy (24Hrs - Weekdays only) (G-4)



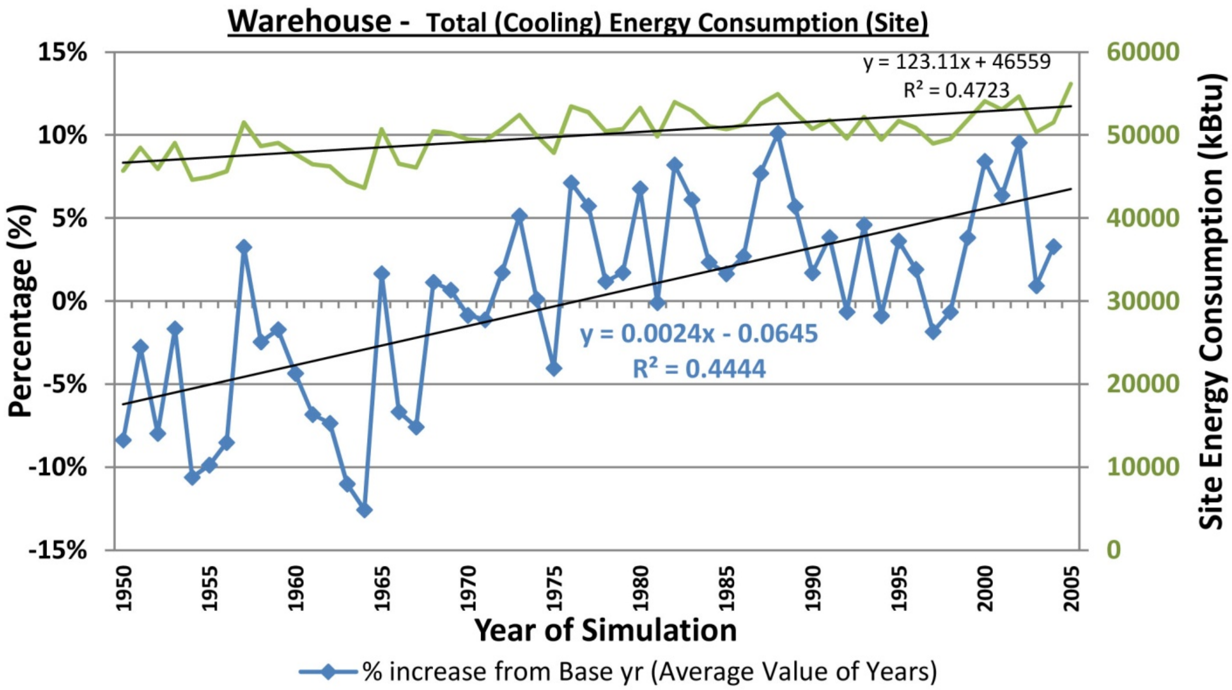
Appendix C- 6-5: Warehouse - Total (Heating & Cooling) Energy Consumption (Source) (G-6)



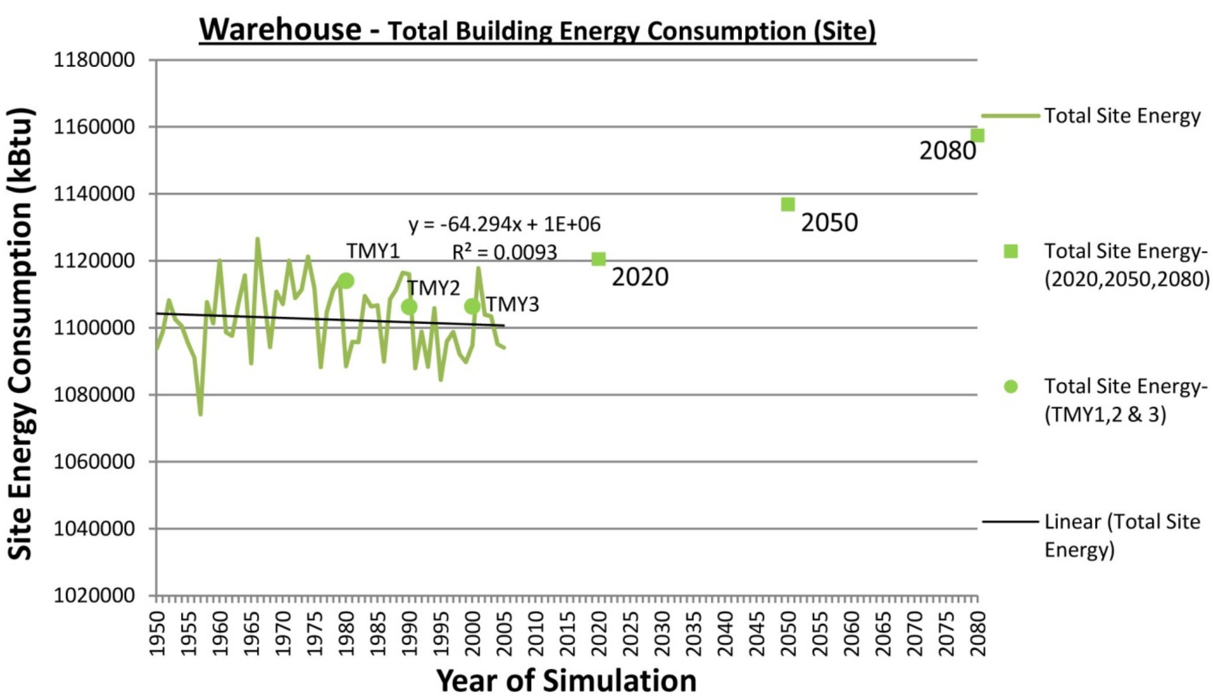
Appendix C- 6-6: Warehouse - Total (Summer Cooling) Energy Consumption (Site) (G-7)



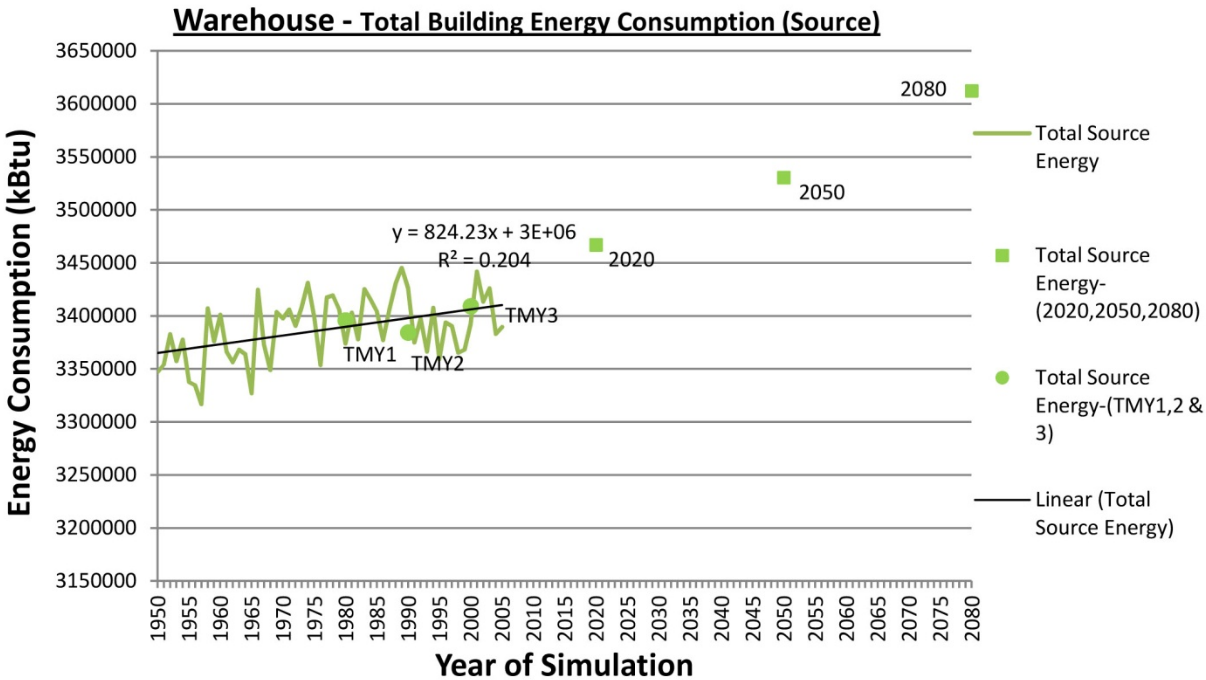
Appendix C- 6-7: Warehouse - Total (Summer Cooling) Energy Consumption (Site) (G-8)



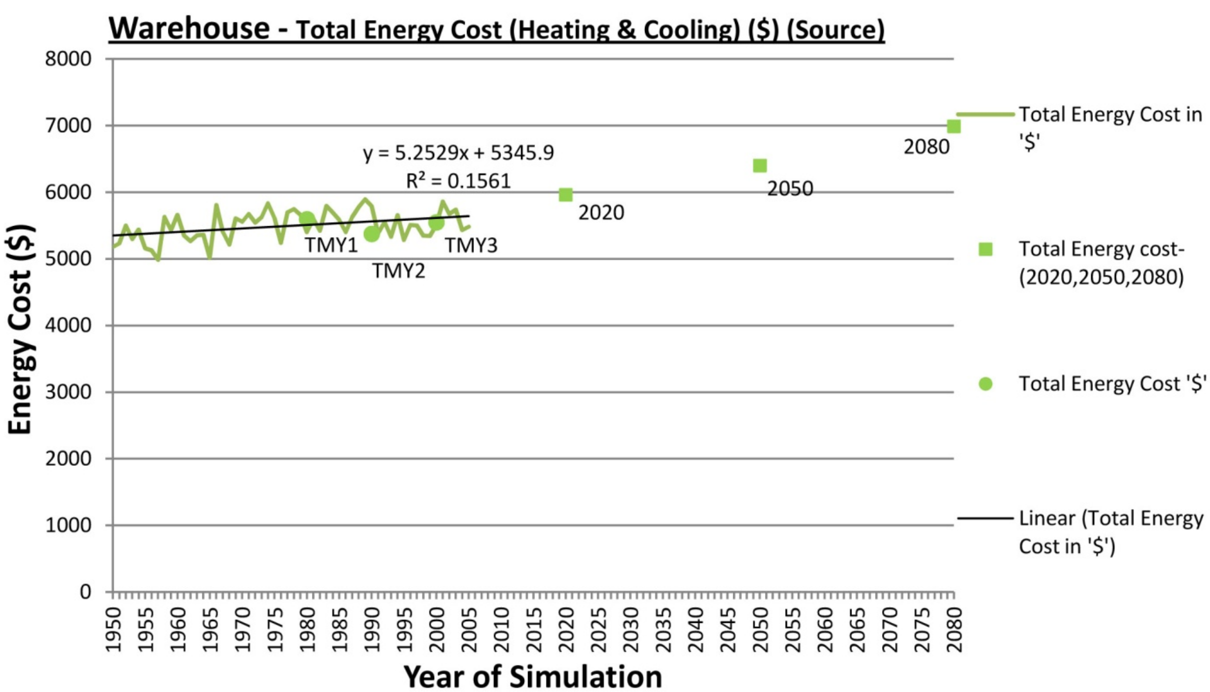
Appendix C- 6-8: Warehouse - Total (Cooling) Energy Consumption (Site) (G-9)



Appendix C- 6-9: Warehouse - Total Building Energy Consumption (Site) (G-10)



Appendix C- 6-10: Warehouse - Total Building Energy Consumption (Source) (G-11)



Appendix C- 6-11: Warehouse - Total Energy Cost (Heating & Cooling) ($) (Source) (G-12)