UNIVERSITY OF APPLIED SCIENCES – MASTER'S DEGREE

ECO-ENERGY ENGINEERING

Municipal Buildings Energy Audits in Savannah examining general conclusions for energy consumption and retrofitting recommendations for the area

Submitted as Master's thesis

to attain the academic title

Master of Science in Engineering (MSc)

by

Sonja Mitsch, BSc

September 2014

Supervision the Master's thesis by:

Prof. Arch. Dr. Herbert Claus Leindecker (University of Applied Sciences Upper Austria)

and Prof. Stanley D. Lindsey, Ph.D, P.E (Georgia Institute of Technology, Savannah)

fh
OBERÖSTERREICH

This project has been established with friendly assistance of Georgia Institute of Technology, 210 Technology Circle, Savannah 31407, GA and the City of Savannah, 6 E Bay St, Savannah 31401, GA.

FH OBERÖSTERREICH

Georgia Institute of Technology

CITY OF savannah

Acknowledgement

I am very thankful for this time and opportunity in my life and for meeting such great and amazing people.

First of all I want to thank Peter Zeller and Vanessa Prüller for making connections with the City of Savannah, taking care of all the arrangements and making this great project possible. And thanks to Herbert Leindecker for supervising the project even on short notice.

Especially I want to thank Garrison Marr too, for all his support and organizing although other plans came in the way of his Career. I wish him and his family all the best in their new hometown.

Further I want to thank Diane Lee, Stan Lindsey and Peggy Hand from Georgia Tech who all did all their best and invested much more time than one would think, so that Andreas Karl and I had this amazing opportunity.

Thanks to the City of Savannah staff, especially the housing department as well, for making us feels very welcomed every day.

Further I want to thank Peter Shonka, for being the best boss/supervisor I will probably have. Thanks to him, for all his efforts showing Andreas and me around and making us feel welcomed and comfortable in Savannah.

Thanks to Andreas Karl to for working together, having a lot of fun and being one of the best colleagues one can have.

Last but not least I want to thank my friends and parents for making this amazing and wonderful experience possible and supporting me whenever I needed it.

I hereby declare that the thesis submitted is my own unaided work. All direct or indirect sources used are acknowledged as references.

This paper was not previously presented to another examination board and has not been published.

....

Sonja Mitsch

Wels, September 2st, 2014

Abstract

The City of Savannah develops various projects focusing on multi- and single- family houses for families with a low yearly income. In order to make these projects possible it is important to keep costs in other sectors to a minimum, being municipal buildings for example.

This work focuses on decreasing the energy demand of municipal buildings in Savannah and thereby the South Atlantic and finding low hanging fruits, easily achievable for energy demand reduction regarding municipal buildings.

The City of Savannah is known for its historic buildings and charm. For this reason a historic brick building from the 1890's has been chosen as a representative sample for the municipal buildings of the city.

First of all am energy analysis has been conducted on this building, in order to determine the main sectors of energy consumption. The outcomes of the energy analysis played a major role in determining the areas of potential utility cost savings.

Secondly simulations, using the software tool eQuest have been done, in order to find sectors with the highest improvement. Thereby historic preservation did influence the boundary conditions for the efficiency enhancing measures. Restrictions were given in the field of wall insulation, window area, outside blinds and potential renewable; since the aim has been that the external appearance is not altered.

Afterwards an economic analysis did show the highest saving potential regarding the proposed measures, which showed the highest demand reduction. Due to missing price information some alterations have been made, comparing different net present values of cash flow, which represent the utility cost savings.

Furthermore a design proposal has been made, including drawings and recommendations regarding energy efficiency. Especially the energy efficiency enhancing measures can be applied for similar buildings in the South Atlantic.

Kurzfassung

Die Stadtverwaltung in Savannah entwickelt sehr viele Nachbarschaftsprojekte, wobei Mehr- und Einfamilienhäuser für Familien mit einem sehr niedrigen Jahreseinkommen im Mittelpunkt stehen. Um dies zu ermöglichen ist es für die Stadt wichtig in anderen Sektoren, wie zum Beispiel bei anderen Häusern die sich im Besitz der Stadt befinden, laufende Kosten zu minimieren.

Der Schwerpunkt dieser Arbeit wurde daher darauf gelegt den Energieverbrauch und demnach die laufenden Kosten der in dem Besitz der Stadt Savannah befindlichen Häuser zu verringern. Ziel dabei ist es einfach zu erreichende Maßnahmen, die ebenso hohe Reduktion zeigen wie auch finanziell leicht zu ermöglichen sind, für die Klimazone Süd-Atlantik der Vereinigten Staaten, heraus zu finden.

Die Stadtgemeinde Savannah ist bekannt für ihren Charme und historischen Gebäude. Deshalb wurde repräsentativ ein historisches Ziegelgebäude aus den 1890zigern gewählt.

Als erstes wurde das Gebäude auf seinen Energieverbrauch untersucht um die Bereiche mit dem größten Verbrauch heraus zu finden. Des Weiteren wurden Simulationen im Tool ‚eQuest' durchgeführt, um die Bereiche mit dem größten Potential zu erkennen. Dabei spielte der Denkmalschutz für die potenziellen Energiesparmaßnahmen eine große Rolle. Zum Beispiel waren Einschränkungen bezüglich Wanddämmung, Fensterfläche, Außenverschattung und das Potenzial erneuerbarer Energieträger vorhanden, da das äußere Erscheinungsbild des Gebäudes nicht verändert werden sollte.

Danach wurde eine Wirtschaftlichkeitsanalyse durchgeführt, um das größte Sparpotenzial darzustellen. Aufgrund fehlender Daten wurden Änderungen in der Amortisationsrechnung vorgenommen. Demnach wurde der Kapitalwert der kumulierten Einsparungen verglichen.

Abschließend wurde noch ein Planungsvorschlag für das Gebäude abgegeben. Dieser beinhaltet Pläne und Vorschläge bezüglich der Energiesparmaßnahmen. Jene Energiesparmaßnahmen sind repräsentativ für die gesamte Klimazone.

Conversion Table

The following Table 1 illustrates the conversion table.

Table 1: conversion table [I MIT Energy Club, 2007]

Massachusetts Institute of Technology

Units & Conversions Fact Sheet

Derek Supple
MIT Energy Club
http://web.mit.edu/mit_energy

Prefixes

Metric
pico (p) = 10^{-12}
nano (n) = 10^{-9}
micro (μ) = 10^{-6}
deca (da) = 10^{1}
kilo (k) = 10^{3}
mega (M) = 10^{6}
giga (G) = 10^{9}
tera (T) = 10^{12}
peta (P) = 10^{15}
exa (E) = 10^{18}
zetta (Z) = 10^{21}

Roman
m = 10^{3}
mm = 10^{6}
quad = 10^{15}

Mass

1 kg = 2.205 lb
1 lb = 453.6 g = 16oz
1 metric tonne = 1,000kg = 2,205lb
1 US short ton = 907kg = 2,000lb
1 UK long ton = 1,016kg = 2,239lb

Temperature

°F = 1.8 • °C + 32
°K = (°F – 32) • 5/9 + 273.15

Time

3,600 sec/hour 730 hour/month
365.25 day/year 8,766 hour/year
31,536,000 sec/year

Fuel Economy

1mpg = 0.4251 km/L
mpg = 235.2/ L/100 km

Distance

1 cm = 0.4 in
1 m = 3.281 ft = 1.094 yd
1 km = 0.62137 mi = 199 rod
1 mi = 1.609km
1 smoot = 1.702 m = 5.83 ft

Area

1 m^2 = 10.765 ft^2
1 km^2 = 0.386 mi^2 = 10^6 m^2
1 ha = 10^4 m^2 = .01 km^2 = 2.47 ac
1 mi^2 = 2.6 km^2 = 640 ac
1 ac = 4,047 m^2 = 43,560 ft^2

Pressure

1MPa = .1bar = 9.87atm = 145psi
1atm = 1.0132 bar = 760 mmHg = 14.696 psi = 10.33 ton/m^2

Volume

1 L = 0.264 gal = 1000 cm^3 (ml)
1 m^3 = 1000 L = 35.3 ft^3 = 264 gal
1 gal = 3.785 L = 4 qt = 16 c = 128 oz
1 ft^3 = cf = 28.32 L = 7.482 gal
1 bbl = 42 U.S. gal = 159 L = 5.6 ft^3
1 cord = 128 ft^3 = 3.62 m^3
1 ac-ft = 43560 ft^3 = 325,851 gal
1 km^3 = 0.24 mi^3 = 810,713 acre-ft
1 bu = 4 pck = 8 gal = 35.2 L = 2,150 in^3

Flow Rates

1mbd = 1 Mbbl/day = 15.34 Ggal/yr = 694.4 bbl/min = 11.57 bbl/sec = 485.9 gal/sec
1 ft^3/s = 641 bbl/hr = 449 gal/min (gpm)
1 bbl oil/day ≈ 50 metric ton oil/yr
1 gpm = 0.063 L/s = 0.00442 ac-ft/day

Energy Unit Conversion

1 J = 1 Nm = 1 kgm^2/s^2 = 0.239 cal = 0.74 ft-lb
1 Cal = 1 kcal = 1000 cal = 4.187 KJ = 3.968 Btu
1 KJ = 0.239 Cal = 0.947817 Btu ≈ 0.95 Btu
1 Btu = 1,055.056 J = 0.252 kcal
1 kWh = 3.6 MJ = 3,412 Btu; (1MWh = 3.6 GJ = 3.412 mmBtu)
1 mmBtu = 10^6 Btu = 1.055 GJ = 1 decatherm
1 mcf nat. gas (LHV) = 10.27 therm = 1.027 mmBtu = 1.082 GJ
1 toe = 41.868 GJ = 39.683 mmBtu = 11.63 MWh = 7.33bbl
1 tce = 29.308 GJ = 27.778 mmBtu = 8.141 MWh
1 Quad = 10^{15} Btu = 1.055 EJ = 293 TWh = 25.2 Mtoe=.974 TCF
1 EJ = 10^9 GJ = 10^{18} J = .95 Quad
1 TWyr = 31.5 EJ = 29.86 Quad

Energy Content (*Lower Heating Values*) (ton = metric tonne)

Crude Oil = 6.119 GJ/bbl = 5.8 mmBtu/bbl = 39.7 mmBtu/ton = 145.7 MJ/gal = 38.5 MJ/L = 43.8 MJ/kg (GJ/ton)
Gasoline = 121.3 MJ/gal (= 32.1 MJ/L = 43.1 MJ/kg = 115 mBtu/gal)
Diesel = 135.5 MJ/gal (= 35.8 MJ/L = 42.8 MJ/kg = 128 mBtu/gal)
Biodiesel = 124.8 MJ/gal (= 33.0 MJ/L = 37.5 MJ/kg = 121 mBtu/gal)
Ethanol = 80.2 MJ/gal (= 21.2 MJ/L = 26.9 MJ/kg = 76 mBtu/gal)
Methanol = 60.4 MJ/gal (= 15.9 MJ/L = 20.1 MJ/kg = 57 mBtu/gal)
UN Standard Coal = 30 GJ/ton
Bituminous = 27-30 GJ/ton (MJ/kg) = 25-28 mmBtu/ton
Sub-Bitum. = 20-26 GJ/ton (MJ/kg) = 19-24 mmBtu/ton
Lignite = 10-19 GJ/ton (MJ/kg) = 9-18 mmBtu/ton
Nat Gas @ STP = 53.2 MJ/kg =38.2 MJ/m^3 = 1027 Btu/ft^3
CNG @ 20 MPa = 50.0 MJ/kg = 9.3 MJ/L = 249.6 mBtu/ft^3
H_2 @ 35MPa (HHV) = 120.0 MJ/kg = 2.7 MJ/L = 72.5 mBtu/ft3
LPG @ 1.5 MPa = 88.1 MJ/gal = 23.3 MJ/L = 625.5 mBtu/ft3
Air-Dried Wood(20% Moisture Content) = 15 GJ/ton
Uranium = 80 GJ/g fissioned = 400 GJ/kg mined (fn'd =.5% mn'd)

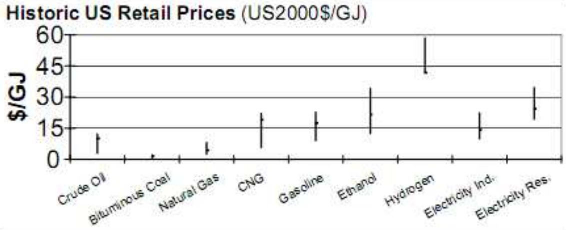
Density

Water = 1 g/cm^3 = 1 g/ml = 1 kg/L = 1 metric tonne/m^3
Air at Sea Level = 1.2 kg/m^3
Crude Oil = 0.88 (0.75 -0.98) kg/L = 7.34 lb/gal = 140 kg/bbl
Gasoline = 0.745 kg/L = 6.22 lb/gal
Diesel = 0.837 kg/L = 7.00 lb/gal; Biodiesel = 0.880 kg/L
Ethanol = 0.789 kg/L = 6.58 lb/gal
Methanol = 0.792 kg/L = 6.61 lb/gal
Nat. Gas = 0.717 kg/m^3 = 44.8 lb/mft^3
CNG @ 20MPa = 0.185 kg/L = 11.5 lb/ft^3 = 5.66 lb/gge
LPG (propane) = 0.540 kg/L = 33.7 lb/ft^3
Hydrogen = 0.025 kg/L (35MPa); 0.08988 kg/m^3 (STP)
Coal ≈ 1.32 kg/L = 1230 metric ton/ha-m = 1800 sht ton/acre-foot
API Gravity = (141.5/[Density in g/cm^3 at 60 °F]) - 131.5
Light Crude API > 31.1°; Heavy API < 22.3°; Bitumen API ~ 8°

Power Unit Conversion

1 W = 1 J/s = 3.6 kJ/hour = 31.5 MJ/year
1 kW = 1.341 hp = 738ft-lb/s
1 hp = 745.7 W = 0.7068 Btu/s
1 TW = 10^{12} W = 31.5 EJ/year
1 ton-refrigeration = 12,000 Btu/hr = 200 Btu/min = 3.517 kW

Historic US Retail Prices (US2000$/GJ)



Energy of Familiar Phenomena/Society

Quart of Boiling Water = 3 MJ 1 wooden match = 1 Btu
Melt 1 lb Ice = 151 kJ = 143 Btu
1-GWe Plant running 24 hrs = 260 TJ
Daily Human Metabolism = 2500 kCal/day = 120 W
Compact Passenger Car at steady 60 mph:
Chem. Energy Consumption = 70 kW = 94 hp
Mech. Energy Production = 15 kW = 20 hp
'05 US Oil Use = 20.55 Mbpd = 7.506 Gbbl/yr = 238 bbl/sec
'05 Global Oil Use = 84.37 Mbpd = 31.89 Gbbl/yr = 976.5 bbl/sec
'05 US Primary Energy Use ≈ 3.35 TW ≈ 105 EJ/yr ≈ 100 quad/yr
'05 Global ≈ 16 TW ≈ 504 EJ/yr ≈ 480 quad/yr
Solar Influx at Earth Surface ≈ 100 PW = 3.1 YJ/yr = 200 W/m^2

Carbon Dioxide (CO_2) Emission Factors

Note: 44/12 or 3.667 ton CO_2 emissions per ton C emissions

Natural Gas = 121 lb/mcf = 117.1 lb/mmBtu = 50.3 kg/GJ
Gasoline = 19.56 lb/gal = 156.4 lb/mmBtu = 67.2 kg/GJ
Diesel = 22.38 lb/gal = 161.4 lb/mmBtu = 69.4 kg/GJ
Bt. Coal = 4,931 lb/sht ton = 205.3 lb/mmBtu = 88.3 kg/GJ
Petrol Coke = 32.40 lb/gal = 225.1 lb/mmBtu = 96.8 kg/GJ
Electric US Av = 1.34 lb/kWh = 0.608 ton/MWh = 168.8 kg/GJ
Coal-fired Elec = 2.095 lb/kWh = .95 kg/kWh = 260 kg C/MWh

Global Warming Potential (GWP) (τ = 100yr)

CO_2 = 1 CH_4 = 23 N_2O = 296 SF_6 = 22,200
HFCs = 12 - 12,000 PFCs = 5,700 - 11,900

Table of Contents

ACKNOWLEDGEMENT 5

ABSTRACT 2

KURZFASSUNG 3

CONVERSION TABLE 4

TABLE OF CONTENTS 1

1 INTRODUCTION 1

2 SCOPE 3

3 LITERATURE RESEARCH 5

3.1 CLIMATE 5
3.2 SIMULATION SOFTWARE 8
3.3 ASHRAE STANDARDS 9
3.4 BUILDINGS IN HOT AND HUMID CLIMATES 12
3.4.1 CONSTRUCTION IN HOT AND HUMID CLIMATES 12
3.4.2 ENERGY CONSUMPTION 14
3.5 ENERGY CONSERVATION CODE 16
3.6 ENERGY SUPPLY 18
3.6.1 ELECTRICITY 19
3.6.2 NATURAL GAS 20

4 METHODOLOGY 21

4.1 BUILDING DESCRIPTION 21
4.2 ON-SITE VISIT 23
4.3 ENERGY ANALYSIS 27
4.3.1 DEFINED BOUNDARY CONDITIONS FOR ENERGY MODEL 28
4.3.1.1 Climate 28
4.3.1.2 Energy supply 29
4.3.1.3 Construction Materials 31
4.3.1.4 Gross Floor Area 32

4.3.1.5 Building structure 33
4.3.1.6 Internal loads 35
4.3.1.7 Infiltration 36
4.3.1.8 HVAC 37
4.3.2 SIMULATION RESULTS 38
4.4 SIMULATION OF ENERGY EFFICIENCY MEASURES 42
4.4.1 OPENINGS 42
4.4.1.1 Inputs 42
4.4.1.2 Results 43
4.4.2 WINDOWS 43
4.4.2.1 Inputs 43
4.4.2.2 Results 44
4.4.3 FLOOR 48
4.4.3.1 Inputs 48
4.4.3.2 Results 49
4.4.4 ROOF 51
4.4.4.1 Inputs 51
4.4.4.2 Results 57
4.4.5 DAYLIGHT SENSORS 60
4.4.5.1 Inputs 60
4.4.5.2 Results 61
4.4.6 OVERALL INSULATION MEASURES 64
4.4.6.1 Input 64
4.4.6.2 Results 65
4.4.7 HVAC SYSTEM 69
4.4.7.1 Inputs 70
4.4.7.2 Results 71
4.5 ECONOMIC ANALYSIS 75
4.5.1 DEVELOPMENT OF ENERGY PRICES 76
4.5.2 INFLATION 76
4.5.3 FINANCING 77
4.5.4 RESULTS 77
4.5.4.1 Windows and daylight sensor 77
4.5.4.2 Floors 78

4.5.4.3 Roof ... 78
4.5.4.4 Overall Measures ... 79
4.5.4.5 HVAC ... 79
4.6 DESIGN PROPOSAL ... 80
4.6.1 DESIGN ... 80
4.6.1.1 Exterior ... 80
4.6.1.2 Engine Room ... 82
4.6.1.3 Boiler Room ... 85
4.6.1.4 Tower ... 87
4.6.2 ROOF ... 88
4.6.3 FLOOR ... 89
4.6.4 WINDOWS AND DAYLIGHTING ... 89
4.6.5 HVAC ... 90

5 CONCLUSION AND SUMMARY ... 91

6 LITERATURE ... 93

6.1 PUBLICATIONS ... 93
6.1 INTERNET RESOURCES ... 97
6.2 ORAL SOURCES AND EMAILS ... 102
6.3 SOFTWARE ... 103

7 REGISTER ... 1

7.1 TABLE OF FIGURES ... 1
7.2 TABLE OF TABLES ... 5
7.3 TABLE OF EQUATIONS ... 6

8 APPENDIX ... 7

8.1 DESIGN PLANS ... 7
8.2 PLANS IN HISTORIC STRUCTURE REPORT ... 7
8.3 WINDOWS AND DOORS INPUT ... 7
8.4 SIMULATION RESULT SUMMARY ... 7
8.5 SIMULATION REPORTS ... 7

1 Introduction

The City of Savannah works on reducing the energy consumption of buildings, since it is one of the most relevant sectors considering energy. This is done while focusing on retrofits of buildings and new-built single and multi family houses for families with a low yearly income. Thereby the opportunity has come up for students of the University of Applied Sciences Upper Austria to do research in this field with assistance of the Georgia Institute of Technology. In order to maintain the city's ability to focus on projects developing a sustainable Savannah it is important to focus on reducing the utility costs and consumption.

The following Figure 1 illustrates a prognosis of the energy consumption in the United States from 2011 to 2040 issued by the United States 'Energy Information Administration'. [P EIA, Appendix A2, 2014] An overall raise in energy consumption of 9.47 % is expected from 2011 to 2014. While regarding the utility costs of the city of Savannahs municipal buildings due to energy consumption the commercial sector will be further emphasized on.

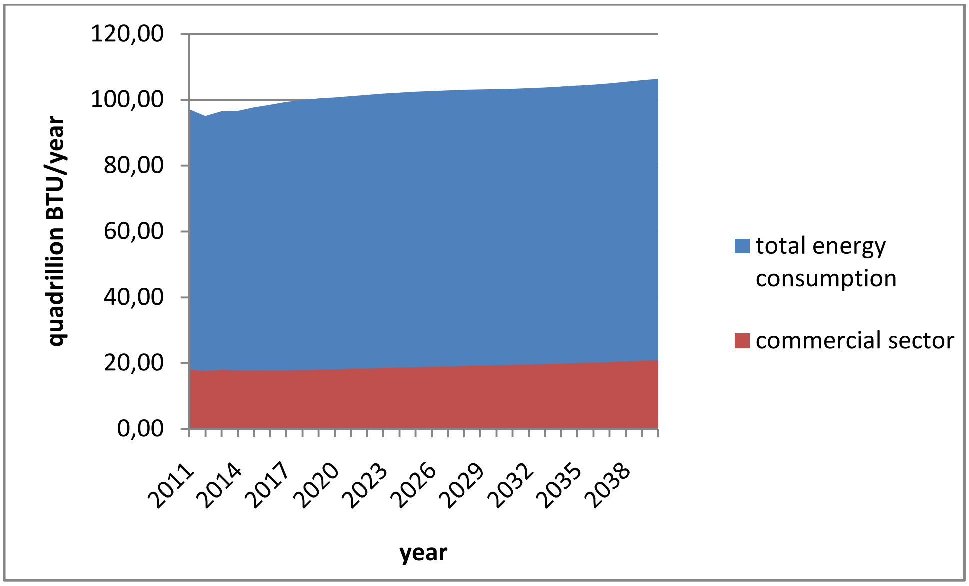


Figure 1: Rise in energy consumption in United States [P EIA, Appendix A2, 2014]

Looking at the commercial sector an overall increase of about 15 % is expected. In 2013 the commercial sector thereby accounted for 18.61 % of the overall energy consumption and is closer depicted in Figure 2.

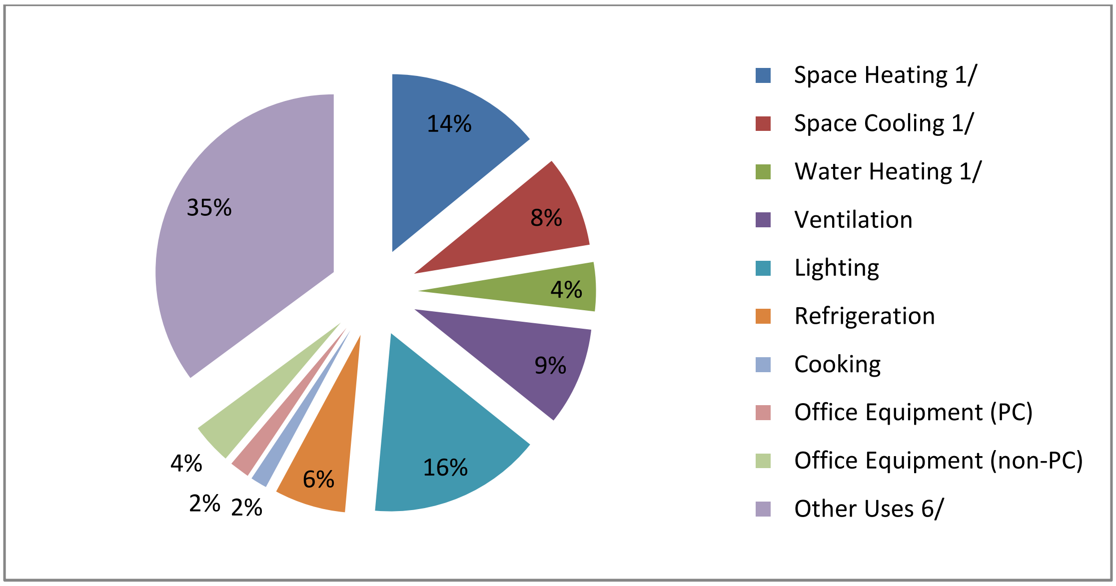


Figure 2: Energy use in commercial sector [P EIA, Appendix A5, 2014]

In the above pie chart it can be seen that space cooling, space heating, ventilation and lighting account for 46 % overall, which shows a very high saving potential in these sectors while retrofitting municipal buildings.

Besides the U.S Energy Information Administration forecasts an average price rise of 1.7 % for natural gas until 2040, or 30 % augmentation until 2040 compared to 2014, shown in Figure 3 below.

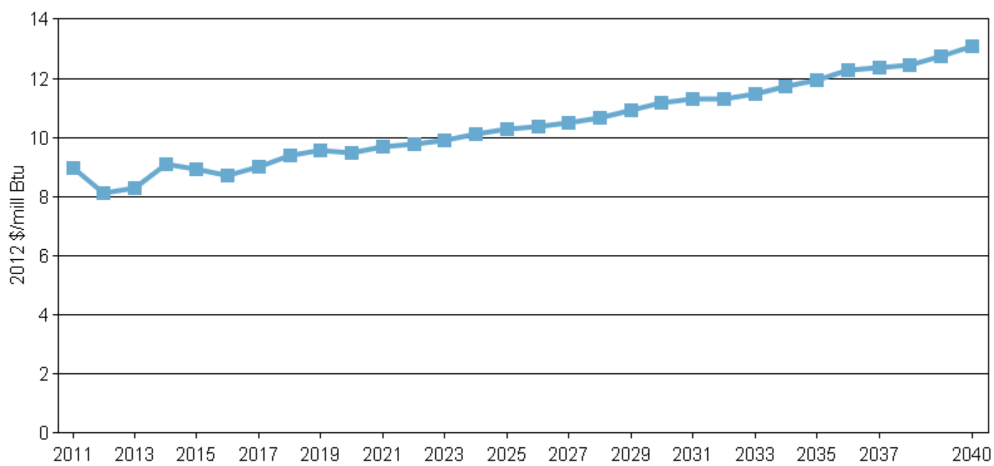


Figure 3: Energy Prices, Commercial Natural Gas, United States, [I EIA, 2014]

Average electricity prices are expected to rise from 29.62 $/MMBTU (28.07 $/kJ) to 33.01 $/MMBTU (34.83 $/kJ), with an average progression of 0.4 % every year. This equals a total increase of 11.44 %, depicted in Figure 4.

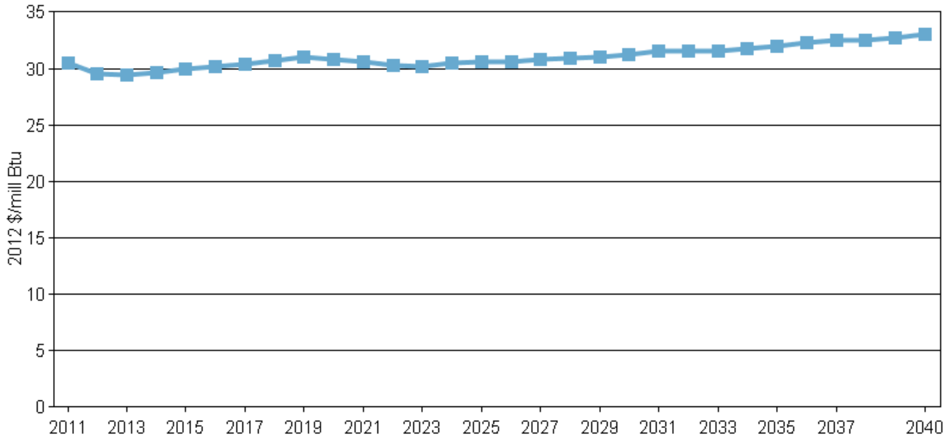


Figure 4: Energy Prices, Commercial Electricity, United States, [I EIA, 2014]

This shows that besides environmental factors other factors are indicative that the City of Savannah invests in energy efficiency enhancing measures.

2 Scope

First of all the municipal buildings will be evaluated based on one representative sample which is a historic brick building from the 1890's. Although buildings built before 1920 account for about 3.5 % of the buildings in the South Atlantic area it is very typical for historic Savannah. Further it has to be said that according to [P EIA, Appendix B4, 2014] 48.5 % of the buildings in the South Atlantic area have brick as an exterior wall and 29.29 % possess metal surfacing roofs ,which is why the representative sample has been most advantageous for investigations.

Doing so, the efficiency of the buildings will be acquired. Secondly diagnosing energy patterns of the sample using energy simulation software will be done. After auditing municipal buildings the main sectors of energy loss and the main saving potential can be assessed. Moreover this means that general sectors can be pointed out where the focus of future energy audits of municipal buildings and probable retrofits lies. Following a design proposal will be made including some recommendations based on the simulated data. At the same time there has to be paid attention to the most needed recommendations due to user patterns and the economic feasibility.

For determination of the economic feasibility financial benchmarking of the recommendations has to be done. Therefore optimal amortization times are essential since the projects supporting families with low income should stay in the centre of the work of the city staff. In the course of financial benchmarking it is important to include the climate and economical influences considering the amortization such as electricity prices in the area which have an effect on the heating/cooling in this area or probable founding's or cultural preferences.

The research should point out the areas of the main energy consumption of municipal buildings in this area. Furthermore it is an important point if general statements can be done for all municipal buildings in Savannah or the different groups of municipal buildings. Either way, the analysis should show the main areas of energy consumption and recommendations with different amortization times. The retrofit options for municipal buildings can receive a ranking due to the outcome of the energy audits including economical aspects and additionally considering cultural effects on user needs and wishes as well.

This will conclude in general rules for energy audits of municipal buildings as well as a list of low hanging fruits easily achievable for the City of Savannah considering the limited budget.

3 Literature Research

The chapter 'Literature Research' contains the research done before the energy analysis has been realized. Therefore it contains information concerning climate, possible simulation software and local standards and codes.

3.1 Climate

As the climate has already been described closely in previous theses written by [P Bachner, p 6-7, 2013] a brief overview will be given. The following Figure 5 illustrates the climate zones within the United States. Thereby one can see that Savannah is right in the hot and humid climate, marked by a green arrow.

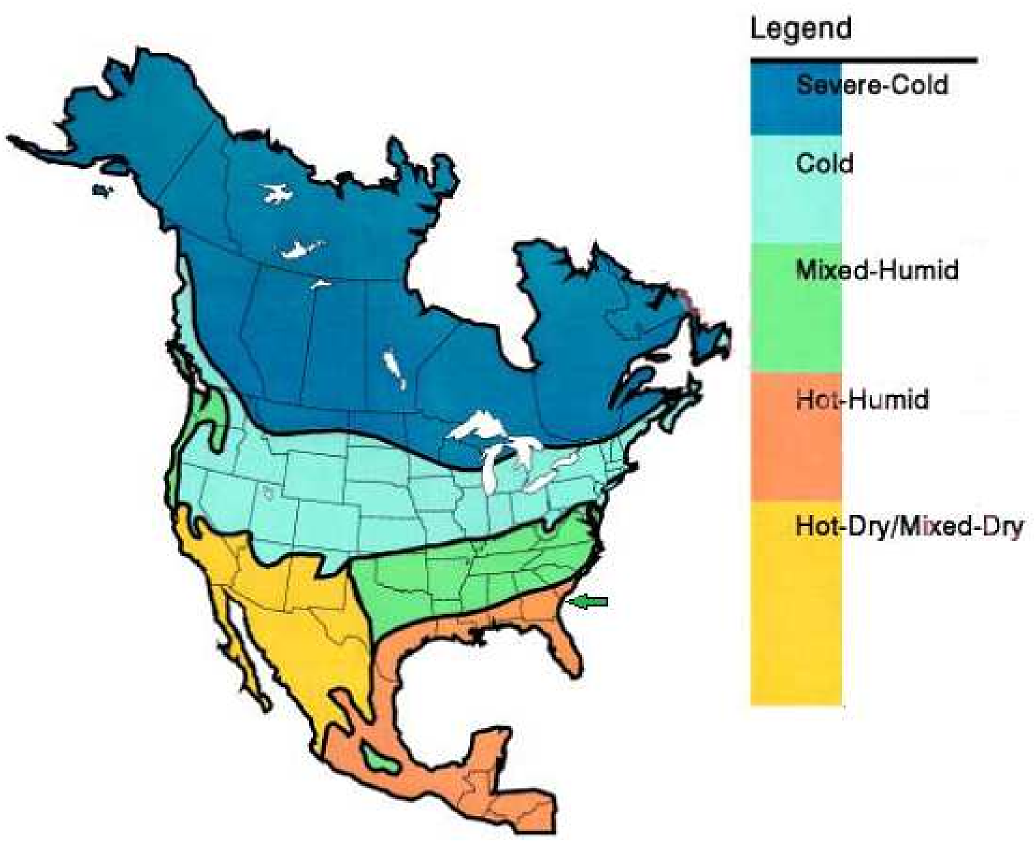


Figure 5: climate zones within the United States [P Lstiburek, J., 2002]

Thereby the average temperature in January is between 50 °F (10°C) and 68 °F (20°C) in January and between 68 °F (20°C) and 86 °F (30°C) in July according to [P Hindrichs U. D., Daniels K., p49, 2007], which is depicted in Figure 6and Figure 7, regarded worldly.

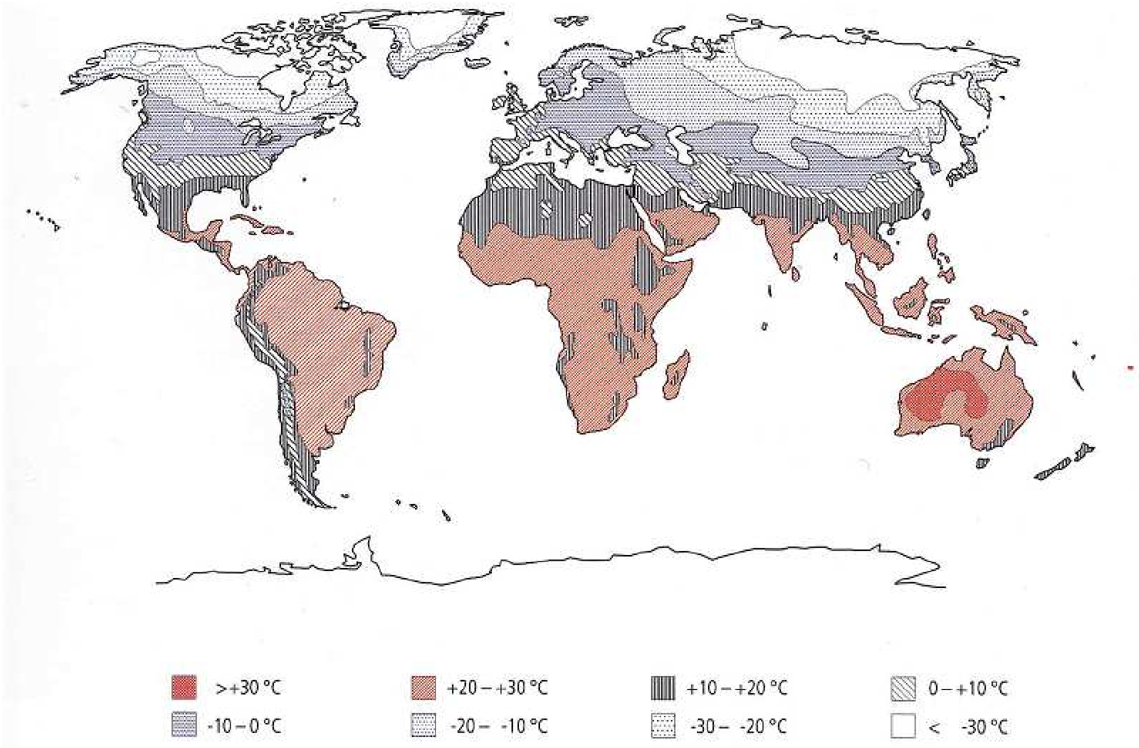


Figure 6: Temperatures in January [P Hindrichs U. D., Daniels K., p49, 2007]

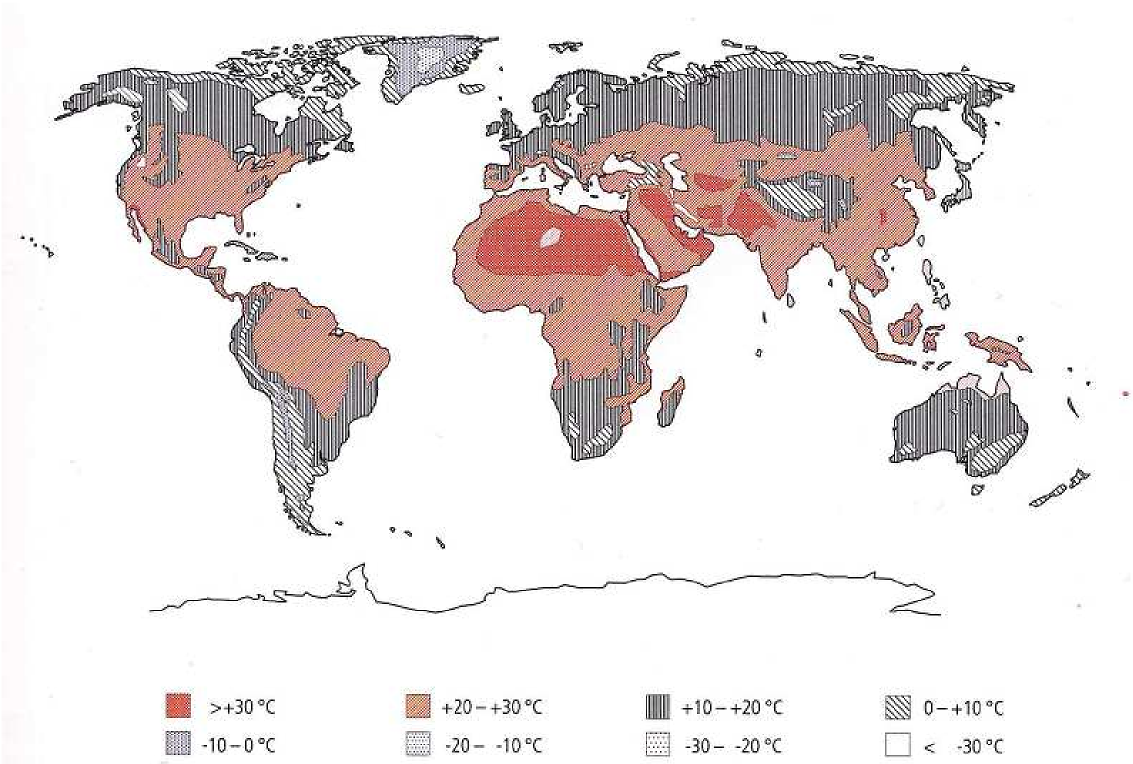


Figure 7: Temperatures in July [P Hindrichs U. D., Daniels K., p49, 2007]

Savannah, being in a rather humid climate, precipitation plays a major role regarding building structures. Figure 8 below illustrates the worldly precipitation, where it is shown that the annual precipitation in Savannah is between 39 inch (1000 mm) and 78 inch (2000 mm).

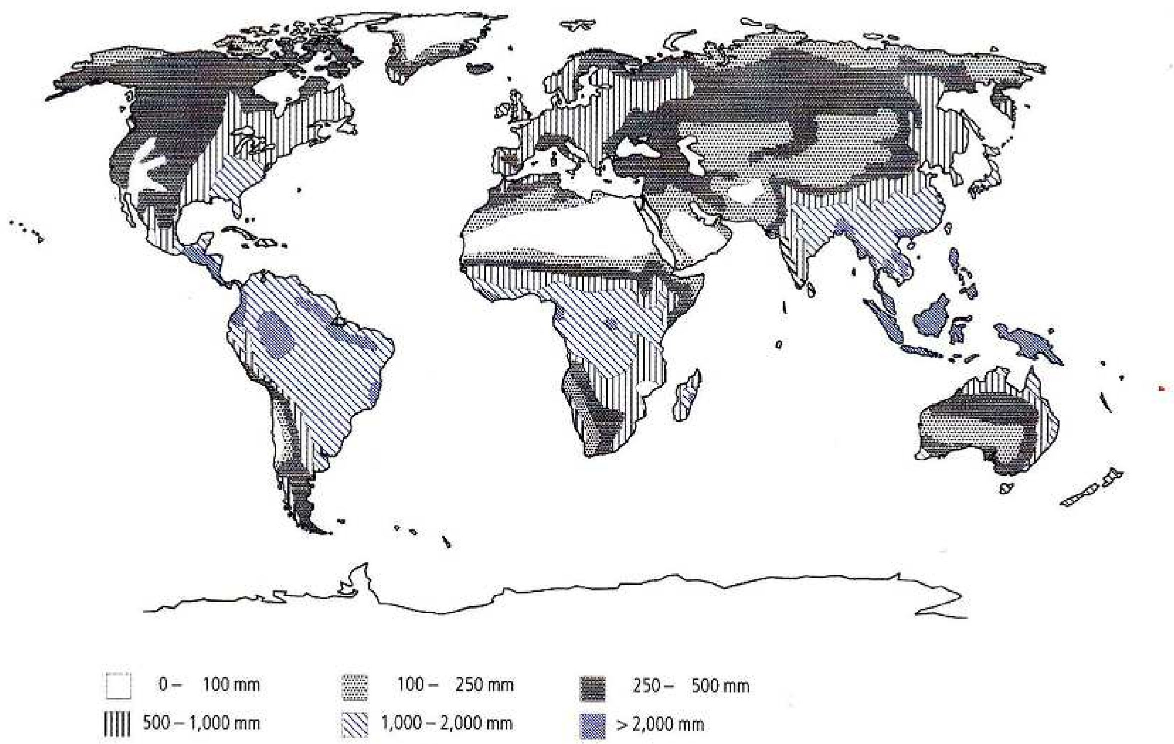


Figure 8: Precipitation over the year [P Hindrichs U. D., Daniels K., p 52, 2007]

Further, regarded worldly Savannah shows an irradiation between 1600 and 1800 KWh/m²a.

For defining the simulation conditions, such as temperature and relative humidity, have been looked at closely for Savannah. The following Figure 9 and Figure 10 depict the dry bulb temperature and the relative humidity in Savannah, Georgia of a typical meteorological year.

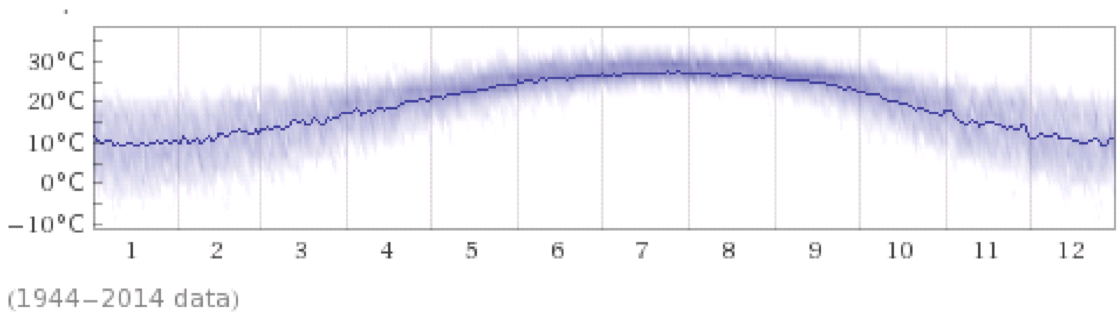


Figure 9: Temperature distribution Savannah, Georgia [I Wolfram Alpha, 2014]

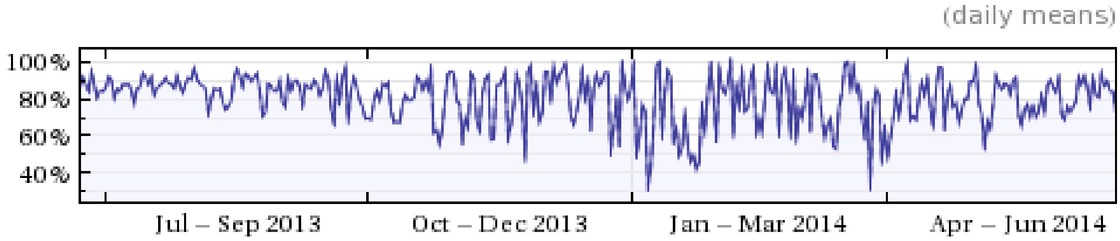


Figure 10: Relative humidity Savannah, Georgia [I Wolfram Alpha, 2014]

Further, Savannah is located in U.S. Climate Zone 2 [I DOE, 2010].

3.2 Simulation software

In order to simulate the representative municipal buildings an energy modeling software had to be chosen. Therefore it has been taken a closer look at 'eQuest' and 'TRNSYS', both accepted at LEEED certifications [I USBGC, 2014] [I Energy Models A, 2014].

TRNSYS is an algebraic and differential equation solver, able to simulate, building envelope, HVAC, energy system, controller and environment. The software uses an air node model, where each node represents a thermal zone [P Brychta, M., p25, 2013]. As Trnsys is not freeware compared to eQuest it is capable of doing more calculations. Concerning solar analysis the software offers a more detailed calculation, compared to eQuest, which is explicitly described in an overview in [P Brychta, M., p22, 2013]. Furthermore TRNSYS is capable of calculating solar radiation through interior windows [P Brychta, M., p22, 2013].

Although TRNSYS would have fit better for the application, since interior windows could have been analyzed, the demo version of 'TRNSYS' offers two thermal zones and up to five components, according to [I TRNSYS, 2014]. Since more thermal zones were required for accurate investigations, eQuest has been chosen to conduct the energy model and simulations.

The simulation tool eQuest offers an interface while using the DOE2 calculator [P eQuest Overview, 2014]. Thereby eQuest offers to input data via a Wizard or entering the data in the detailed mode [I Energy Models B, 2014]. For this reason very quick results are possible for simple constructions but complex models as well. However it has some restrictions considering the solar radiation models and sketching the models.

Two different methods of calculating heat transmission through opaque exterior surfaces are possible in eQuest. One uses a steady state assumption, which allows quicker results. The second one uses conduction transform functions, which allow mass effects to be considered [P eQuest Overview, 2014].

3.3 ASHRAE standards

According to [P UC Berkley, 1981] the DOE-2 engine, which is implemented in eQuest is based on the ASHRAE standards. [P ASHRAE 55-2010, 2010] describes the thermal comfort by using the percentage of persons dissatisfied. Thereby the thermal comfort is shown in a range were 90 % of the occupants, wearing average clothing and doing light activities, are satisfied. The following short facts show a short overview of the data used in eQuest for HVAC modeling.

Table 2, illustrates the median temperature data as a function of wet bulb temperature at a wind speed of 0.15 m/s, which are comfortable for 90 percent of the occupants. Further it has to be mentioned that the effective temperature is displayed, which is an average of the mean radiant temperature and the dry bulb temperature. The effective temperature is shown for both, summer and winter and is dependent on the wet bulb temperature.

The wet bulb temperature is described as the lowest temperature reached by direct evaporative cooling. The following Figure 11 illustrates the wet bulb temperature in the h, x-diagram, where enthalpy, absolute humidity, relative humidity and temperature are plotted. Further the h,x-diagram shows various example condition changes and their impact on thermodynamic conditions. The wet bulb temperature is displayed next to the saturation curve. It can be observed that if the level of absolute humidity is lower, the lower wet bulb temperatures can be achieved.

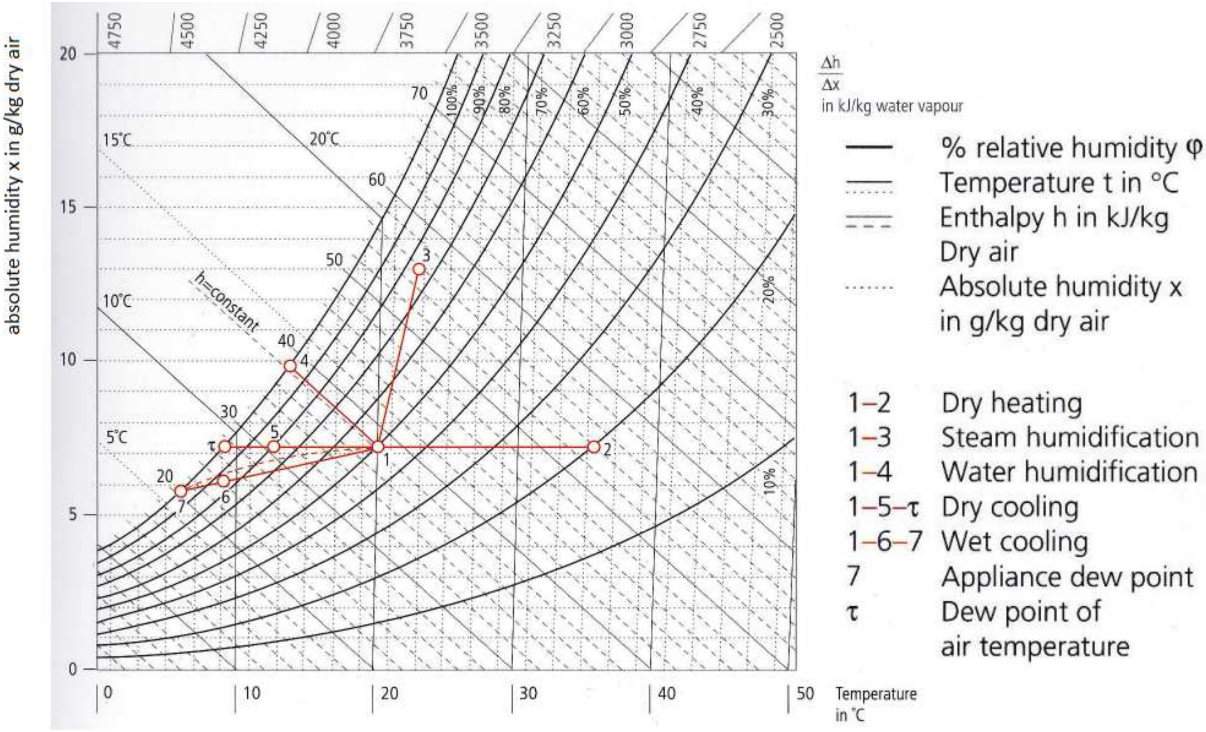


Figure 11: condition changes in h,x-diagram, [P Hindrichs U. D., Daniels K., p33, 2007]

Therefore the wet bulb temperature itself is reliant on the dry bulb temperature and the amount of moisture in the air. For this reason the accepted effective temperature varies with the absolute humidity.

Table 2: Overview of the accepted experienced temperature conditions as a function of wet bulb temperature with a maximum air velocity of 0.15 m/s [P Cleary N, 2011] according to ASHRAE 55-2010, 2010].

	Winter	
Wet bulb temperature	**Minimum Temperature**	**Maximum Temperature**
35.6 °F (2 °C)	68.9 °F (20.5 °C)	76.1 °F (24.5 °C)
64.4 °F (18 °C)	68 °F (20°C)	74.3 °F (23.5 °C)
	Summer	
	Minimum Temperature	Maximum Temperature
35.6 °F (2 °C)	74.3 °F (23.5 °C)	80.6 °F (27°C)
68 °F (20 °C)	72.5 °F (22.5 °C)	78.8 °F (26°C)

Thus the mean radiant temperature should be lower than the air temperature in summer. In winter it should be reverse. Further it can be determined that the air velocity in the room should be below 0.15 m/s to obtain a low PDD (percentage of persons dissatisfied), which can be higher with air temperatures above 78.8 °F (26 °C). In general though it can be said that the velocity should not exceed 0.4 m/s in work areas and 0.2 m/s were the occupants are seated.

Figure 12 below illustrates the accepted temperature in imperial and Si- units, with a maximum air speed of 40 ft/min (0.2 m/s) according to [P ASHRAE 55-2004, p4-5, 2004]. The acceptable temperature region for 80 % of occupants is shown with two different clothing factors.

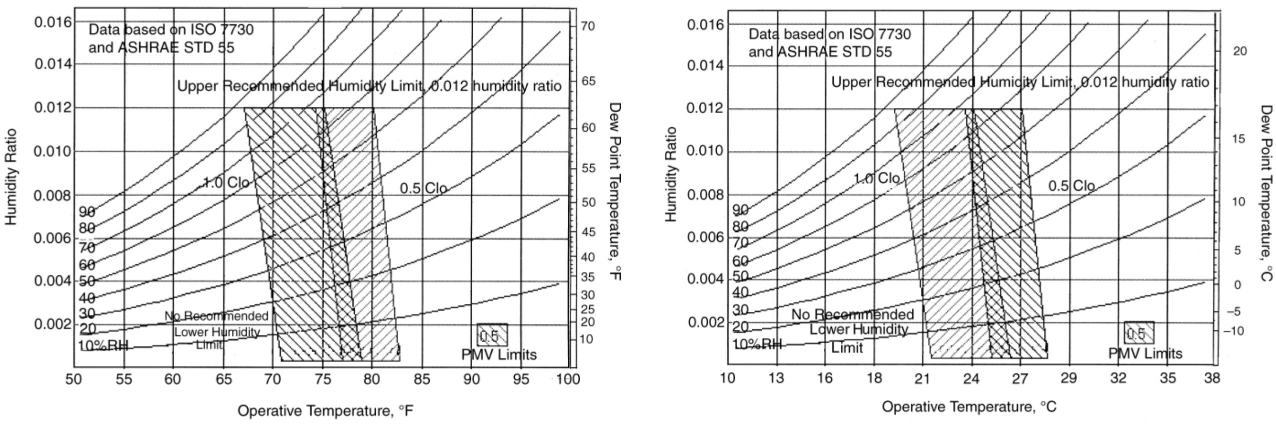


Figure 12: acceptable range of temperature and humidity in air, [P ASHRAE 55-2004, p5, 2004]

Thus the graphs depict the dependency of thermal comfort on humidity. The higher the humidity ratio, the cooler are the temperatures being comfortable. Therefore during summer dehumidification plays a major role regarding comfort, especially concerning the high humidity ratios in the South Atlantic area. Not only can dehumidification enlarge thermal comfort, also potential in reducing cooling energy due to higher acceptance is shown. In colder regions this issue usually is discussed vice versa.

Thus, an especially essential key factor in thermal comfort being relative humidity, it can be said that it should mainly lie between 45 and 60 per cent, and never exceed 70 per cent. Additionally it is significant that the carbon dioxide content should not exceed about 0.1 per cent, which is taken care of by the set air change in eQuest, [P Cleary N, 2011] according to [P ASHRAE 55-2010, 2010].

3.4 Buildings in hot and humid climates

The following subchapters show the climatic influence on building structures, such as windows or humidity in the building envelope. Furthermore, potential energy savings will be shown especially focusing on the climate conditions.

3.4.1 Construction in hot and humid climates

The following Figure 13 depicts the transmission in percent over wavelength of a standard window glass. Thereby B shows the visible light range and C the infrared light range.

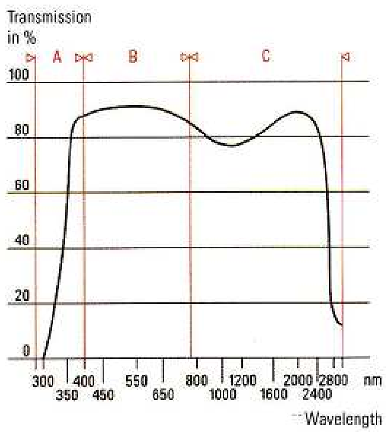


Figure 13: Radiation transmission of standard window glass [P Hindrichs U. D., Daniels K., p 242, 2007]

Thereby it has to be kept in mind that especially in hot climates with high radiation, it is important to keep the thermal transmission low. It has been tried to keep the window area in order to preserve the external appearance. Additionally it has been important to keep the visible amount of light the same in order to reduce energy consumption for interior lighting. Therefore possibilities have been researched, where two examples are shown in Figure 14.

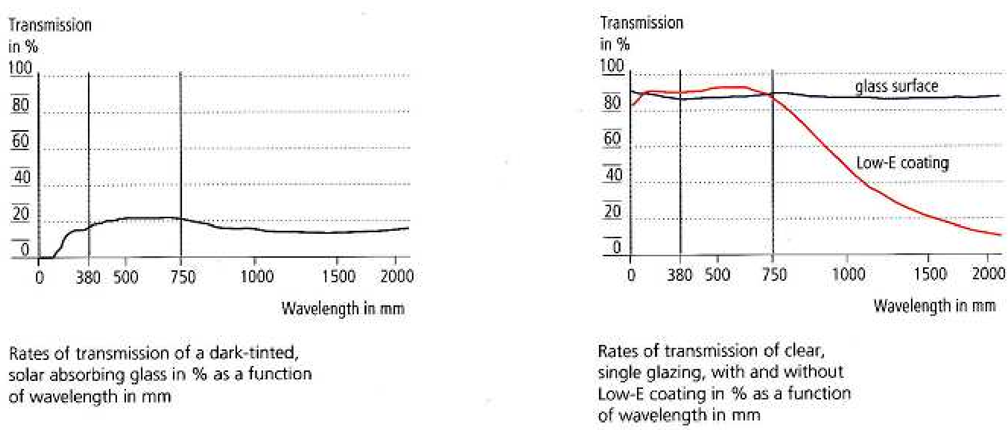


Figure 14: transmission of different glass types over wavelength [P Hindrichs U. D., Daniels K., p 242, 2007]

The window on the left is a dark tinted window, where it can be seen that the transmission is reduced in the visible and infrared light range. These windows usually show high reduction on cooling load and demand. Anyway, while wanting to keep the electricity demand for lighting low, the window on the right with 'low-E' coating shows better results. It transmits the light in the visible light range and reduces light transmission in the infrared range.

Furthermore, since relative humidity is rather high, humidity in building envelopes have been researched. Figure 15 below illustrates humidity impact on exterior building components. Thereby, due to high precipitation as it has been mentioned in 3.1 Climate, rain plays one of the major roles on the building envelope in such climates. Though, it has been focused on vapor diffusion and condensate, regarding the simulations and design of the building elements.

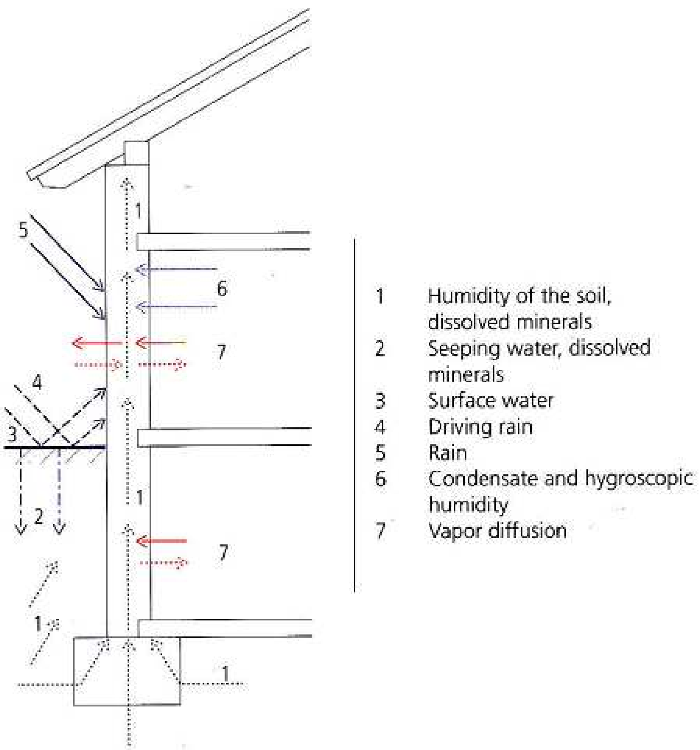


Figure 15: humidity impact on exterior building components [P Hindrichs U. D., Daniels K., p 220, 2007]

Regarding vapor diffusion through exterior building components, the following Figure 16 illustrates a comparison of dry and cold climates and hot and humid climates. Thereby the cold and dry climate is shown on the left and the hot and humid climate is shown on the right [P Hindrichs U. D., Daniels K., p 220, 2007].

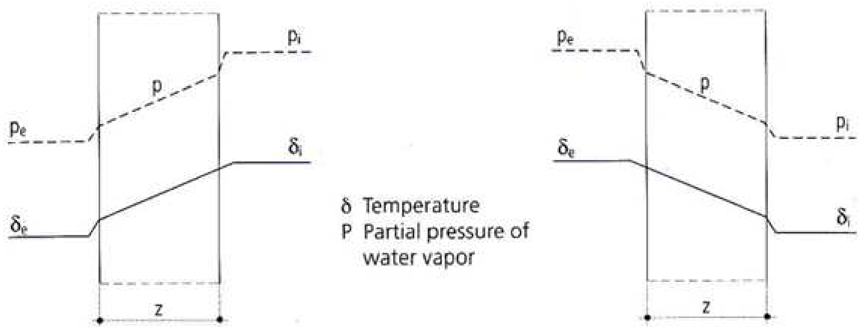


Figure 16: vapor diffusion through exterior building component [P Hindrichs U. D., Daniels K., p 220, 2007]

Thereby it can be seen that the vapor retarders, barriers or similar foils have to be applied differently regarding building structure. Moreover, [P Lstiburek, W., p 40-50, 2004] did propose climate zones regarding vapor retarders and barriers. Thereby the South Atlantic and thus Savannah are situated in Zone 2. Further, [P Lstiburek, W., p 40-50, 2004] highlights that in Zone 2, no vapor retarder is required, which is illustrated in Figure 17 below.

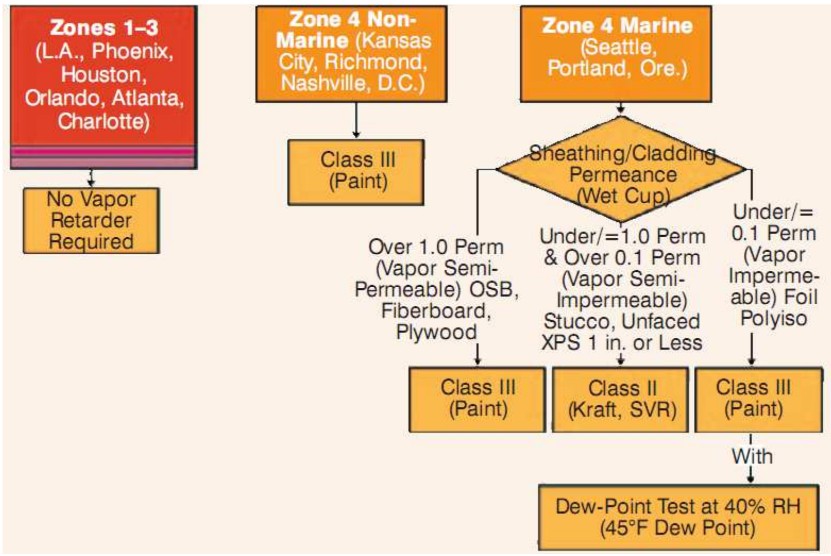


Figure 17: Vapor Barrier Flow Chart for Zone 1-to 4 [P Lstiburek, W., p49, 2004]

3.4.2 Energy consumption

Regarding energy consumption, saving potentials in the climate such as the South Atlantic have been researched. By this means it has to be noted that in [P Hindrichs U. D., Daniels K., p 117, 2007] Georgia is referred to as being in the 'hot-arid' climate, regarded worldwide. [P Hindrichs U. D., Daniels K., p 222, 2007] made some simulations, calculating energy demand, using a representative example. Following descriptions and results are based on this example. The following Figure 18 illustrates the savings of cooling energy in hot and arid climate depending on the orientation of the building.

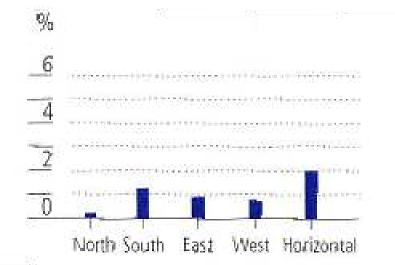


Figure 18: cooling demand savings example dependent on the orientation [P Hindrichs U. D., Daniels K., p 223, 2007]

Furthermore Figure 19 depicts the saving potential regarding cooling demand through insulation. The highest potential has the insulated wall for cooling demand savings, although the roof insulation shows a saving potential of 2.5 per cent as well.

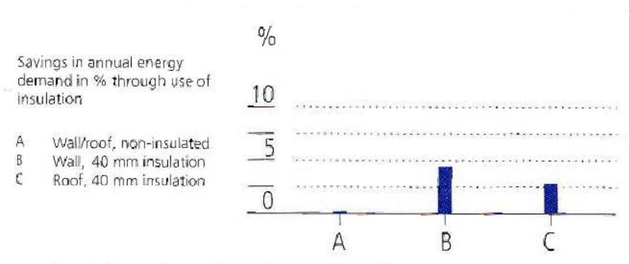


Figure 19: cooling demand savings example dependent on the insulation [P Hindrichs U. D., Daniels K., p 223, 2007]

Regarding the insulation thickness, the following Figure 20 illustrates the thickness dependency on cooling and heating demand savings. Thus the major savings of the annual cooling demand are reached in the given example until an insulation of 60 mm. The heating demand is shown in red.

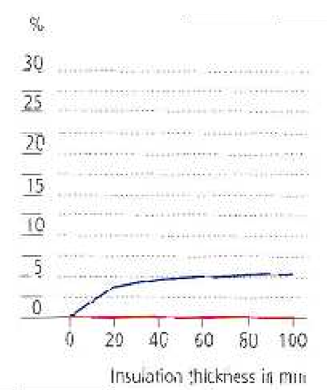


Figure 20: cooling and heating demand savings example dependent on the insulation [P Hindrichs U. D., Daniels K., p 223, 2007]

Additionally it has been found that the solar absorption coefficient of the roof shows major influence on the annual cooling demand, also in the hot-arid region, where Georgia is in. Savings up to 15 per cent could be reached by color and roof coating, which is shown in Figure 21.

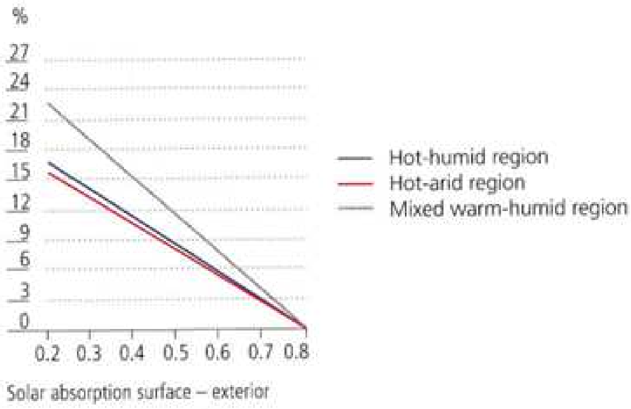


Figure 21: savings in annual cooling energy demand in % for various solar absorption coefficients in different climates [P Hindrichs U. D., Daniels K., p 223, 2007]

3.5 Energy conservation code

The energy conservation code [I International Code Council, C402, 2014] declares the required thermal resistance for all building envelope components and all states. Thereby the following Table 3 shows the values for climate zone 2A, which applies for Chatham County according to [I International Code Council, C301, 2014]. Thereby 'ci' stands for continuous insulation and LS stands for liner system.

Table 3: Thermal Envelope Requirements according to Energy Conservation Code, Climate Zone 2A [I International Code Council, C402.2, 2014], [I International Code Council, C402.1, 2014] according to [P ASHRAE 90.1-2010, p 27, 2010]

Component	Specification	Maximum R- Value of insulation Btu-in/h-f^2 °F	Minimum Assembly U-Value h-f²°F/Btu-in	Minimum Assembly U-Value W/m²K
	Insulation Entirely Above Deck	R-20 ci	0.048	0.273
Roof	Metal buildings (with R-5 thermal blocks)	R-19 + R-11 LS	0.055	0.312
	Attic and other	R-38	0.027	0.153

Component	**Specification**	**Maximum R- Value of insulation Btu-in/h-f^2 °F**	**Minimum Assembly U-Value h-f²°F/Btu-in**	**Minimum Assembly U-Value W/m²K**
Walls, Above Grade	Mass	R-5.7 ci	0.151	0.857
	Metal Building	R13 + R-6.5ci	0.093	0.528
	Metal Framed	R-13 + R-5ci	0.124	0.704
	Wood-Framed and other	R-13 + R-3.8ci or R-20	0.089	0.505
Walls, Below Grade	Below-Grade Wall	Not relevant	No u- value	-
Floors	Mass	R-6.3ci	0.107	0.608
	Joist-framing	R-30	0.033	0.187
Slab on Grade Floors	Unheated slab	Not relevant	No u-value	-
	Heated Slab	R-7.5 f or 12 below	No u-value	-
Doors	Swinging		0.61	3.464
	Roll-up or sliding	R-4.75	-	-

For the below grade walls, a C-value of 1.14 BTU/h-ft²-°F (6.47 W/m²K) for the whole assembly, has been specified instead of a u-value. The C-value or C-factor is described as being the heat flow through a unit area per time of a material or construction, evoked by a temperature difference between two surfaces. It therefore basically describes a thermal conductance, although it has to be noted that the c-factor does not take soil or air films into account, [P ASHRAE 90.1-2010, p 6, 2010].

For the slab on grade floors an F-Value is given, which is the perimeter heat loss factor for slab on grade floors. Regarding the unheated slab on grade floor, no requirement is given for the insulation, however an F-value of 0.73 Btu/h-ft-°F (1.263 W/mK) for the assembly is required. The F-factor for heated slab is 0.9 Btu/h-ft-°F, illustrated in [I International Code Council, C402.1, 2014].

Additionally, requirements for Climate Zone 2A, concerning the u-value and solar heat gain coefficient (SHGC) of windows, are shown in Table 4 below. The solar heat gain coefficient is thereby equivalent to the total solar energy transmittance [P Pilkington Ltd., 2012] or g-value, meaning it specifies the fraction of radiation transmitted through a building element into the building. It is defined in respect to the wavelength of light between 320 to 2,500 nm [P Hindrichs U. D., Daniels K., p 2412007].

However, regarding the solar gain eQuest asks for the shading coefficient. The shading coefficient was very commonly used in the U.S before it has been replaced by the Solar Heat gain coefficient. It is equivalent to the German b-factor and is defined as the fraction of energy transmitted through a window compared to a double pane glass. Earlier it was related to a 1/8 inch (or 3 mm) thick single-pane glass which is the reason for two different relationships can be found [P Hindrichs U. D., Daniels K., p 241, 2007]. Equation 1 shows the more commonly found equation, also described in [I Energy Models C, 2014].

Equation 1: shading coefficient, [I Energy Models C, 2014], [P Hindrichs U. D., Daniels K., 2007]

$$Shading\ Coefficient\ (SC) = \frac{Solar\ Heat\ Gain\ Coefficient\ (SHGC)}{0.87}$$

The following Table 4 below depicts a summary of the required values for fenestration in climate zone 2A.

Table 4: Window Requirements according to Energy Conservation Code, Climate Zone 2A [I International Code Council, C402.3, 2014]

<table>
<tr><th>Component</th><th>Specification</th><th>U-Value
h-f^2°F/Btu-in</th><th>Solar Heat Gain
Coefficient</th><th>U-Value
W/m^{2}K</th></tr>
<tr><td rowspan="3">Vertical fenestration</td><td>Fixed fenestration</td><td>0.5</td><td rowspan="3">0.25</td><td>2.839</td></tr>
<tr><td>Operable fenestration</td><td>0.65</td><td>3.691</td></tr>
<tr><td>Entrance Doors</td><td>0.83</td><td>4.713</td></tr>
<tr><td colspan="2">Skylights</td><td>0.65</td><td>0.35</td><td>3.691</td></tr>
</table>

3.6 Energy supply

The following subchapters indicate how the common bills for energy consumption are put together in Georgia, necessary for eventual utility cost reducing measures.

3.6.1 Electricity

The electricity charges in the United States can be mainly divided into four divisions: the basic charge, the demand charge the reactive power charge and the energy charge. The following Figure 22 depicts an example how these charges could come together.

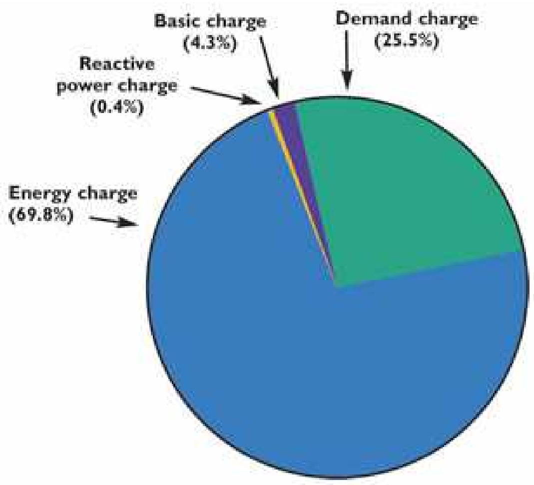


Figure 22: electricity charge divisions, [I Pacific Power, 2014]

The basic charge or basic service charge recovers distribution and billing related costs, whereby the minimum charge is often the same but could also include a charge/kW of demand based on a minimum monthly demand for the schedule [I Pacific Power, 2014] which applies for Savannah [P Georgia Power, p 1-3, 2014].

Besides the monthly minimum rates the demand charge has to be paid in $/kW. It is depended on the cycle of 15 minutes with the largest amount of energy consumed [I Pacific Power, 2014]. Thereby [P Georgia Power, p 1-3, 2014] gives further options for this rate to be calculated. However, it is strongly dependent on the peak demand and therefore can be reduces during design stage.

The energy charge is specified as the use in kWh, calculated monthly. The amount of the energy charge in $/kWh depends on the overall usage, divided in blocks in [P Georgia Power, p 1-3, 2014].

Further included are fuel cost recoveries, nuclear rebuilt charges and renewable rebuilt charges for example, which is strongly dependent on the year and effective costs of [P Georgia Power, p 1-3, 2014].

3.6.2 Natural Gas

The Natural Gas Bill provided by Georgia Natural Gas is divided in base charge, costumer charge, gas charge, interstate pipeline capacity charge and sales tax [I Georgia Power, 2014]. The base charge is firstly charged by Atlanta Gas Light Company billed through to every of their marketer and then passed through from Georgia Natural Gas to its customers.

Besides the base charge the costumer service charged is charged for maintaining and service concerning the account by Georgia Natural Gas. Further the gas charge bills the used amount of gas in therms. The last on the list, the interstate pipeline capacity charge, is a separately billed transportation charge calculated annually. It is dependent on the consumption over the past year and measured by the pipeline capacity for gas needed on peak demand days [I Georgia Power, 2014].

4 Methodology

In order to achieve the aim of defining the highest sectors of energy consumptions in municipal buildings and giving easy achievable recommendations for energy efficiency improvements a representative municipal building has been chosen to evaluate.

The City of Savannah provided an industrial building, built in the 1890's, as a representative sample for analysis. First of all the building and its main sector of energy consumption have been analyzed. Based on this data various options have been simulated in order to find out the retrofitting measures with the highest energy consumption and cost reduction. This led to an economic analysis which is necessary to point out the measures which are the easiest economically feasible for municipal buildings in this area in general.

Once the bullet points for retrofitting municipal buildings in the area have been detected a design proposal for the representative building has been made.

4.1 Building Description

The representative example is a brick building built in 1892 as a Waterworks Pump Station. Since the construction back in the 19th century the building has been used as an industrial building and storage, although the building will now be rebuild as an office, meeting and event space for the area as an arena will be constructed in the next view years [O Shonka, 13th March, 2014]. The building is located in Savannah on the corner of Stiles and Gwinnett Street. The following Figure 23 illustrates the location of the building close to Savannah Downtown, 32.072045° N and 81.113300° W.

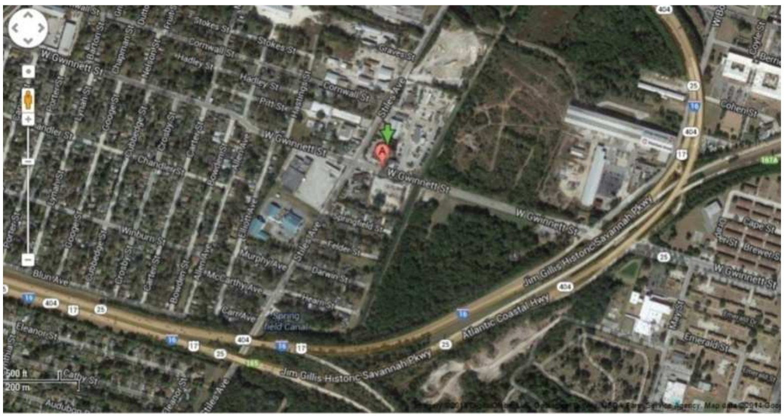


Figure 23: Location Waterworks Building [I Google Maps, 2014]

The City off Savannah has contracted Felder & Associates for a report on the historic structure, which has been handed over to the City of Savannah in March 2014.

The following Figure 24 depicts a Context Map. The non-historic additions to the building are indicated in yellow and will be removed while repurposing the building into a meeting and office space [O Shonka, 13th March, 2014].

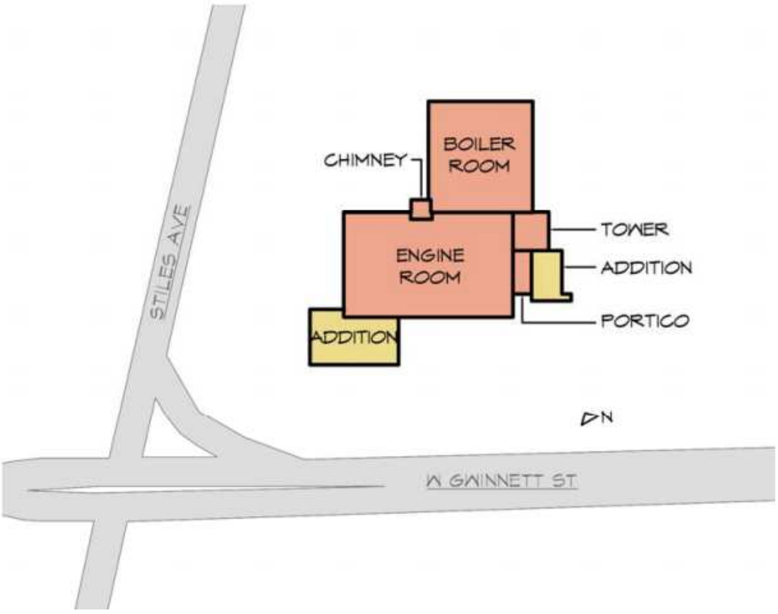


Figure 24: Building Context Map [P Felder & Associates, II p 19, 2014

The report done by [P Felder & Associates, 2014] proposed several structural measures which should be implemented. Additionally they made statements according to the historic structure and magnificent architectural components from the 1890's throughout their report. Likewise research has been done by the City of Savannah on the History of the Building [P Spracher L., 2014] and on the Development of the Building and its Architecture by the Savannah College of Art and Design [P SCAD, 2014].

The thermal resistance of the existing building is described further in the following chapters, although it can be said that the building does not meet energy conservation code. Thereby the existing building at adaption of energy code is not prevented from being used without being conform to code. If the building will be altered, renovated or repaired, the alterations have to match energy conservation code [P Felder & Associates, 2014]. Buildings that are noted on a National Register for Historic Places do not have to meet those requirements, though [O Harrise, 6th June, 2014].

4.2 On-site visit

An on-site visit has been executed. Table 5 lists an overview of the data.

Table 5: On-site visit data

Date	**19th March 2014**
Time	12:30 pm to 14:15 pm
Attendants	Sonja Mitsch Andreas Karl
Collected Data	58 Pictures Window conditions Roof Structure Elevations Window measurements Openings Alterations

As the building has been used as storage for the last few years and the building has several openings no measurements have been made at the on-site visit. The measurements of the building have been taken by [P Felder & Associates, 2014] and plans of the building have been drawn. The on-site visit provided data and information listed in Table 5, necessary for the energy model. Further the pictures which have been made at the on-site visit mainly focused on the energy model, since an observation of the architecture has been done in [P Felder & Associates, 2014].

The following Figure 25 shows the front entrance at east elevation of the building. The white building addition at the left hand side of the tower will be removed and the portico will be restored as the main entrance.

Figure 25: On-site visit front entrance

Figure 26 shows the original roof construction with the steel joists in between. The vertical area of the roof can be opened, as there are no windows in place. Figure 27 shows the wall construction. While the On-site visit brick dimensions of 8’’ by 4’’ by 2 ½ ’’ (20.3 cm by 10.16 cm by 6.35 cm) have been measured, although they vary slightly throughout the building due to brick construction back in the day.

Figure 26: On-site visit, roof construction

Figure 27: On-site visit, wall construction

The following Figure 28, Figure 29 and Figure 30 illustrate the temporary windows in place, which data have been recorded for the energy model.

Figure 28: On-site visit, windows 1

Figure 29: On-site visit, windows 2

Figure 30: On-site visit, windows 3

Figure 31 and Figure 32 depict several openings which have been closed over time to prevent damage and provide structural assistance to the existing structure. These have been observed for the first energy models, but it is assumed that the openings and altered openings will be opened and brought back to their original design in the retrofitting process.

Figure 31: On-site visit, closed openings 1

Figure 32: On-site visit, closed openings 2

Figure 33: On-site visit, altered opening

Figure 34 shows an example for the interior stucco in the engine room, which has been observed at the on-site visit and is also mentioned in [P Felder & Associates, 2014]. If the historic stucco in the interior side of the wall and window arch should be kept, it prevents interior insulation from being an energy efficiency measure.

Figure 34: On-site visit, Interior Stucco [P Felder & Associates, 2014]

4.3 Energy Analysis

Since the building has been used for industry and for storage rather than for office or meeting spaces no utility data could be provided. Therefore an energy model has been made in eQuest [SW eQuest, 2014] in order to evaluate the energy consumption of the building. Thereby various values had to be set and assumptions due to missing data have been made, which are outlined in the following subchapters. In general the Energy Analysis has been made with assumption that the existing structure is only restored and temporarily fixed rather than altered in any way. Details are described in the associated subchapters. The following Figure 35 depicts the Model done in eQuest.

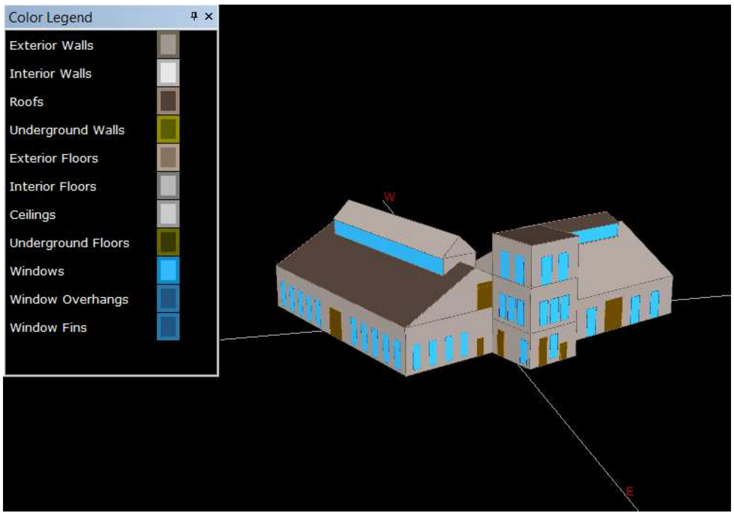


Figure 35: Energy Analysis, Model drawn in [SW eQuest, 2014]

As described in 3.2 Simulation software it is possible to first implement the basic data via the "Wizard" and then add the detailed information in the 'Detailed Mode', which has been done in the Energy Analysis. Due to the complex structure the roof has been added in the 'Detailed Mode' later on.

Besides the condensation, the u-values and the temperature phase shift have been calculated in [I U-value, 2014]. Due to the fact that it is an online tool using the 'Glaser-Method' for construction physic purposes, the simulation results are restricted.

Thereby, one has to input the climate set points as no simulation with weather data is available in the tool, since it uses the 'Glaser-Method', a method for estimating the amount of condensate in a construction. This method has some restrictions though and should only be used while knowing them. First of all it neglects the capillary conductance of an element and is therefore the results are worse than real test conditions would be. Further the temperature and humidity is applied for 60 days through in this calculation, in order to ensure steady state boundary conditions.

Nevertheless one winter and one summer case, both rather extreme than ordinary, have been tested for all structures with having in mind that these are not applied throughout 60 days.. Anyhow, the tool has been used to examine the structures regarding relative humidity and condensate.

4.3.1 Defined boundary conditions for energy model

The following subchapters describe the main boundary conditions influencing the energy model which has been done. Due to missing utility data some assumptions have been made as described below.

All calculations in eQuest and further boundary conditions are set according to the ASHRAE Book of Fundamentals [P UC Berkley, 1981].

4.3.1.1 Climate

The climate has already been described in 3.1 Climate For calculations weather data representing a typical meteorological year have been loaded into eQuest from [I NREL, 2008]. The following Table 6 shows the parameter used for the condensation trend analysis done in [I U-value, 2014]. Thus it has to be mentioned that rather extreme conditions especially considering relative humidity have been chosen in order to make sure no condensate damages appear for the proposed components.

Table 6: condensation analysis, temperatures [P Bachner p6, 2013] [I Wolfram Alpha, 2014]

	Dry bulb temp in °F	Relative Humidity in %	Dry bulb temp in °C
Summer case	80	85	26.67
Winter case	50	70	10

The temperatures have been ascertained for summer and winter in [P Bachner p6, 2013] and the relative humidity is shown in chapter 3.1.

4.3.1.2 Energy supply

Overall the Municipal Buildings of the City use a natural gas furnace for heating [O Knight, 23rd April, 2014] and DX coils for cooling [O Marr, 6th March, 2014], which has been implemented for the first energy analysis.

Secondly the costs have been updated in order to estimate the expected utility data for the energy analysis and the cost reduction for further adapted measures.

Natural gas

Values for the natural gas costs and consumption have been provided by [O Knight, 23rd April, 2014]. The billing amount for the natural gas bill of the city divides in Costumer Charge and Commodity Charge. The Costumer Charge has been divided by department and is shown in the following Figure 36.

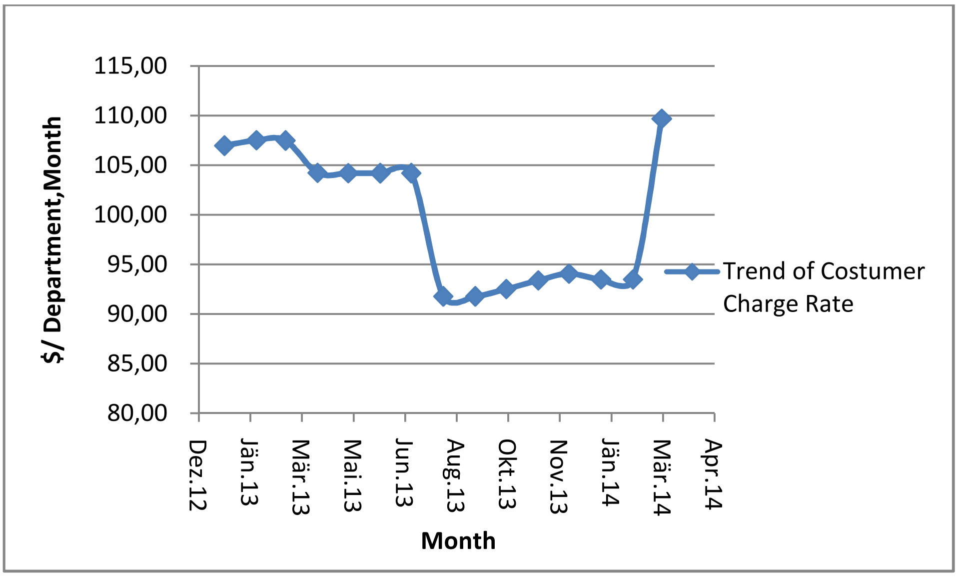


Figure 36: Trend of natural gas costumer charge rate, City of Savannah, [O Knight, 23rd April, 2014]

The following Figure 37 depicts the natural gas commodity charge rate trend over the last months in $/therm. Since the period of data for both, costumer and commodity charge, is too short to predict any future trends, a mean value of 104.19 $/Month costumer charge and 0.73 $/therm (0.025 $/kWh) have been inputs for the simulation tool.

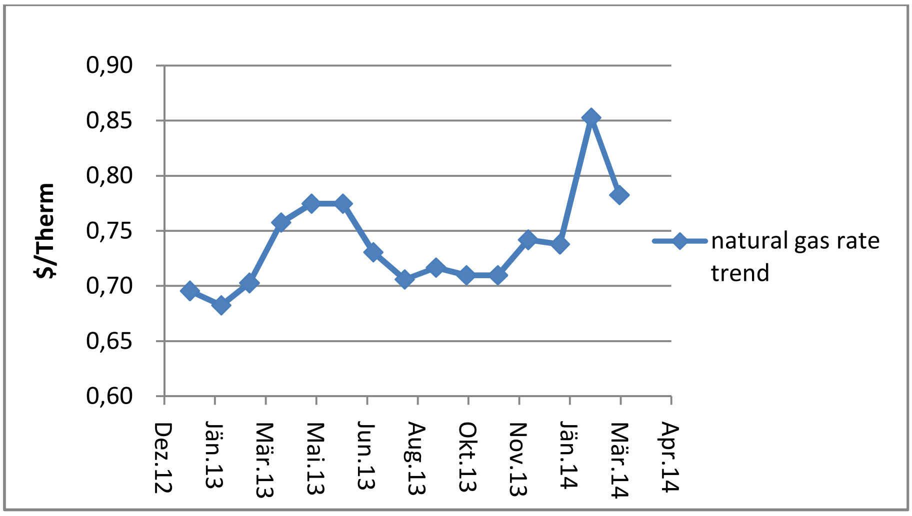


Figure 37: Trend of natural gas commodity charge rate, City of Savannah, [O Knight, 23rd April, 2014]

Electricity

Values for the electricity costs and consumption have been provided by [O Saxon, 23rd April, 2014]. The following data show the overall electricity rates already including additional monthly charges. The composition of the overall electricity rate has already been described in 3.6.1 Electricity.

Figure 38 depicts the average electricity rate over the last view years noted by the city of Savannah.

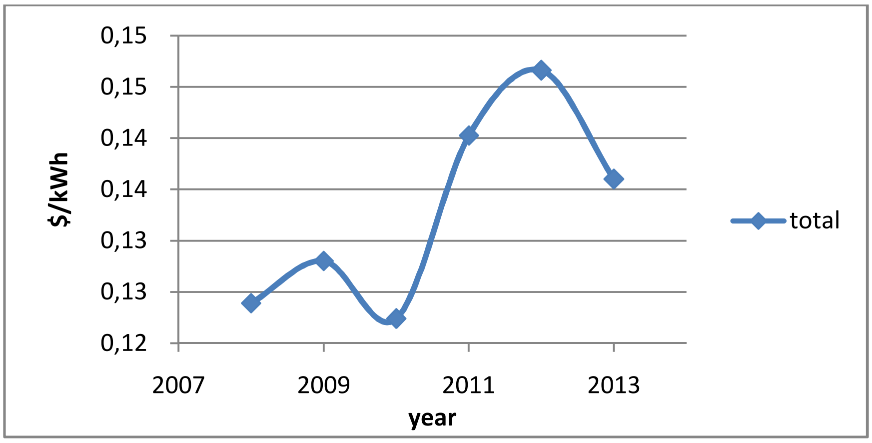


Figure 38: Average yearly electricity rate, city of Savannah, [O Saxon, 23rd April, 2014].

Hence the electricity rate is fluctuating throughout the year; the following Figure 39 illustrates the electricity fluctuation for the last years on a monthly basis. Since the electricity consumption is the highest during summer months, the peak load defines the electricity rate for one summer month depending on the contract. Although the peak load is unknown and an average electricity price will be the input for the simulations, reducing the cooling peak load will be reducing the utility costs in reality.

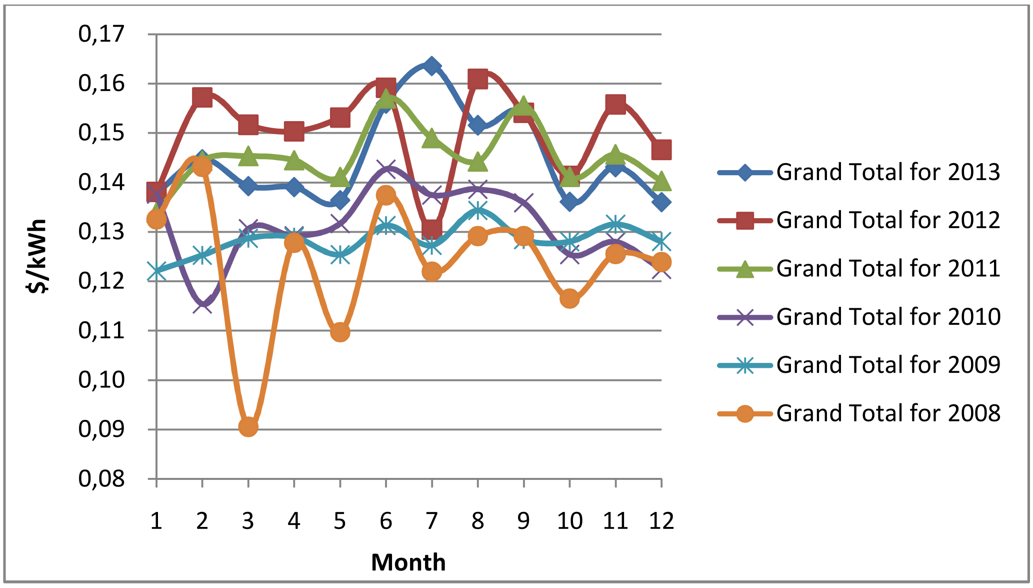


Figure 39: electricity rate, 6 years, monthly fluctuation, [O Saxon, 23rd April, 2014].

Figure 40 depicts the electricity rate trend. As the period of data is too short to predict the future value an average value of 0.14 $/kWh has been used for the simulation in eQuest.

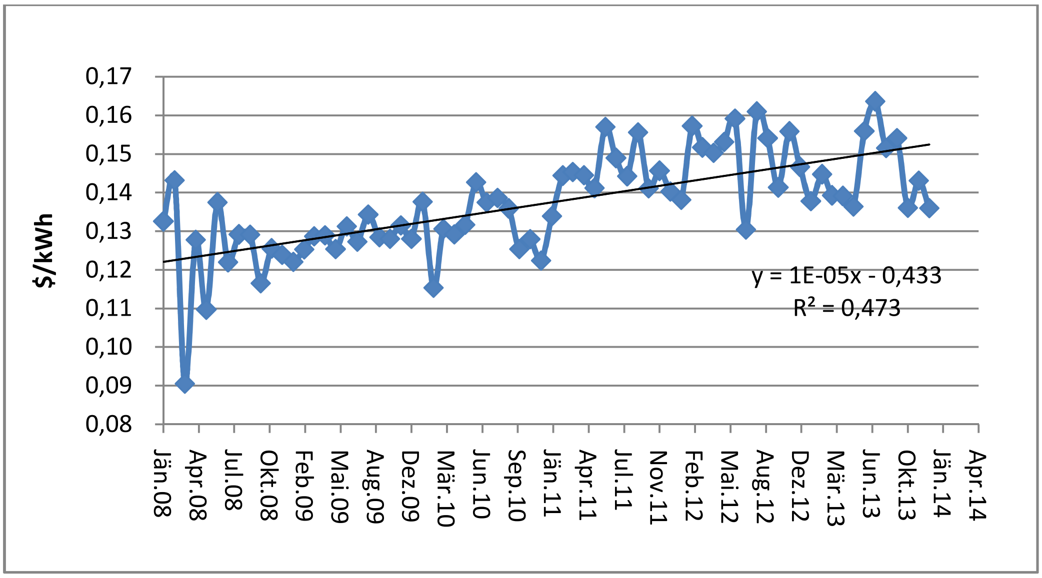


Figure 40: electricity rate trend city of Savannah, [O Saxon, 23rd April, 2014].

4.3.1.3 Construction Materials

As the material properties of the built- in solid bricks are unknown and are dependent on the density, it has been found that the density will vary between 96.77 lb/ft³ (1550 kg/m³) and 112.37 lb/ft³ (1800 kg/m³) during the time the Waterworks has been built [P Fernandes et al, chapter III p 6, 2010]. Further [I Engineering ToolBox, 2014] shows a density for brick in mortar of 100 lb/ft³ (1601.8 kg/m³), which has been chosen for the energy analysis. The corresponding material data such as conductivity and specific heat have been found in [P ONV, chapter 31, p12, 2001].

The Material Properties for the Metal Roof have been taken from [P Riccabona, p329, 2003].The following Table 7shows the converted values into imperial units, converted with factors from [I MIT, 2014].

Table 7: Construction Materials for Energy Analysis, [I MIT, 2014], [P Fernandes et al, chapter III p 6, 2010], [P ONV, chapter 31, p12, 2001], [P Riccabona, p329, 2003]

Material	Density		Conductivity		Specific heat	
	lb/ft^3	(kg/m^3)	Btu/h-ft-F	(W/mK)	Btu/lb-F	(J/kgK)
Steel	486.9522	(7800)	34.6681	(60)	0.1146	(479.82)
Brick	100	(1601.8)	0.40446	(0.7)	0.21495617	(900)

4.3.1.4 Gross Floor Area

The gross floor area for the energy analysis has been calculated from the plans drawn by [P Felder & Associates, 2014]. Thereby the irregularities of the exterior wall have been neglected. The potential of a second and third floor have been neglected in the energy analysis, since a design will be made after the investigations concerning energy efficiency enhancing measures. Table 8 lists the collected data of the gross floor area.

Table 8: gross floor area, energy analysis

	Engine Room	**Boiler Room**	**Tower**	
1st floor	10255,5 ft^2 (952.77 m^2)	6675,5 ft^2 (620.17 m^2)	812 ft^2 (75 m^2)	
2nd floor			812 ft^2 (75 m^2)	
3rd floor			812 ft^2 (75 m^2)	
Sum	10255,5 ft^2 (952.77 m^2)	6675,5 ft^2 (620.17 m^2)	2436 ft^2 (226.3 m^2)	19367 ft^2 (1799.25 m^2)

4.3.1.5 Building structure

The following subchapters show specific input values which have been defined.

As described in 3.2 Simulation software two simulation methods of heat transmission through opaque exterior surfaces are possible in eQuest. In the following inputs the "delayed" method has been used due to the massive construction of the building unless it is specifically described that the u-value has been used to calculate the heat transmission in the subchapter.

Roof

The Historic Structure Report of [P Felder & Associates, 2014] defined the Roof as a Corrugated Metal Roof. As found in [I National Park Service, 2014] and [I Corrugated Metal, 2014] a thickness of ½ '' (1.27 cm) has been estimated as a thickness for the Corrugated Metal Roof in the simulation.

As the thermal conduction could not be calculated due to the high density of the material a u-value of 1.256 Btu/hft²°F (7.13 W/m²K) has been used to calculate the heat transmission through the metal roof.

Further the steel panel has been tested for condensate. In the described summer case as in 4.3.1.1 Climate there are no issues shown, although the winter case does indicate issues. If the internal conditions to be allowed were to be 70 °F (21.11 °C) and 65 % water is expected. If the relative humidity inside would be set to a section between 45 % and 60 % mold grow is to be expected or cannot be included.

Wall

Table 9 shows the observed wall thickness in [P Felder & Associates, Appendix D, 2014], neglecting the irregularities in the shape of the exterior walls. Therefore at some points the real wall will have a higher u-value and at some a smaller one due to irregularities in the density of the brick and irregularities of the mortar.

Table 9: Wall thickness, energy analysis

	Thickness in "	Thickness in cm	U-Value in BTU/hft²°F	U-Value in W/m²K
Tower Wall	15	38.1	0.265	1.5047
Engine Room Wall	22	55.88	0.192	1.0902
Boiler Room Wall	20	50.8	0.208	1.1811

Floor

The report from [P Felder & Associates, III p 2, 2014] indicates that the existing floors do not meet the necessary floor elevation, required to avoid flooding. According to [O Shonka, 13th March, 2014] the floor elevation has to be raised to 13 feet (3.95 m) above sea level. The current level varies throughout the building, but overall levels of the engine room and tower have to be increased 3 feet (0.91 m) and the level of the boiler has to be raised 5 feet (1.53 m). Since this increases the external wall surface, it has already been considered in the energy analysis.

The following Figure 41 illustrates the floor structure for the energy analysis. Thereby a fill has to be assumed between the existing floor and the new stabilizing floor and no further attention has been brought to this, since a structural engineer will decide further measures considering the floor structure. Further it has to be mentioned that the exact depth of the buildings floor structure is unknown.

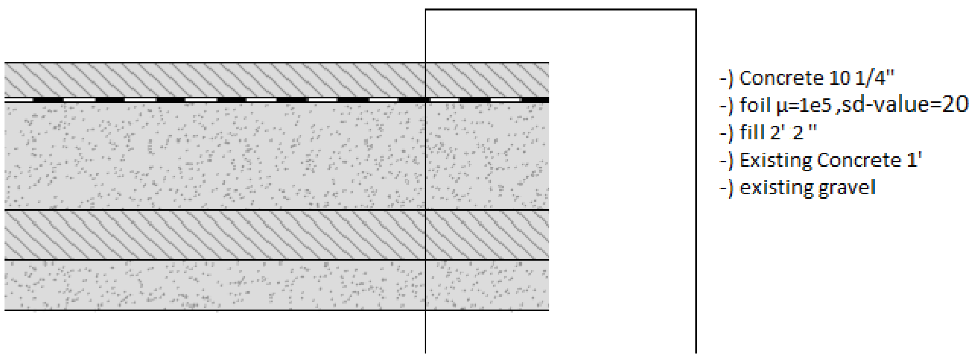


Figure 41: Energy Analysis, Floor structure, [P Felder & Associates, III p21, 2014], [O Shonka, 13th March, 2014]

While assuming the maximum allowed temperature inside is 78 °F (25.56 °C) with a maximum relative humidity of 65 %, according to ASHRAE, the floor dries in 16 days. Thereby the ground temperature remains unknown since the depth of the fundament is undefined and the type of fill is unknown, which is why the results of the mold calculation are not significant.

Due to the fact that the above, in Figure 41 shown, floor structure is too thick or too dense for simulations in eQuest the light soil under the existing concrete floor has been neglected. Thereby eQuest calculates a u-value of 0.2 BTU/h-ft^2-°F (1.14 W/m^{2}K). Further it has been assumed that the boiler room, although the floor will be thicker, has the same floor structure for the reasons mentioned above. However it has been layed focus on simulation expecially the floor structure ‚delayed' in eQuest in order to regard the thermal phase shift of the massive structure.

Windows

As described in 4.2 On-site visit the sizes of the windows, the frame material as well as the frame and spacer thickness have been compiled. For the energy analysis, clear single pane windows from the "Wizard" in eQuest have been chosen with a U-value of 1.31 BTU/hft^2°F (7.44 W/m^{2}K) and a solar heat gain coefficient of 0.82. The frame thickness and materials are shown in the Appendix.

Doors

The doors chosen for the Simulation vary, depended on the observation from the on- site visit. In the first energy analysis the main entrance doors have been defined as solid core flush wooden doors with a thickness of 1 ¾ '' and a u-value of 0.56 BTU/hft^2°F (3.18 W/m^{2}K). Further, the openings such as the chimney are assumed to be closed by thin wood panels and the altered closed openings with brick for example are assumed to be left the same. The ventilators are assumed to be closed and therefore treated as aluminum panels.

Details for the doors and openings are listed in the Appendix.

4.3.1.6 Internal loads

Since the floor plan is unknown the default values proposed by the software have been used for the simulation. The following Table 10 shows the percentage of area for each area type. Thereby 230 people have been estimated for the area, already described in detail in 4.3.1.4 Gross Floor Area.

Table 10: Energy Analysis, Percentage of Area

Purpose	Percentage of Area
Office	70 %
Corridor	10 %
Lobby	5 %
Restrooms	5 %
Conference Room	4 %
Mechanical Room	4 %
Copy Room	2 %

4.3.1.7 Infiltration

Seeing that the building is not fully closed the infiltration for the Energy analysis had to be defined. In [P Tamara, Shaw, p125-143, 1976] the infiltration of various U.S. office buildings have been tested and ranged from 0.213 to 1.028 cfm/ft^2 (0.0649 m^3/m^2min to 0.313 m^3/m^2min) at 0.3 inch (0.76 cm) of water. It is also said in the same study, which is referenced by in [P ASHRAE Handbook, chapter 16 p25, 2009], that typical air leakage varies between 0.1, 0.3 and 0.6 cfm/ft^2 (0.03, 0.091 and 0.183 m^3/m^2min) for tight, average and leaky walls. Since the building is open right now a rather leaky value of 1.028 cfm/ft^2 (0.313 m^3/m^2min) has been set as the infiltration at 0.3 inch (0.76 cm) of water for the energy analysis.

The following Equation 2 shows the calculation from the tested infiltration at 0.3 inch (0.76 cm) of water/n-75 value [P Persily et al, p125, 1985], to natural ventilation for eQuest.

Equation 2: Energy Analysis, calculation of natural ventilation [P Pacific Northwest, p12, 2009],

$$I_{nat} = (\alpha + 1) I_{75} \left(\frac{U_H \rho \, C_S 0.5}{75} \right)^n$$

I_{nat} natural ventilation

U_H wind speed at building height

α wind profile

I_{75} infiltration value at n75 or 0.3 inch of water

ρ density

C_S calculated average surface pressure coefficient

n flow exponent

The values for n, C_S, ρ have been defined in [P Pacific Northwest, p12, 2009]. 0.28 has been chosen for α, like described in [P Reichl et al, 2004, p4] fitting to the surrounding area. This results in a natural ventilation of 0.1209 cfm/ft^2 (0.0369 m³/m²min), as shown in Equation 3.

Equation 3: Energy Analysis, calculation of natural ventilation, [P Reichl et al, 2004, p4], [P Pacific Northwest, p12, 2009], [P Persily et al, p125, 1985],

$$I_{nat} = (0.28 + 1)1.028\frac{cfm}{ft^2}(\frac{4.47\frac{m}{s}1.18\frac{kg}{m^3}0.1617 * 0.5}{75})^{0.65}$$

The influence of wind altering the natural ventilation has been neglected due to missing wind data on site.

4.3.1.8 HVAC

The overall HVAC unit has been broken down to 7 subsystems. Allthough only one HVAC system will supply fresh air into the buildings with several sub zones, more HVAC units have been used in this simulation in order to get the exact energy consumption and peak load amounts per each zone.

The following Table 11 shows the HVAC systems and their assigned thermal zones.

Table 11: Energy Analysis, HVAC systems and assigned Zones

HVAC System	Zone
System 1	Tower 1st floor
System 2	Tower 2nd floor
System 3	Engine Room
	Engine Room Under Roof
System 3	Engine Room Top
	Engine Room Top Under Roof
System 4	Boiler Room
	Boiler Room Under Roof
System 4	Boiler Room Top
	Boiler Room Top Under Roof
System 5	Tower 3rd floor

Further an air cooled condenser has been used for cooling and a natural gas furnace for space heating. The air conditioning system is illustrated in Figure 42.

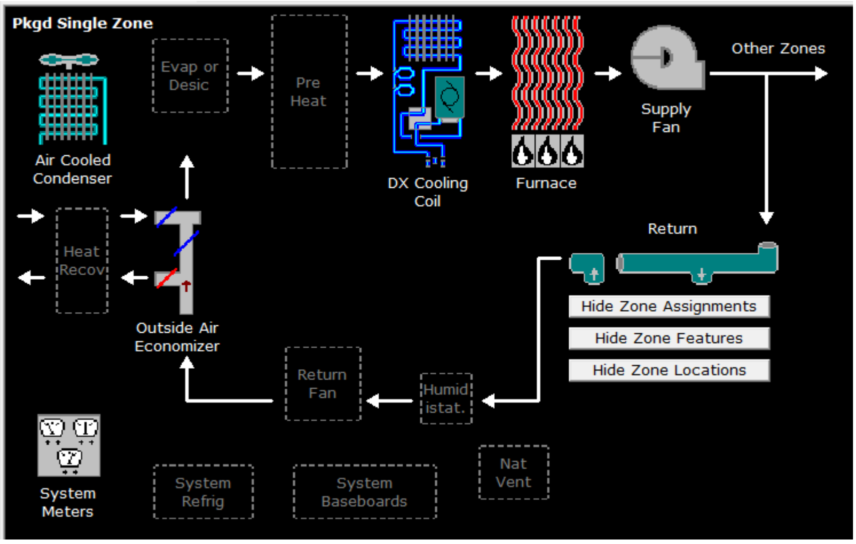


Figure 42: Energy Analysis, air conditioning, depicted in [SW eQuest, 2014]

4.3.2 Simulation Results

Figure 43 gives an overview over the annual energy consumption for electricity and natural gas. Thereby 271 MWh electricity and 655 MMBTU (192.25 MWh) would be consumed.

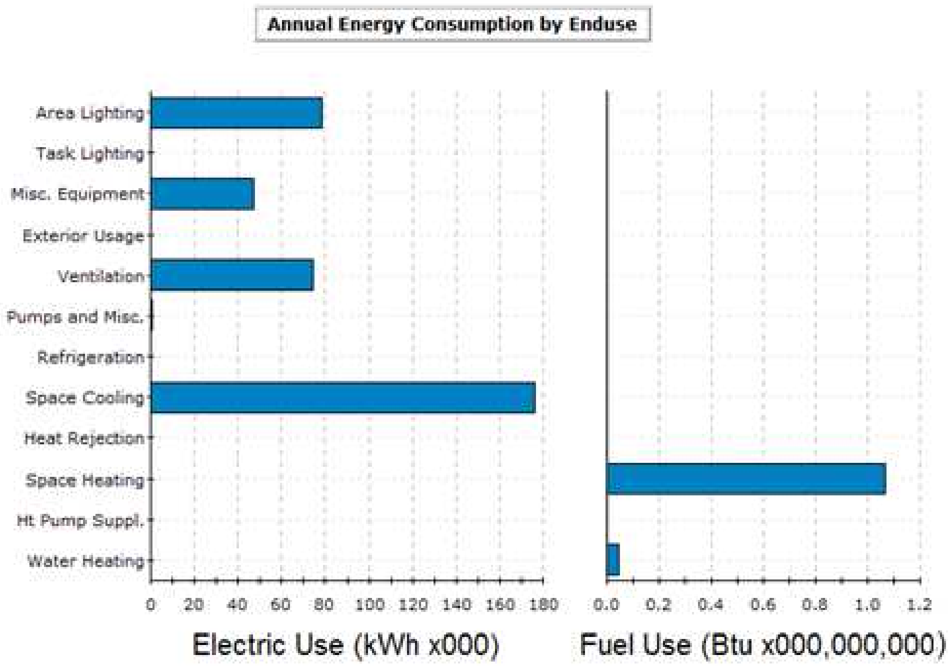


Figure 43: Energy Analysis, simulation result, annual energy consumption by enduse

Thereby 110.8 MWh electricity are consumed for space cooling and 612 MMBTU (179.58 MWh) natural gas are required for space heating in one year. In other words 47 % of the electricity consumption is used for space cooling and 20 % for ventilation, which is illustrated by the following pie charts in Figure 44. The natural gas demand for space heating is 60 % higher than the electricity demand for cooling. Thus the energy efficiency measures will first focus on reducing space heating, space cooling, area lighting in this order.

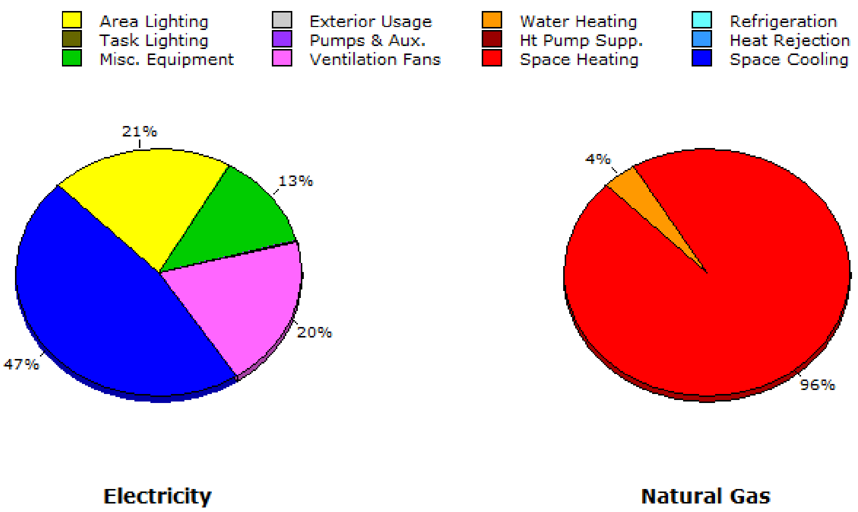


Figure 44: Energy Analysis, simulation result, energy consumption in sectors

The following Figure 45 shows the monthly distribution of the energy demand, followed by the monthly distribution of the peak load Figure 46.

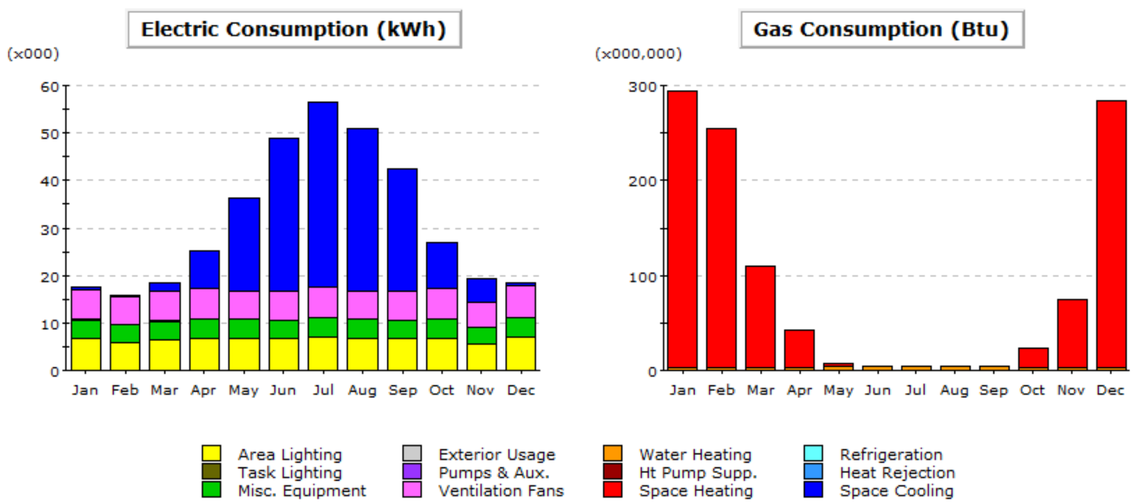


Figure 45: Energy Analysis, simulation result, electricity and gas consumption

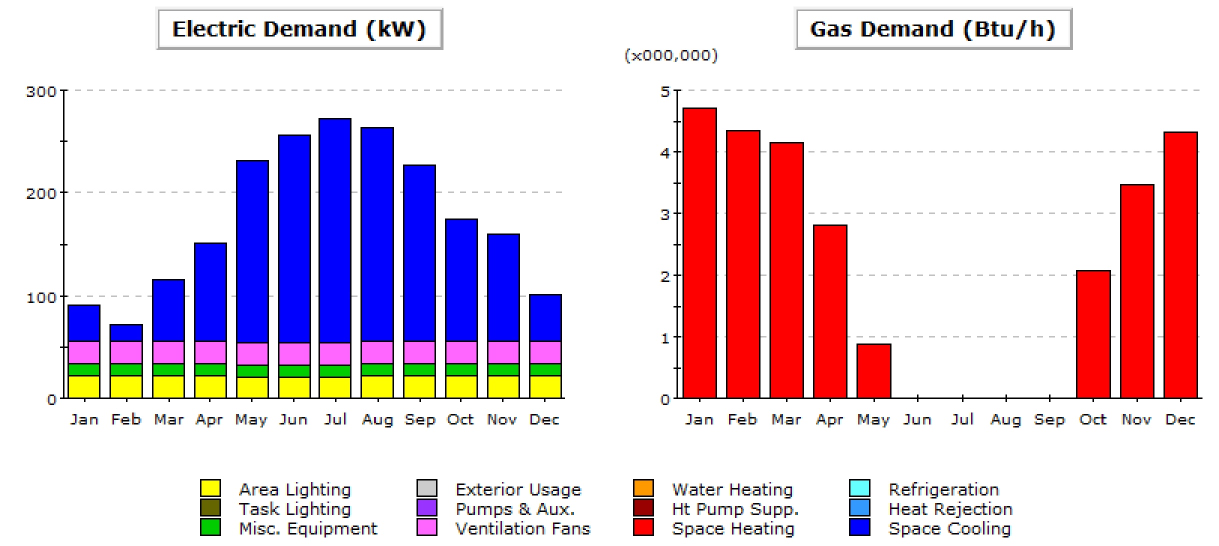


Figure 46: Energy Analysis, simulation result, electricity and gas peak demand

Since the electricity input in eQuest did not take the peak demand into account as the peak load of the city and its price influences are unknown, the peak load has no impact on the utility cost estimation of eQuest. In reality though, this will have an impact on the utility costs and therefore has been tried to reduce as much as possible while going through energy efficiency enhancing measures.

Due to the fact that this simulation has been taken as a reference for simulating energy efficiency enhancing measures the key results are shown in the following Table 12.

Table 12: energy analysis, key results

	Imperial units		SI units	
electricity				
electricity demand total	271360			
electricity demand per sqft	14,043277	kWh/ft²	151,1606	kWh/m²
cooling demand total	110810	kWh		
cooling demand per sqft	5,7345797	kWh/ft²	**61,72653**	**kWh/m²**
natural gas				
natural gas demand total	655990000	BTU	192251,7	kWh
natural gas space heating	612740000	BTU	179576,4	kWh
space heating demand per sqft	19323,125	BTU/ft²	**100,0327**	**kWh/m²**
domestic hot water demand per occupant	188043,48	BTU/pers	55,1101	kWh/pers

annual utility costs	**Imperial units**		**SI units**	
electricity	38000	$		
natural gas	6030	$		
electricity per sqft	**1,97**	**$/ft²**	21,17	$/m²
natural gas per sqft	**0,31**	**$/ft²**	3,36	$/m³
HVAC system				
space cooling load	**115,29**	**kW**		
space heating load	2163700	BTU/h	**634,1179**	**kW**

Thereby it has to be mentioned that all data given per person are not informative, since the number of persons has been estimated by eQuest related to the purpose of the area.

4.4 Simulation of energy efficiency measures

In this chapter various energy efficiency enhancing measures have been simulated in order to get the efficiency enhancing measures with the least economical effort and easy to accomplish. Due to historic features of the building, to which [P Felder & Associates, 2014] already addressed in depth, measures such as insulation on exterior walls, outside blinds and changing window areas have not been tested although they are highly recommended for other municipal buildings with non-historic appearance.

Further it has to be mentioned that the reference area for all the following simulations remains the gross floor area, outlined in 4.3.1.4 Gross Floor Area, since the floor design has been dependent on the following simulations and because the values needed to be comparable and therefore having the same reference data . For the simple reason that no existing utility data could be used for energy analysis and plenty assumptions have been made, most of the results are shown in percentage of consumption compared to the outcomes presented in 4.3.2 Simulation Results.

Nevertheless, insulating measures have been tested for their effects on energy demand, peak load and utility costs. Afterwards one insulated example has been picked out and tested for further efficiency enhancing opportunities in the fields HVAC, daylighting, lighting systems and energy supply.

4.4.1 Openings

4.4.1.1 Inputs

The openings such as the chimney and ventilators have been closed in order to get the u-value of the wall. Thereby a u-value for the openings of 0.192 Btu/h-°F-ft² (1.09 W/m²K) has been achieved in order to match the thermal resistance of the engine room wall. The following Figure 47 illustrates the simulated structure. In doing so, no moisture issues occur in both, summer and winter case.

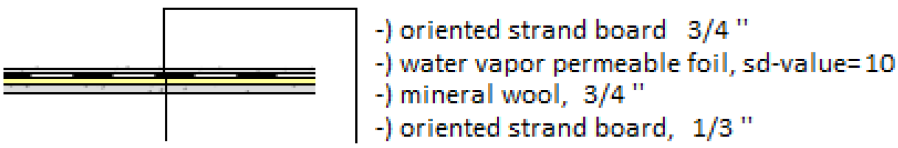


Figure 47: Openings, structure input

Furthermore all former windows in the original design, which have been altered and closed, are restored in this simulation, with similar windows as described in 4.3.1.5 Building structure.

4.4.1.2 Results

The overall energy demand is decreased by 0.61 %. Although insulating of the openings decreases the heating and cooling demand, the single pane windows lead to a rise in demand, which results in the small difference. Since the influence of this simulation is rather small it is included in all further energy efficiency enhancing measures.

4.4.2 Windows

4.4.2.1 Inputs

The windows have been specified via the 'Glass-Type'- Method which refers to the eQuest library and is used to have a shading coefficient approach [P Hirsch, p 97, 2009]. As for the frame, a thickness of 0.11 ft has been assumed for all following windows.

Window B

Window B is a double pane window compared to window A, which has a u-value of 0.26 BTU/h-ft^2-°F (1.476 W/m^{2}K) without frame, a solar heat gain coefficient of 0.59 and is referred to as 'window 2632' in eQuest. With these values it serves energy conservation code due to u-value but not due to solar heat gain coefficient, in climate zone 2. Although code requirements, concerning the solar heat gain coefficients, are not met while using this window, the importance of it in climate zone 2 can be shown.

The frames have been simulated as made of metal with non- insulated spacers in order to outline the impact of the frame, while comparing the outcomes of window B and window C.

Window C

Except for the frame window C has the same characteristics as window B, which is a double pane window compared to window A, having a u-value of 0.26 BTU/h-ft^2-°F (1.476 W/m^{2}K) without frame, a solar heat gain coefficient of 0.59 and is referred to as 'Window 2632' in eQuest. With these values it serves energy conservation code due to u-value but not due to solar heat gain coefficient, in climate zone 2. Although code requirements, concerning the solar heat gain coefficients, are not met while using this window, the importance of it in climate zone 2 can be shown. Compared to window B, window C has a non-metal frame with insulated spacers.

Window D

Window D is a double pane window, like window B and C, but specified as reflective glazing, having a u-value of 0.38 BTU/h-ft^2-°F (1.258 W/m²K) without frame, a solar heat gain coefficient of 0.17 and is referred to as 'Window 2405' in eQuest. Further a nonmetal framing and insulated spacers have been assumed. With all this, window D meets energy code requirements.

Window E

As described in 4.1 Building Description, the building does not have to meet energy code requirements if listed as a historic landmark. In considerations of historic preservation Window E is a double pane window, being as thin as a single pane glazing in order to meet the optics of the original window [P Pilkington, p 3, 2011].

The 'Pilkington Spacia Cool' thereby has a u-value of 0.18 BTU/h-ft^2-°F (1.022 W/m²K) and a solar heat gain coefficient of 0.49, without the frame [O Lanier, 27th May, 2014]. For the reason that this window has not been available in the library, a window with a u-value of 0.17 BTU/h-ft^2-°F (0.965 W/m²K) without frame and a solar heat gain coefficient of 0.47 has been chosen, which is referred to as 'Window 3622'

4.4.2.2 Results

Figure 48 depicts the energy demand in percentage of each simulated window compared to the energy demand of a single pain window.

Window B as a double pane window with non- insulated spacer shows a significant reduction, especially regarding natural gas demand. Since it does not meet the solar heat gain coefficient requirements of energy conservation code the energy demand potential is not fully exploit. Window C, having the same parameter as Window B, shows major enhancement in natural gas and space heating demand, although only the spacers are insulated and non-metal. Even though the measure is not very costly, it did improve the natural gas demand by 1.18 percentage points and the space heating demand by 1.33 percentage points.

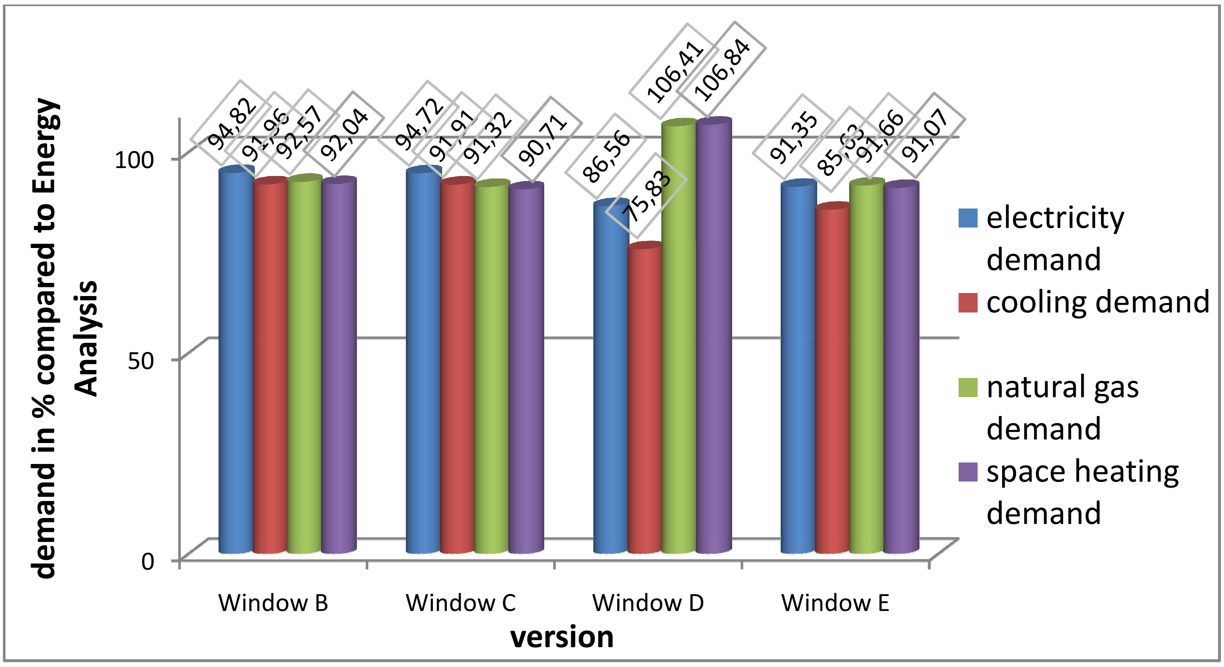


Figure 48: Windows, Energy Demand Reduction

Window D possesses a much lower solar heat gain coefficient and higher u-value compared to Window B and C, which reduces the solar heat gain in the heating period and increases the heating and natural gas demand over 6 percentage points compared to a single pane window. Window E shows best results while looking at the energy demand improvements. It reduces the cooling demand from 5.73 kWh/sqft (61.71 kWh/m²) in the Energy Analysis by about 14 percentage points to 4.91 KWh/sqft (52.86 KWh/m²) and the natural gas demand by over 8 percentage points as well.

Figure 49 depicts the peak load reduction of the simulated windows.

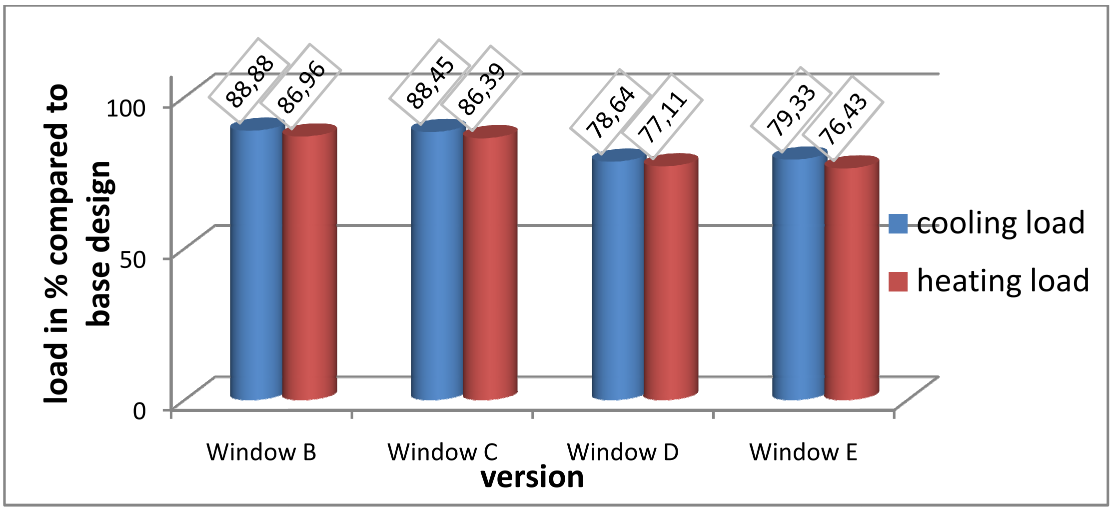


Figure 49: Windows, Peak Load Reduction

Not only does a reduction of peak load reduce the costs of investment since smaller HVAC system can be installed, it also does reduce the utility costs, as it has already been described in 3.6 Energy supply. Therefore the peak load is a key figure while looking for energy efficiency enhancing possibilities. Especially, as it can be observed from Figure 49, windows show a lot of potential for a peak load reduction. Also Window E shows best results while reducing the peak load of both cooling and heating by 20 and 23 percentage points. Although Window D shows a similar peak load reduction the space heating demand is about 15 percentage points higher.

As previously mentioned in 3.6 Energy supply various billing options are available for calculating the peak load charge for either electricity or natural gas. Furthermore as shown in 4.3.1.2 Energy supply the charges for peak load have not been noted in the billing. For this reasons the share of the peak load charge has been neglected during simulations. This has to be kept in mind while looking at the utility cost results in Figure 50 below. For example window D and E did produce much lower peak loads than Windows B and C. Thus, the real utility costs of Window D and E will be much lower than simulation results show.

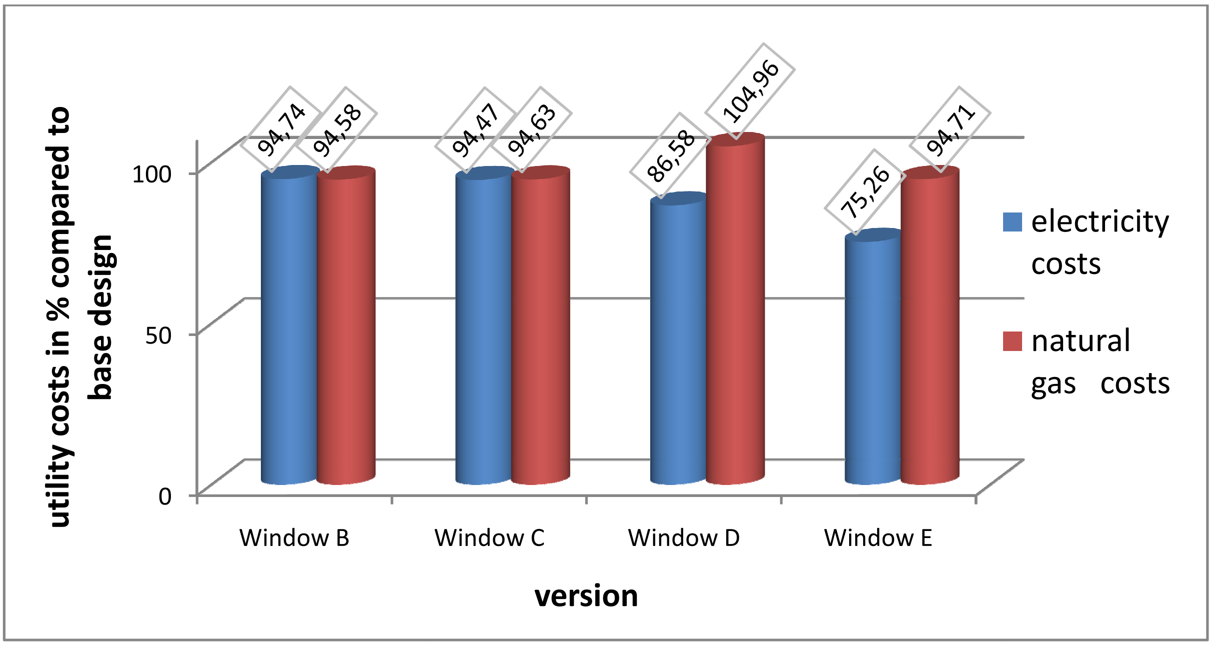


Figure 50: windows, utility costs reduction

Due to assumptions while simulating in eQuest, the utility costs are mainly related to energy demand except for reduced lighting costs. Window A as a single pane window with metal frame did have 1.97 \$/ft² (21.17 \$/m²) costs for electricity and 0.31 \$/ft² (3.36 \$/m³) costs for natural gas. Window E or 'Pilkington Spacia Cool', which is the window best fitting regarding historic preservation, on the other hand shows 1.8 $/ft² (19.39 $/m²) for electricity and 0.29 $/ft² (3.09 $/m³) for natural gas, with all the assumptions being 9719 $ of savings in total per year. Since a lot of assumptions have been made, the result in percentage of costs or demand is still more conclusive. Furthermore it has to be mentioned that the savings still would be enhanced due to peak load reduction, since much smaller equipment is necessary and annual utility costs would be way smaller in reality.

Figure 51 shows a summary of the results displayed already above. Thereby an average reduction has been calculated for all three categories.

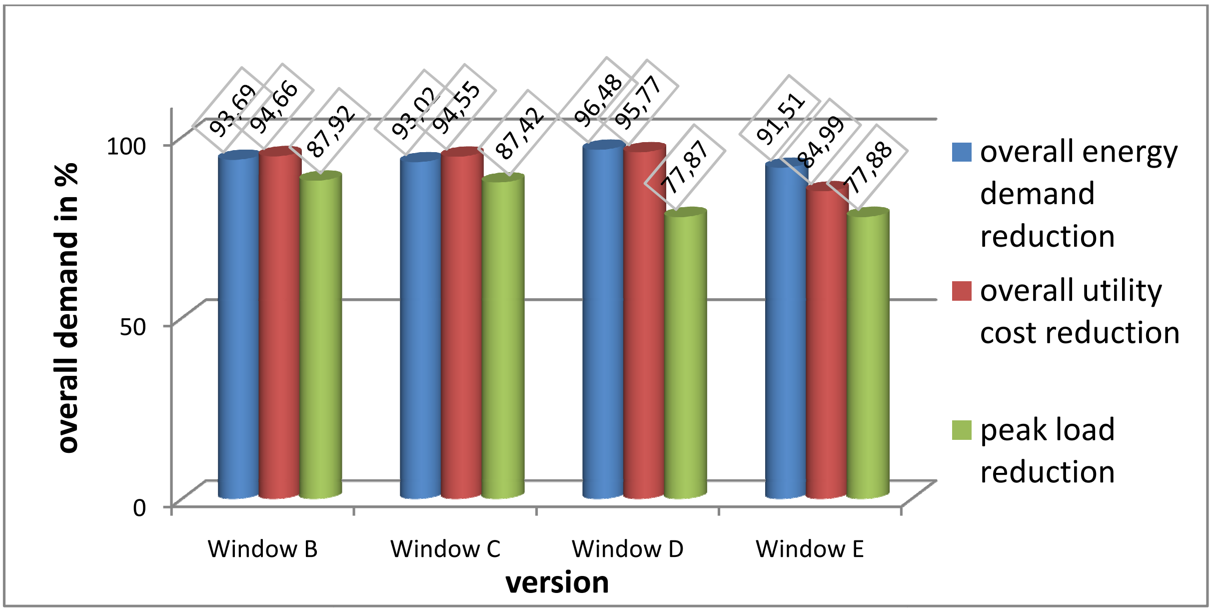


Figure 51: Windows, overall percentage of demand

Window D did serve the energy code requirements, with a u-value of 0.38 BTU/h-ft^2-°F (1.258 W/m²K) without frame and a solar heat gain coefficient of 0.17. In order to get such a low value for the solar heat gain, the glass is tinted slightly. Further the results showed higher natural gas costs though. A solar heat gain coefficient of 0.25 or lower is necessary to meet code requirements. Thus, it can be seen that especially in this climate a balance has to be achieved between solar heat gain coefficients an u-values, while choosing windows in order to reduce energy demand notably.

4.4.3 Floor

4.4.3.1 Inputs

While improving the floor, two varieties have been simulated, which are described in the following subchapters.

Floor B

Floor B meets the thermal resistance requirements of energy code with a u-value of 0.069 Btu/h-ft²-°F (0.392 W/m²K) and is shown in Figure 52. Regarding moisture and condensate, a foil with a water vapor diffusion resistance factor of 10^5 has been implemented as well as an extruded polystyrene board possessing low water vapor permeability

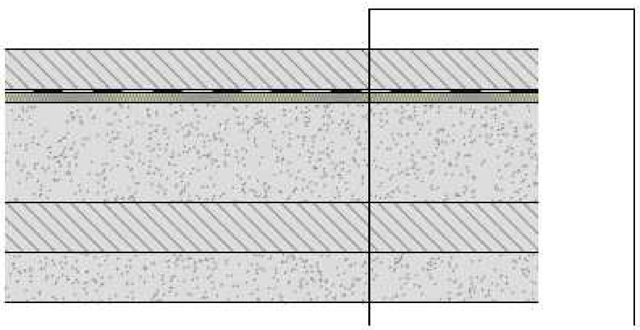


Figure 52: Floor B input

As the same issues occurred while simulating the floor as in the energy analysis, which have been described in 4.3.1.5, the simulation input in eQuest differentiated. The existing floor structure had to be neglected since the overall floor structure would have been too dense or too thick. In order to meet a similar thermal resistance the insulation thickness has been increased to 0.25 ft (7.6 cm), which results in a simulated u-value of 0.069 Btu/h-ft²-°F (0.392 W/m²K). Although, the u-value of the simulation is correct to three decimal places the simulation result may vary compared to the proposed design concerning the heat phase shift of the floor.

Floor C

The following Figure 53 illustrates Floor C, which possesses double the insulation of floor B and a u-value of 0.042 Btu/h-ft²-°F (0.238 W/m²K).

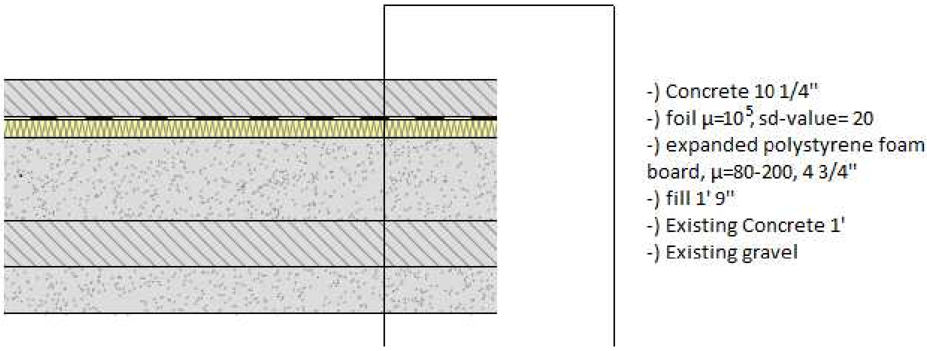


Figure 53: Floor C input

Thus the input of this simulation showed the same issues, as described above, the existing floor structure has been neglected and the insulation thickness has been increased to 0.45 ft (13.68 cm), which is why the same restrictions due to heat phase shift occur.

4.4.3.2 Results

Two adapted have been simulated for the floor construction. The results for the reduced demand are shown Figure 54. Floor B shows minor improvements compared to Floor A. However, due to condensate issues it is necessary to investing in insulating the floor while elevating the floor level. On the other hand Floor C shows a significant escalation of the cooling demand. The space heating demand and therefore the natural gas demand did decrease by over one percentage point, after adding 2 3/8 inch more of insulation.

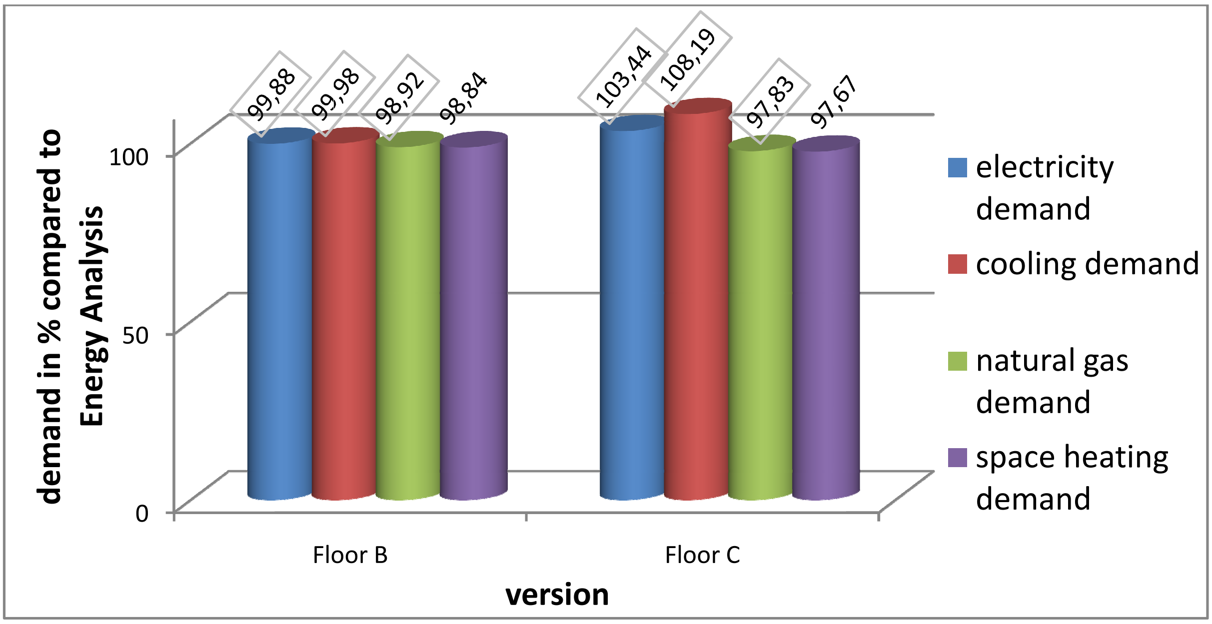


Figure 54: Floor, Energy demand reduction

One possible reason for this increase in demand could be that Floor A has a powerful storage mass due to its density, leading to an influence on the phase shift by adding insulation.

The following Figure 55 depicts the peak load reduction, which is hardly reduced in Floor B, due to minor insulation measures.

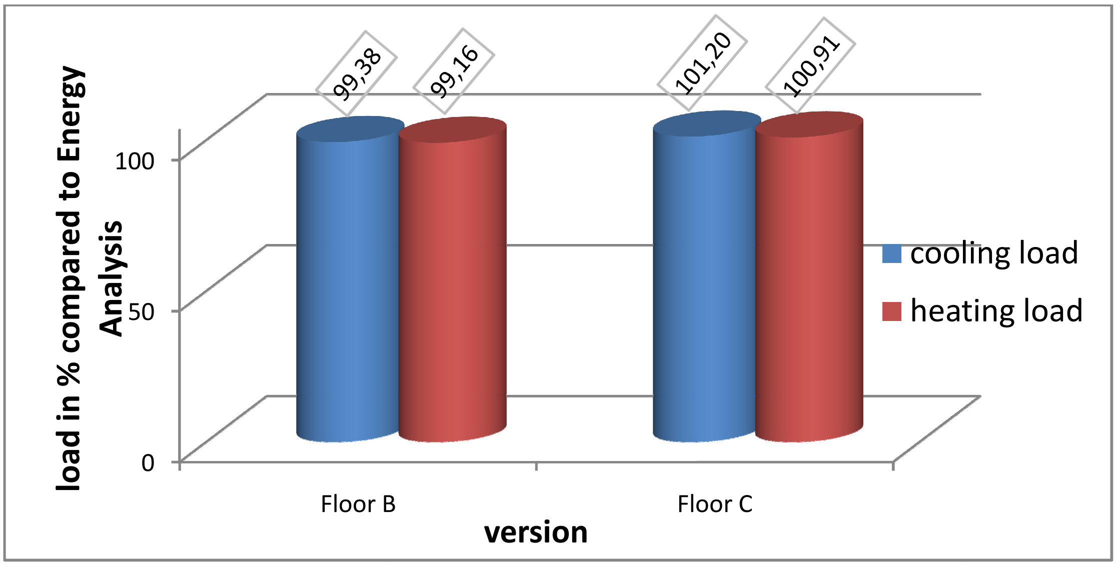


Figure 55: Floor, peak load reduction

Figure 56 illustrates the utility cost reduction for Floor B and C in comparison to Floor A. Withal, it has to be mentioned, that the reduction of peak load is not included which would lower the utility costs, as described in 4.4.2.2 Results.

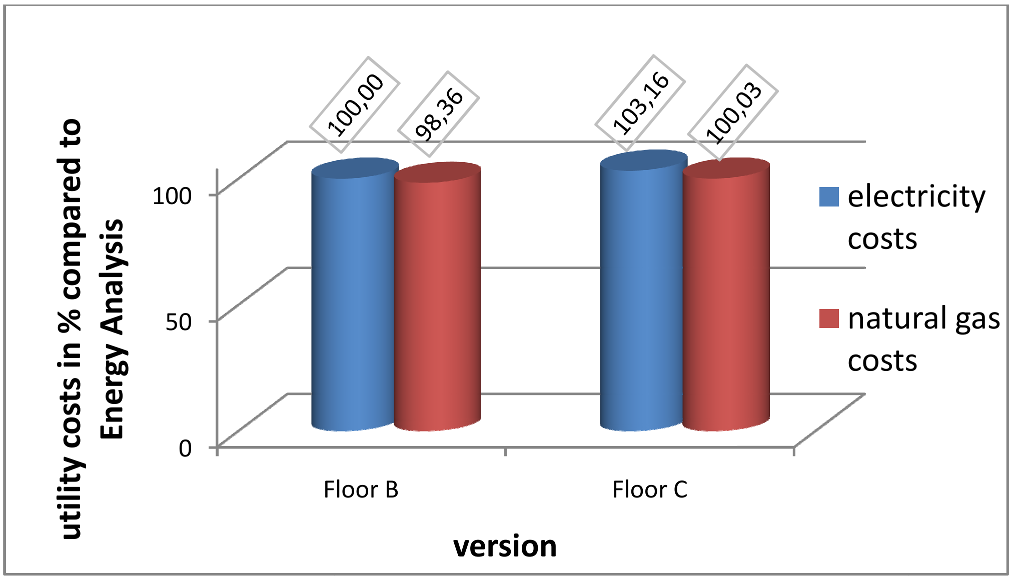


Figure 56: Floor, utility cost reduction

Figure 57 represents a summary of the above shown results for the floor simulations. Looking at the results Floor B will be recommended in the design proposal.

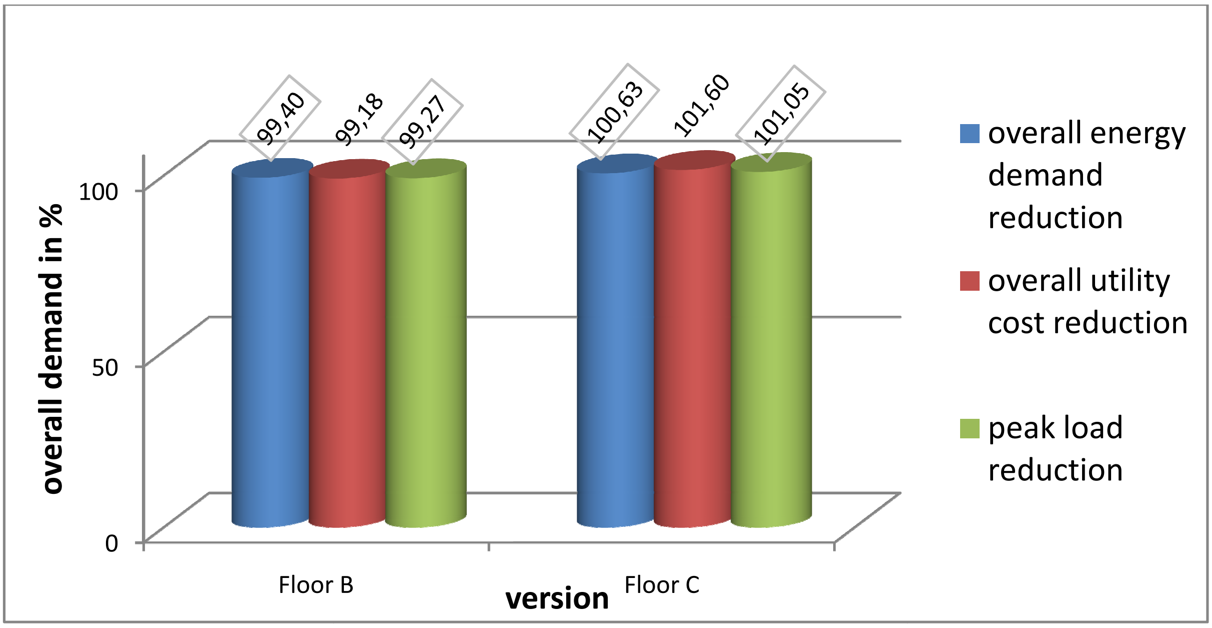


Figure 57: Floor overall demand reduction

4.4.4 Roof

4.4.4.1 Inputs

In this subchapter two roofs have been simulated with various coating on the metal sheet.

Roof B

The following Figure 58 depicts the roof structure for 3 various simulations in eQuest. Thereby a regular metal sheet has been applied in simulation 'Roof B' compared to 'Roof B CMR' and 'Roof B CMR & Coating'.

Furthermore it has to be noted that the roof structure displayed in Figure 58 is shown with the foil, which has been used for the thermal simulations in eQuest afterwards. Before the thermal evaluation, the roof structure has been examined regarding moisture and condensate issues.

The humidity has been checked rather by focusing on the summer case than on the winter case, since the calculation in [I U-value, 2014] assumes for the weather conditions to be applied for 60 days, which has been described in 4.3.1 Defined boundary conditions for energy model.

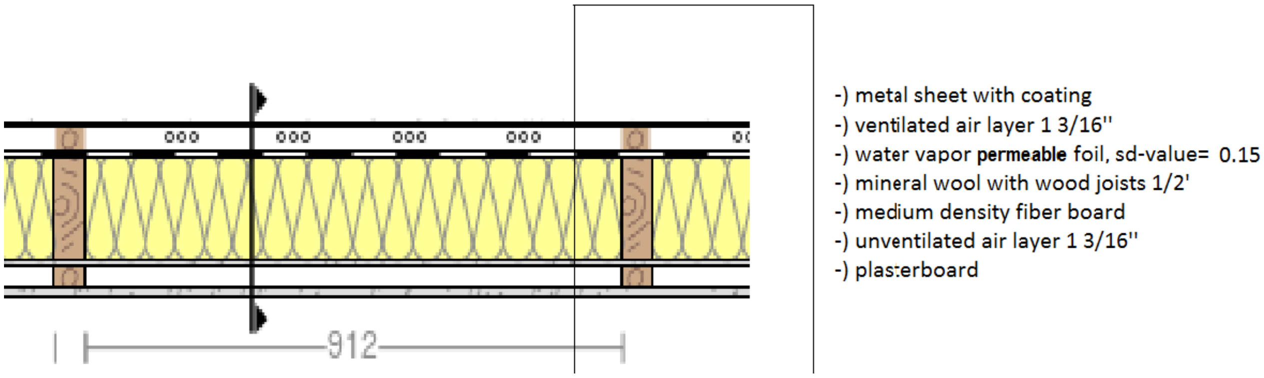


Figure 58: Roof B input, drawn in [I U-value, 2014]

The above figure shows the roof structure with the finalized foil, showing best results regarding humidity and condensate. Prior to that, several cases have been examined for both summer and winter. Regarding the results, the relative humidity of the roof structure is shown from the interior to the exterior, from left to right.

First of all Figure 59 below, illustrates the roof structure without any foil, hence it has been stated in 3.4 Buildings in hot and humid that the South Atlantic does not necessarily show need for such foils.

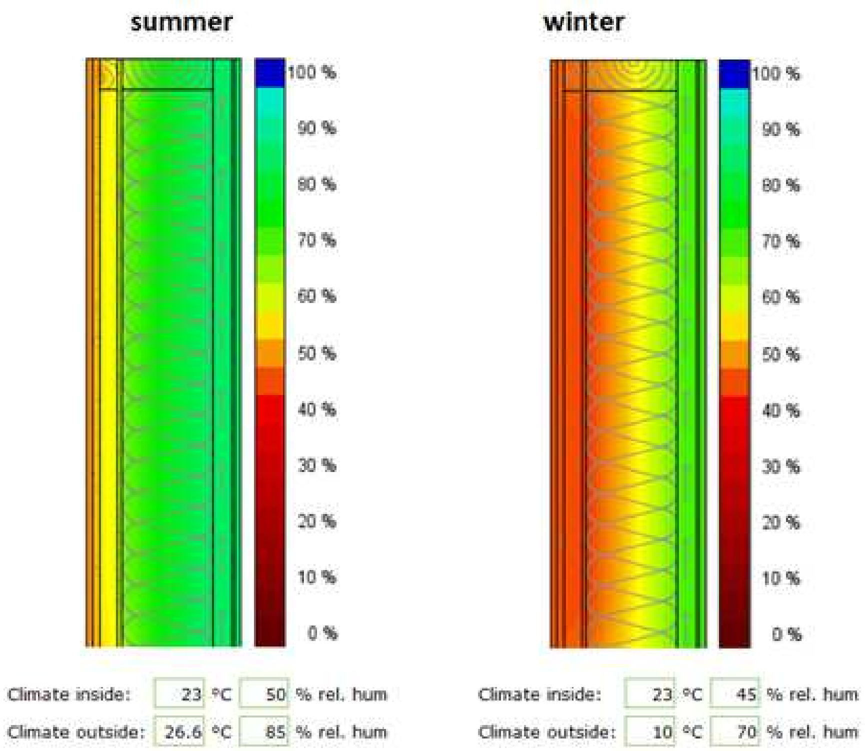


Figure 59: Roof B, relative humidity in summer and winter, without foil, drawn in [I U-value, 2014]

Due to the ventilated layer on the exterior, the relative humidity in the exterior air layer is always the same as outside. Although the results for 'Roof B' without foil do not show moisture, condensate or mold issues, it has been tried to lower the relative humidity inside of the roof structure in order to enhance enduring durability. Therefore four different variants have been calculated.

The first one is shown in Figure 60, involving a vapor barrier on the interior with an sd-value of 10 and a water vapor permeable foil on the exterior with a sd- value of 15. For winter conditions this roof construction shows very good results, much better than the results shown in Figure 59. During summer time though, condensate appears in the insulation layer due to the vapor barrier. Although this result could be slightly changing, when capillary conductance is considered in the calculation, it is advised not to foils with a high water vapor diffusion equivalent air layer thickness (sd- value) on the interior.

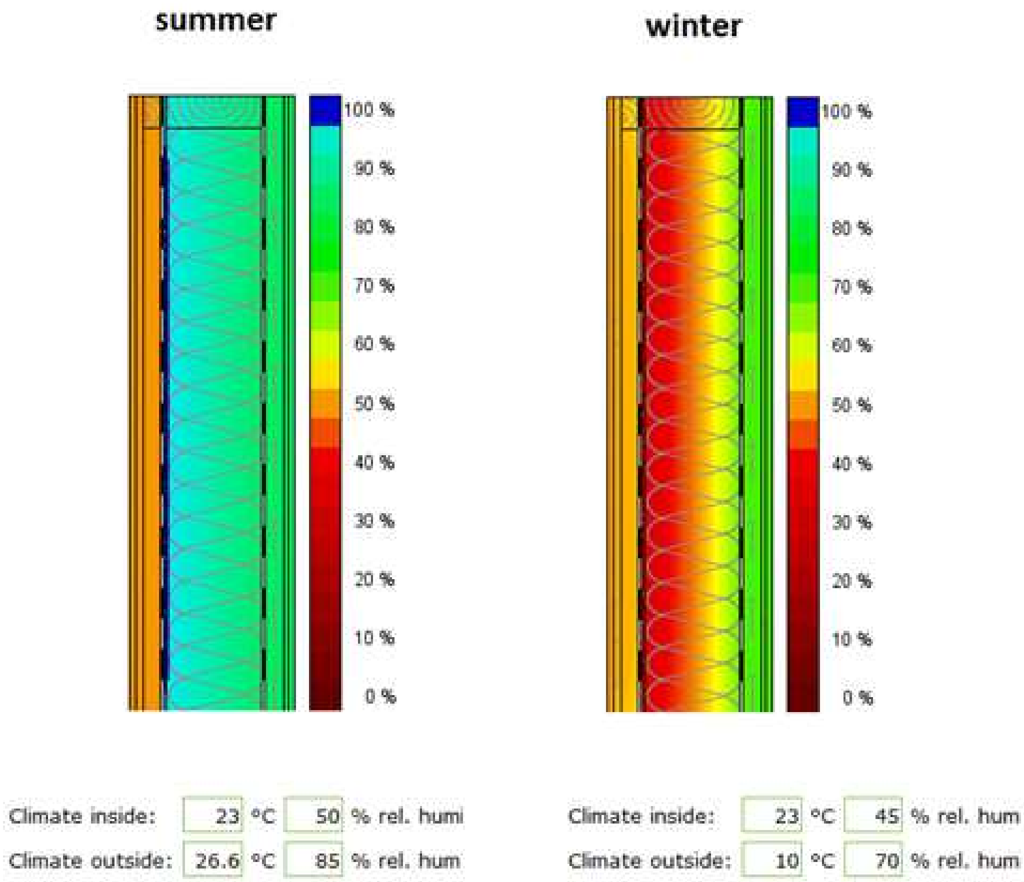


Figure 60: Roof B, relative humidity in summer and winter, with vapor barrier, drawn in [I U-value, 2014]

Secondly it has been tried to use a moisture variable vapor check on the exterior of the roof structure. The results are depicted in Figure 61 below. The results in summer are very good regarding relative humidity, especially in the insulating layer compared to the initial roof structure shown in Figure 59. Thereby a maximum of 60 % relative humidity is reached within the mineral wool.

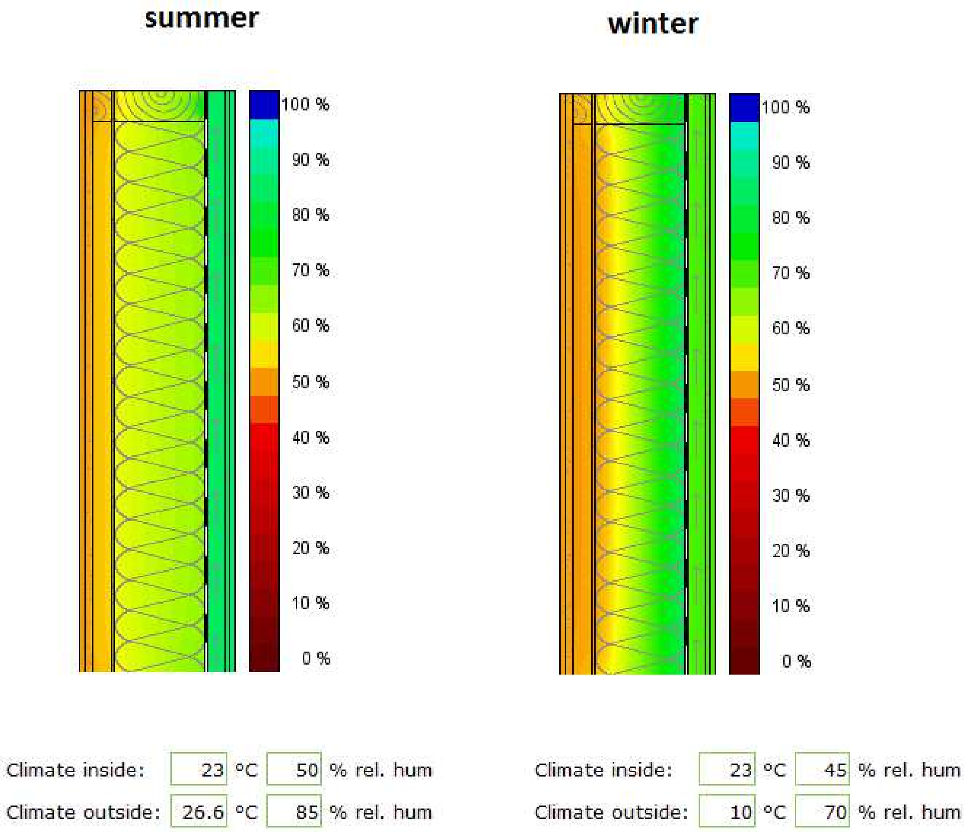


Figure 61: Roof B, relative humidity in summer and winter, with moisture variable vapor check, drawn in [I U-value, 2014]

Furthermore it can be observed in the above figure, that high relative humidity appears close to the foil, while applying winter conditions. Hence capillary conductivity has been neglected during calculations the real results might me much better.

The diffusion open structure with a water vapor permeable foil on the exterior which has a sd- value of 0.15 provides the best moisture conditions ([I Building Science A, 2014] [I Building Science B, 2014]) and no condensate appears during constant conditions. Furthermore it has been calculated that even if the humidity inside where 65 % in summer case, no mold grow is expected if these conditions are applied 60 days in a row. Figure 62 below depicts the relative humidity in both, summer and winter, for roof B. The layer with the highest relative humidity in summer is the ventilated air layer, which is helping to carry the moisture away.

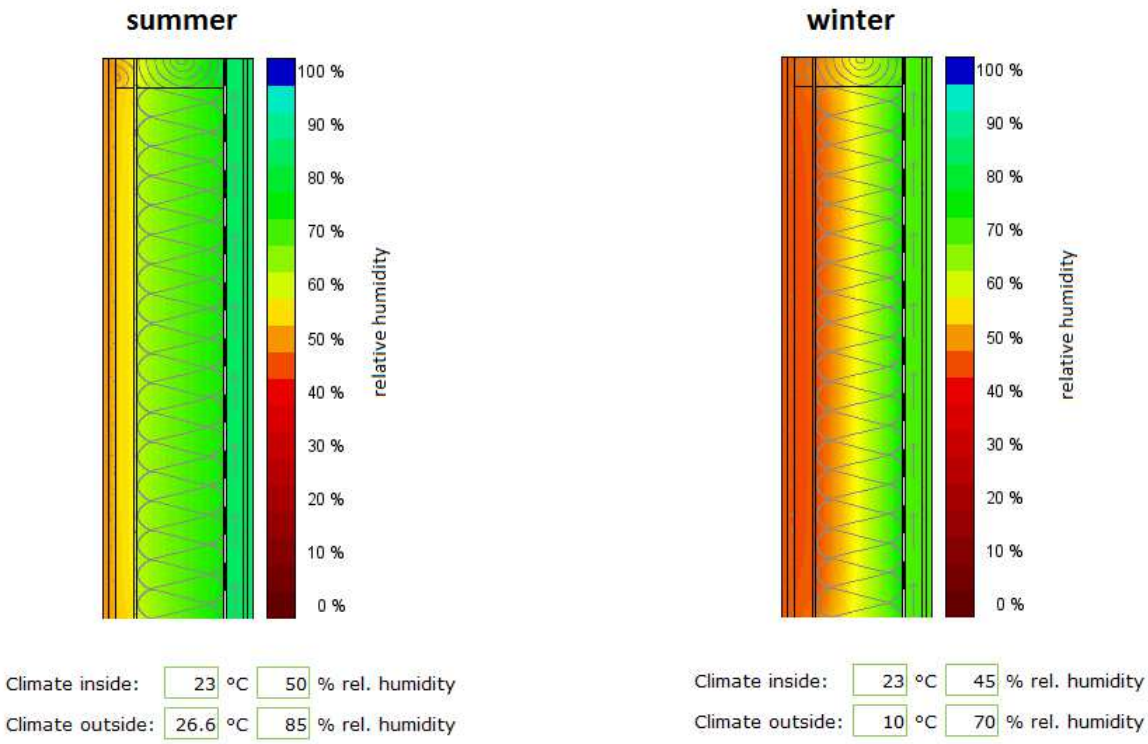


Figure 62: Roof B, relative humidity in summer and winter, with water vapor permeable foil and an sd-value of 0.15, [I U-value, 2014]

Although it can be seen that the results for summer in Figure 62 are slightly worse than the results in Figure 61, the relative humidity in winter shows better outcomes. In the last example, where a moisture variable vapor check has been implemented, the relative humidity inside the insulation layer did exceed the maximum relative humidity applied on the exterior. The construction with a water vapor permeable foil as shown in Figure 62 does not show these conditions for summer and winter case. The 1/64 inch (0.3 mm) thick foil is diffusive open and shows a sd-value of 0.15. Especially during summer time the foil reduces the relative humidity going inside of the roof structure. Consequently the major amount of moisture is carried away in the ventilated air layer.

Regarding the simulation input in eQuest no more than the thermal envelope had to be considered. Since the 'ventilated air layer' is ventilated from behind it is considered outside concerning the thermal system boundary. Further the insulation had to be calculated as homogeneous, which results in a u- value of 0.044 BTU/h-ft"-°F (0.2498 W/m²K).

Roof B CMR

'Roof B CMR' uses 'cool metal roofing' with a solar reflectance of 0.67 and an emissivity of 0.87. Further it is 'Energy Star' certified and listed on [P energy star ,p 3 , 2013] as 'BRIGHT WHITE XW3G41832'.

Roof B CMR & Coating

'Roof B CMR & Coating' provides coating on top with a solar reflectance of 0.92 and an emissivity of 0.87. Further the coating is 'Energy Star' certified and listed on [P energy star, p 95 , 2013] as 'A590'.

Roof C

Figure 63 depicts the structure of 'Roof C' and 'Roof C CMR'. Thereby it possesses double the insulation of 'Roof B' and has a u-value of 0.023 BTU/h-ft"-°F (0.1306 W/m²K).

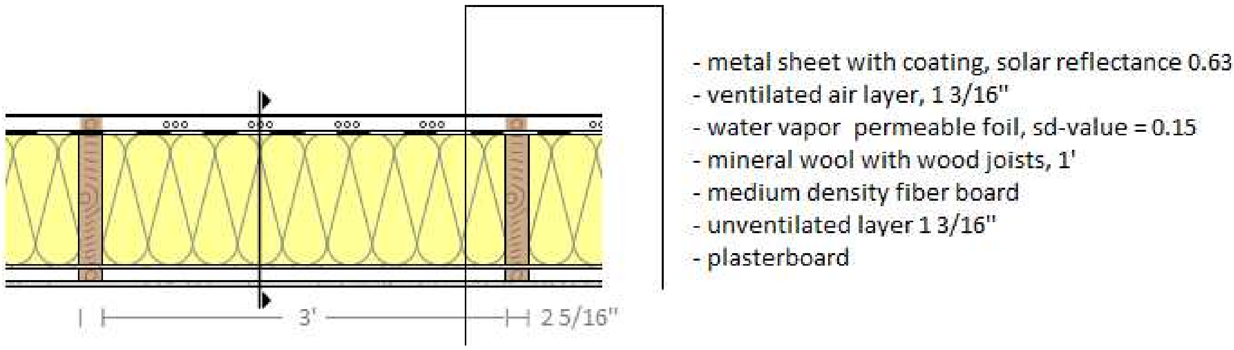


Figure 63: Roof C input

Despite the double amount of insulation, Roof C shows the same construction details as Roof B. Therefore the same water vapor permeable foil is advised for this construction, although it has to be mentioned that due to the thickness of the insulation layer, better results regarding relative humidity in the building element are shown.

Figure 64 below illustrates the relative humidity, without any foil for Roof C. Thereby it has to be noted that by implementing the water vapor permeable foil with an sd- value of 0.15 would enhance the condensate conditions, as described in the last chapter already.

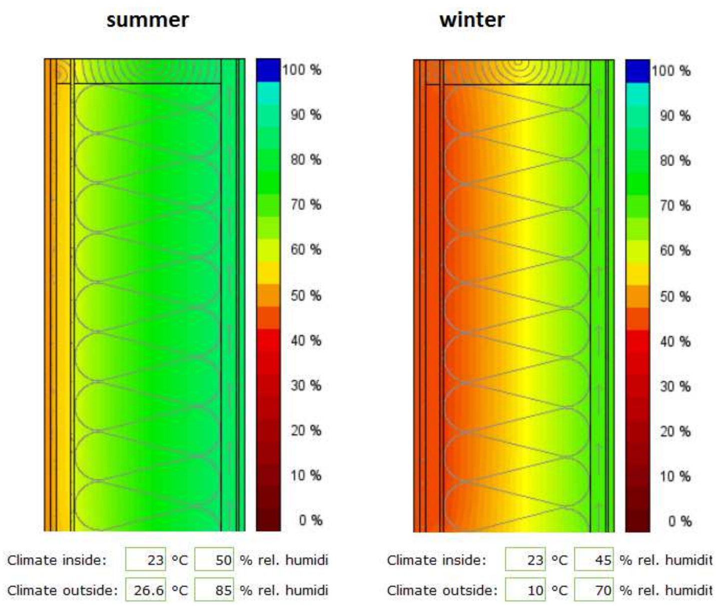


Figure 64: Roof B, relative humidity in summer and winter, without foil, drawn in [I U-value, 2014]

Roof C CMR

In this simulation Roof C has been simulated with the metal sheet described in 'Roof B CMR' above.

4.4.4.2 Results

Two different thicknesses of insulation have been simulated. Both of these variants have been calculated with various coating, as described above. The following Figure 65 depicts the energy demand in % compared to 'Energy Analysis'.

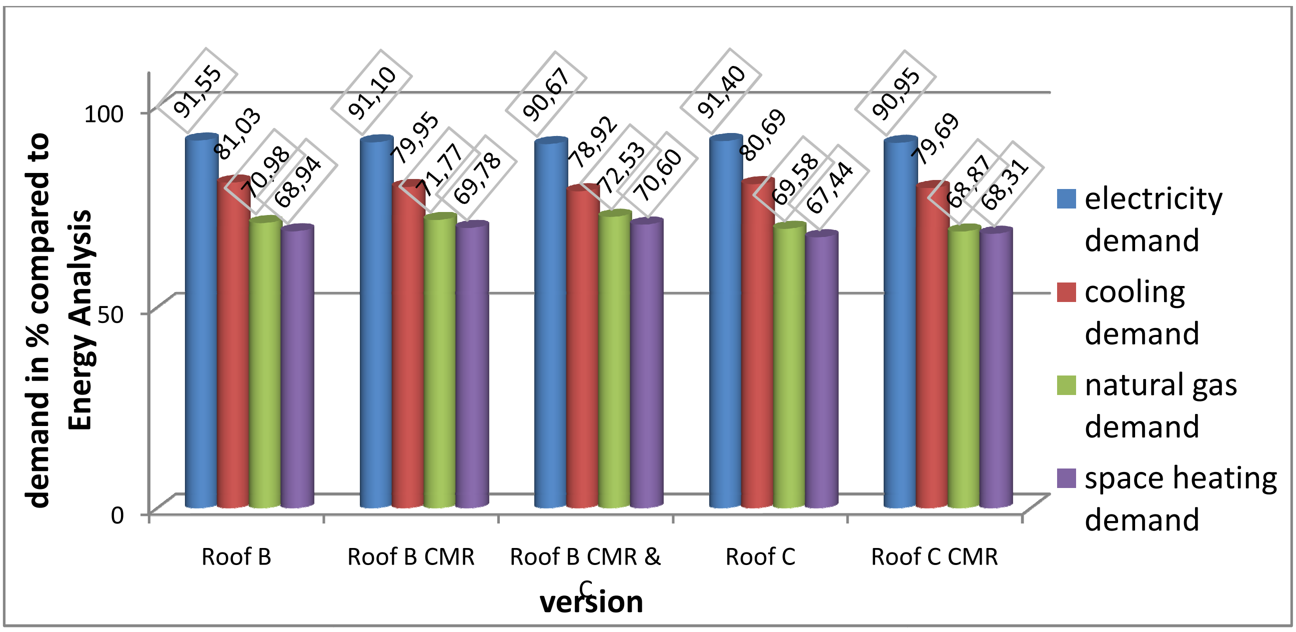


Figure 65: Roof, energy demand reduction

Roof B shows serious reduction in energy demand, especially regarding space heating. The main reason for this enormous reduction is Roof A itself. However, the space heating demand can be reduced by over 31 percentage points and the cooling demand by 19 percentage points with only 6 inch of insulation. Since the differences between Roof B with a 'Cool Metal Roofing' metal sheet and Roof B with further Coating on the metal sheet are very little, one can only make a statement when looking at the overall demand reduction graph.

Roof C however did reduce the space heating demand by further 2.34 percentage points. On the other hand the cooling demand did increase slightly. Hence, measure Roof C or Roof C CMR should only be implemented, when the internal loads are reduced and thus the cooling demand. Cutting down the internal loads could be realized by

- Implementing lighting system with low waste heat
- Implementing daylight sensors
- Reducing times where electronic devices are switched on
- or reducing waste heat of pipes by insulating.

Moreover improving tightness of the building would decrease the infiltration loss and thereby lessen an internal load. If the devices are of same size though, the internal heat would rise, as well as the cooling demand. Therefore when the tightness is improved during retrofitting it has to be made sure that the HVAC equipment is sized smaller, meaning it has to serve smaller heating loads and possesses reduced waste heat.

Figure 66 illustrates the utility cost reduction for all roof simulations. In the bar chart Roof C shows slightly lower utility costs compared to Roof B, although it has to be remarked, that the influence of peak load is missing in the utility cost observation.

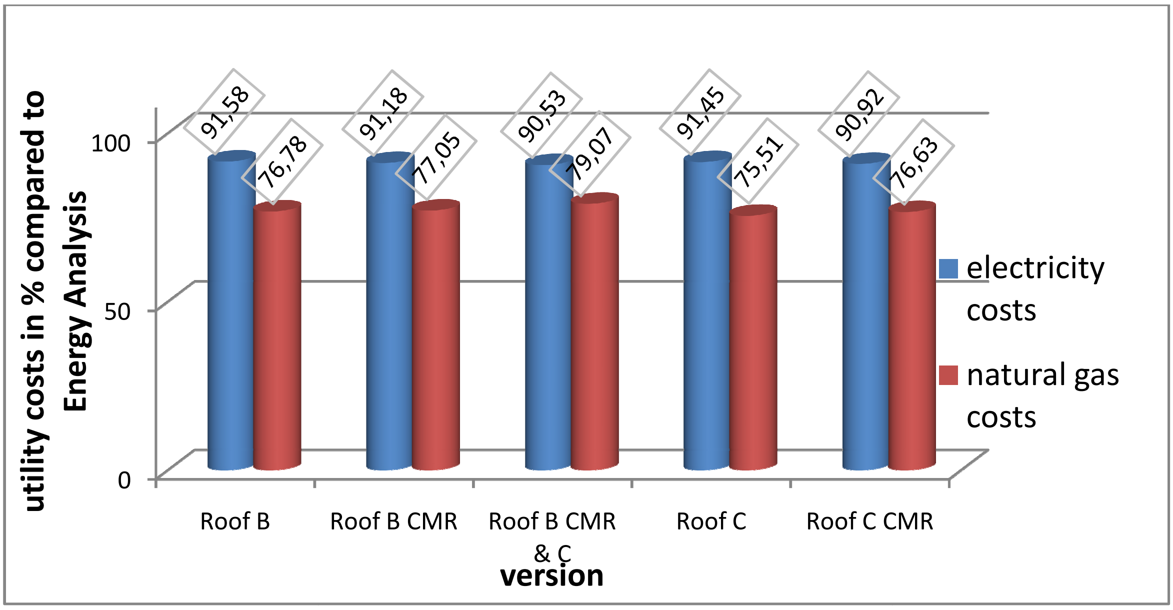


Figure 66: Roof, Utility cost reduction

The following Figure 67 shows the peak load reduction compared to Roof A of the Energy Analysis.

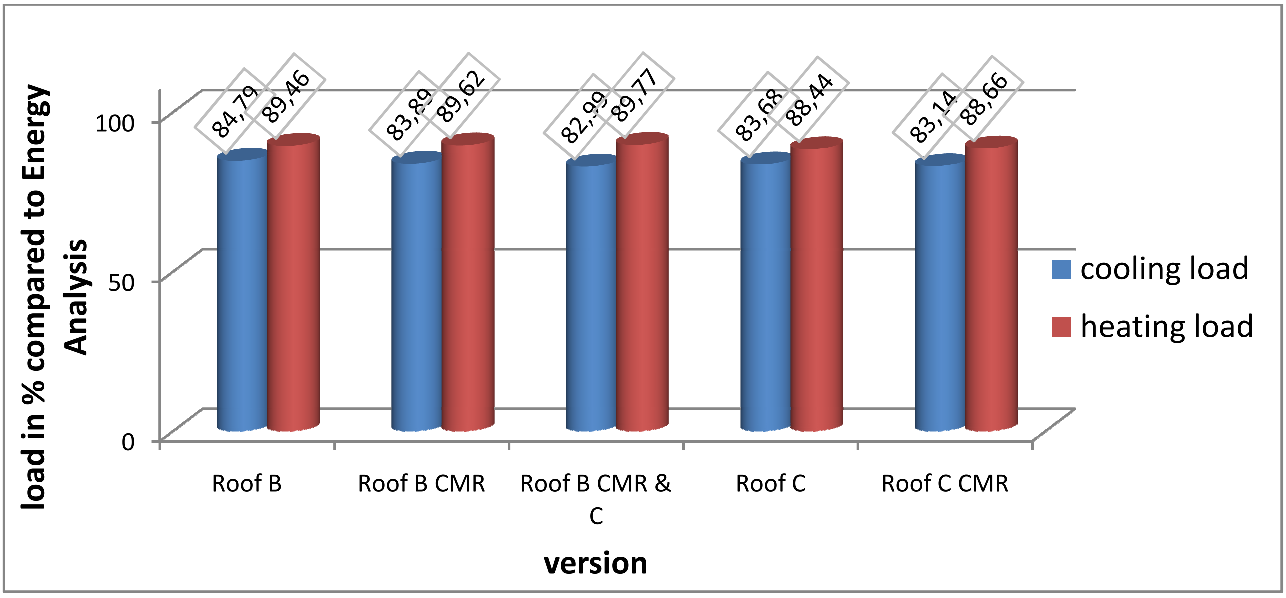


Figure 67: Roof, peak load reduction

Only slight difference in percentage can be observed regarding heating and cooling load, which is also shown in Figure 68 below, since an average value of reduction is shown in all three categories.

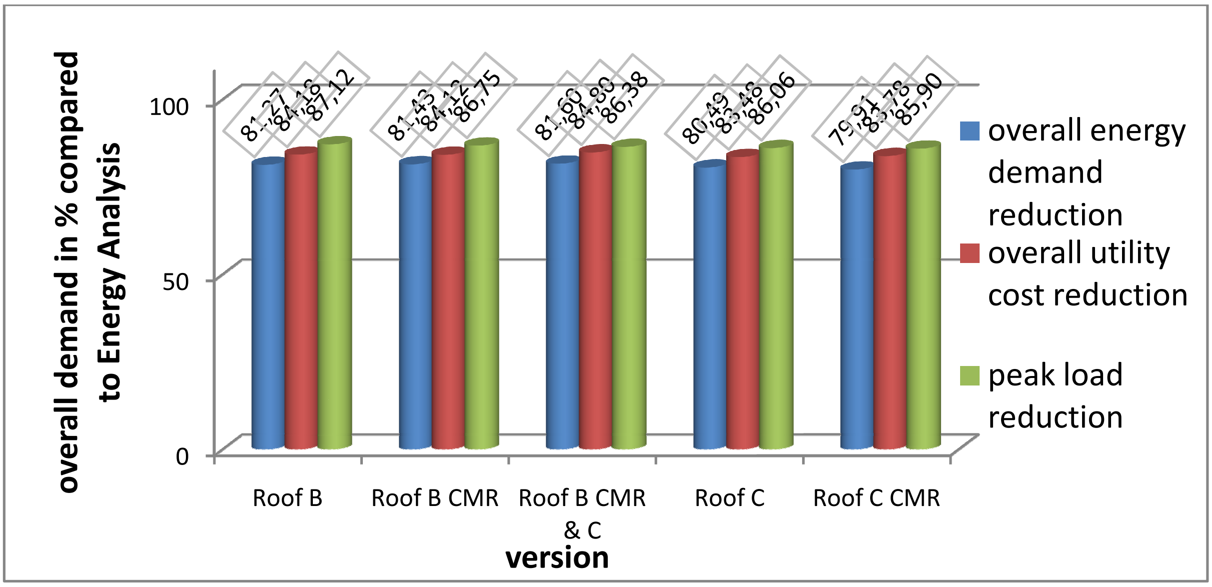


Figure 68: Roof, overall demand reduction

4.4.5 Daylight sensors

4.4.5.1 Inputs

In this simulation, daylight sensors have been implemented at the height of 2.5 feet (76 cm) above each room level and have been positioned in the middle of each room. This simulation does not necessarily refer to daylight sensors, rather than the energy reduction potential. There are various ways implementing this option in the final design, such as motion sensors on floors, infrared sensors in meeting rooms, user attention and daylight sensors as well.

Thereby software restrictions, due to the complex roof structure, aroused while making the connection between the top roof space and the main roof of boiler and engine room, which is shown in Figure 69. This leads to daylight sensors being implemented in every space except for the main roof of boiler and engine room; hence the actual energy demand reduction potential is higher than shown in the following chapter.

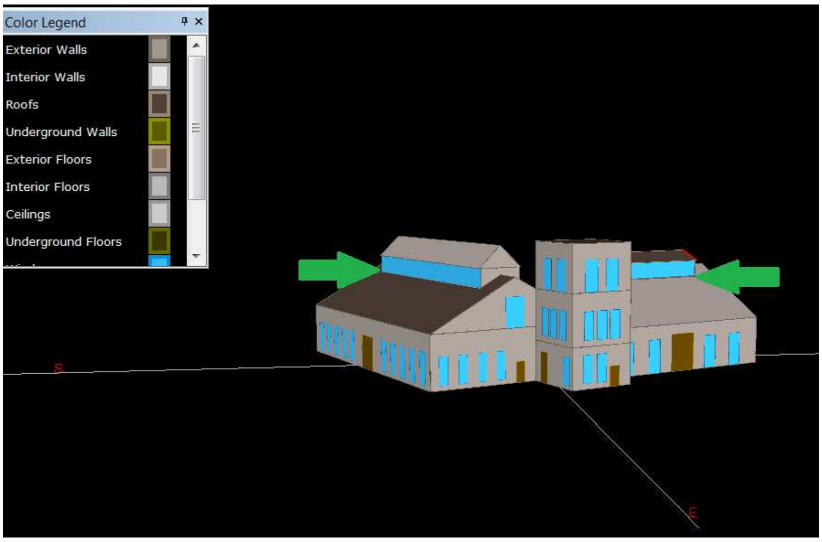


Figure 69: Daylight measure, restrictions

Making the connection between the rectangular shaped top roof space and the upper roof space of the top roof has been possible while implementing an external wall with a neglect able low u-value and inserting windows between those two spaces. Thereby a single glass layer has been used, which fits as an assumption regarding the glass area in the 3rd floor of the design, later on.

4.4.5.2 Results

This subchapter illustrates the results of daylight sensors in almost all thermal zones. Thereby the reduction of energy demand peak load an utility costs have been calculated for the two window types Window D and E, since they had the best results shown in 4.4.2 Windows. Figure 70 below depicts the demand reduction comparing the results with and without daylight sensor, being used.

Looking at Window D with and without daylight sensor first, a reduction of electricity demand by further almost 8 percentage points can be observed. The cooling demand, being a part of the electricity demand decreases by additional 3.8 percentage points. The other part of the reduction accounts for the lighting.

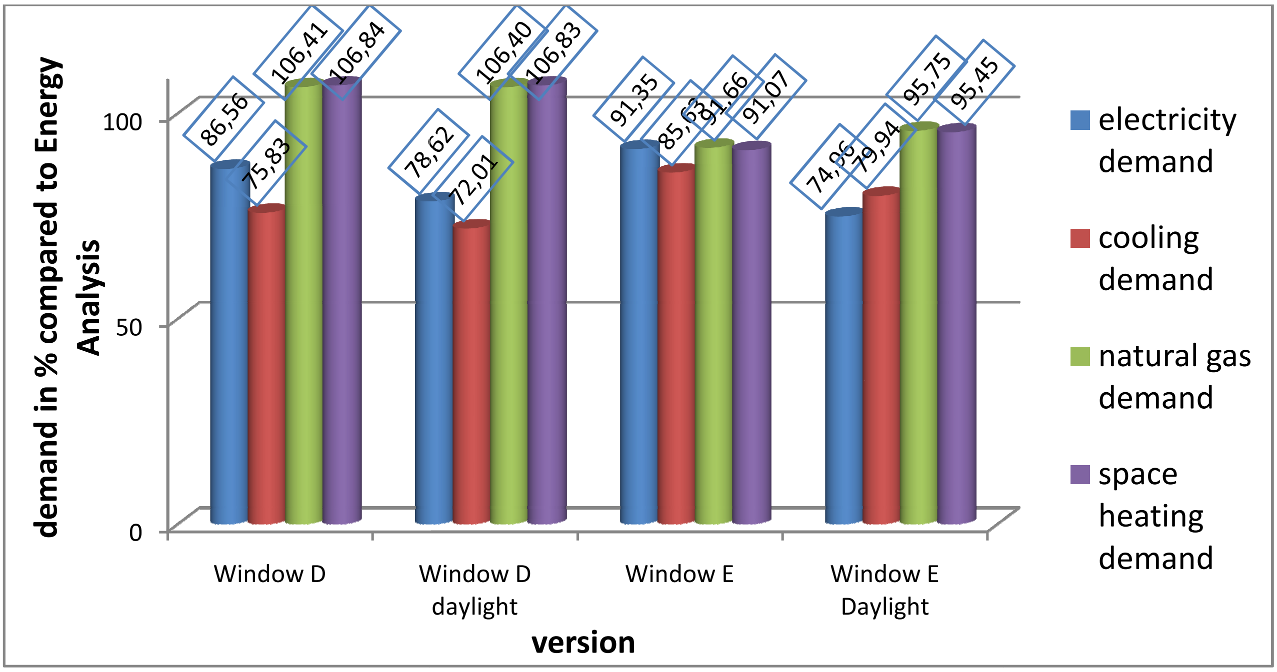


Figure 70: Daylight measures, demand reduction

Window E has higher demands regarding cooling and electricity demand due to the higher solar heat gain coefficient compared to Window D. For the same reason the natural gas and space heating demand are lower. Implementing daylight sensor while having window type E does make a major impact on the electricity and cooling demand. In this manner the electricity demand has been reduced by further 16 percentage points and is less than the electricity demand of simulation 'Window D daylight sensor'. It has to be noted that the space heating demand did rise by four percentage points though. Such being the case it is important to enforce insulation in combination with daylight measures, keeping the overall energy demand reduction in mind.

Figure 71 below depicts the peak load of the daylight sensor simulations compared to the Energy Analysis. The bar chart illustrates a decrease of slightly more than 4 percentage points at cooling and heating load, when using daylight sensors and having Window D. Daylight sensors had no influence on the peak load while having Window E. Further Window D with daylight sensor shows the best results regarding peak load.

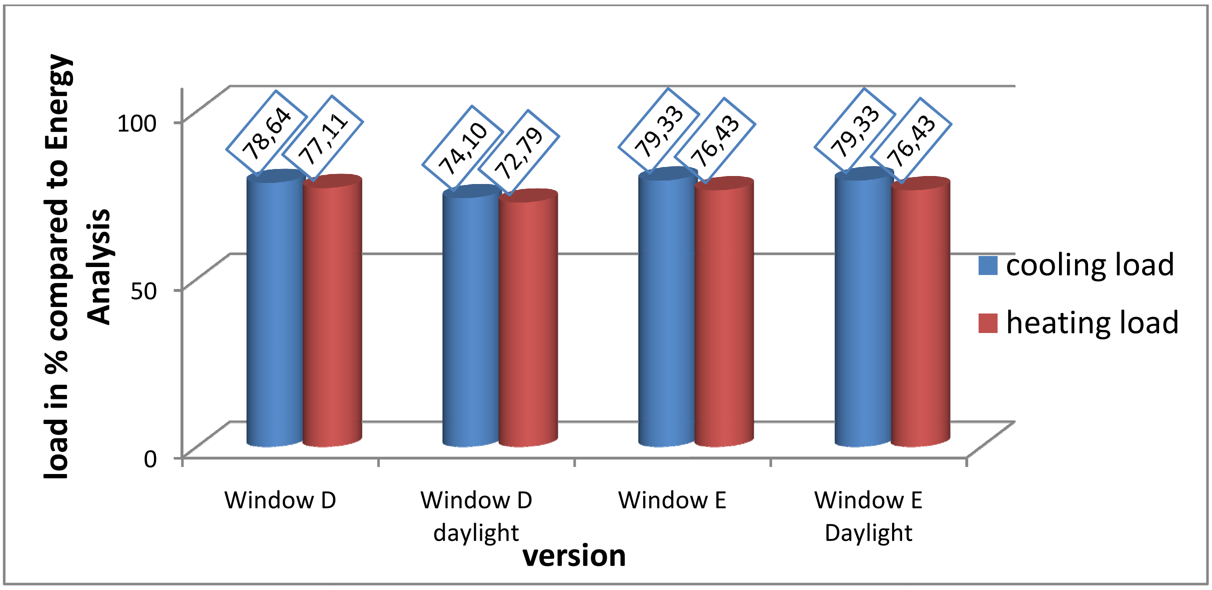


Figure 71: Daylight measures, peak load reduction

Figure 72 illustrates the utility cost reduction. Thereby it has to be kept in mind that the influence of peak load on the utility costs has not been taken into account.

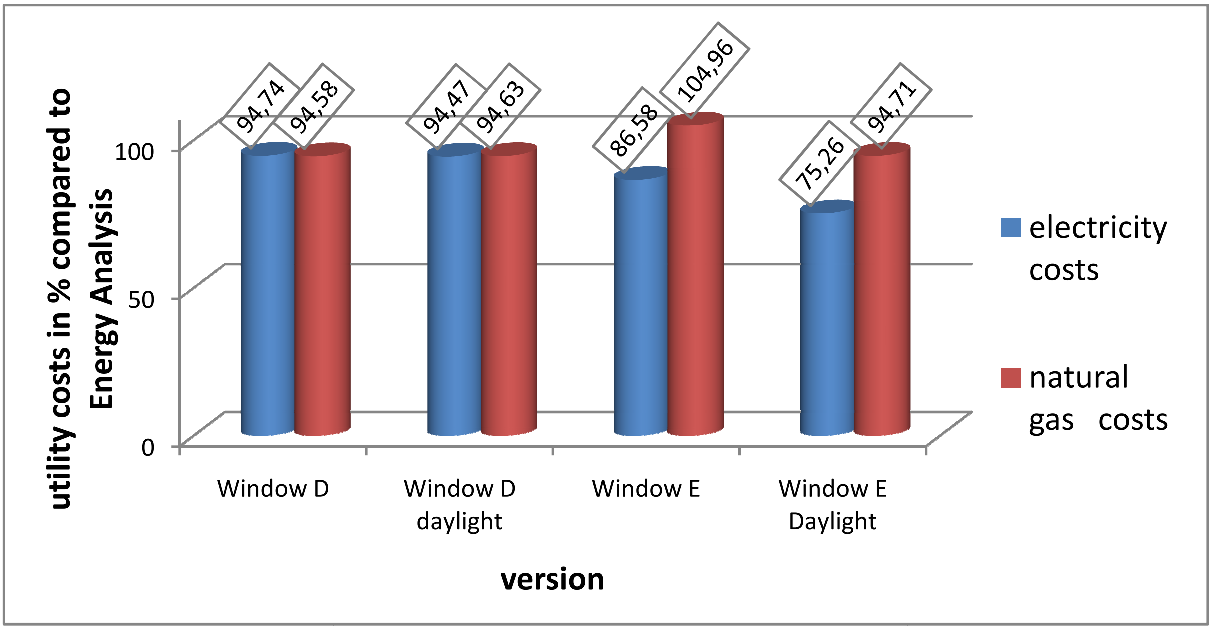


Figure 72: Daylight measures, utility cost reduction

As it has already been established in 4.4.2 Windows, without daylight control, Window D shows lower natural gas costs and Window E lower electricity costs. By implementing daylight sensors the utility costs, having Window E, drop down further. Looking at the overall utility costs, shown in Figure 73 below, Window E with daylight control shows the best results with 1.48 $/ft² (15.93 $/m²) electricity costs and 0.38 $/ft² (3.18 $/m³) natural gas costs.

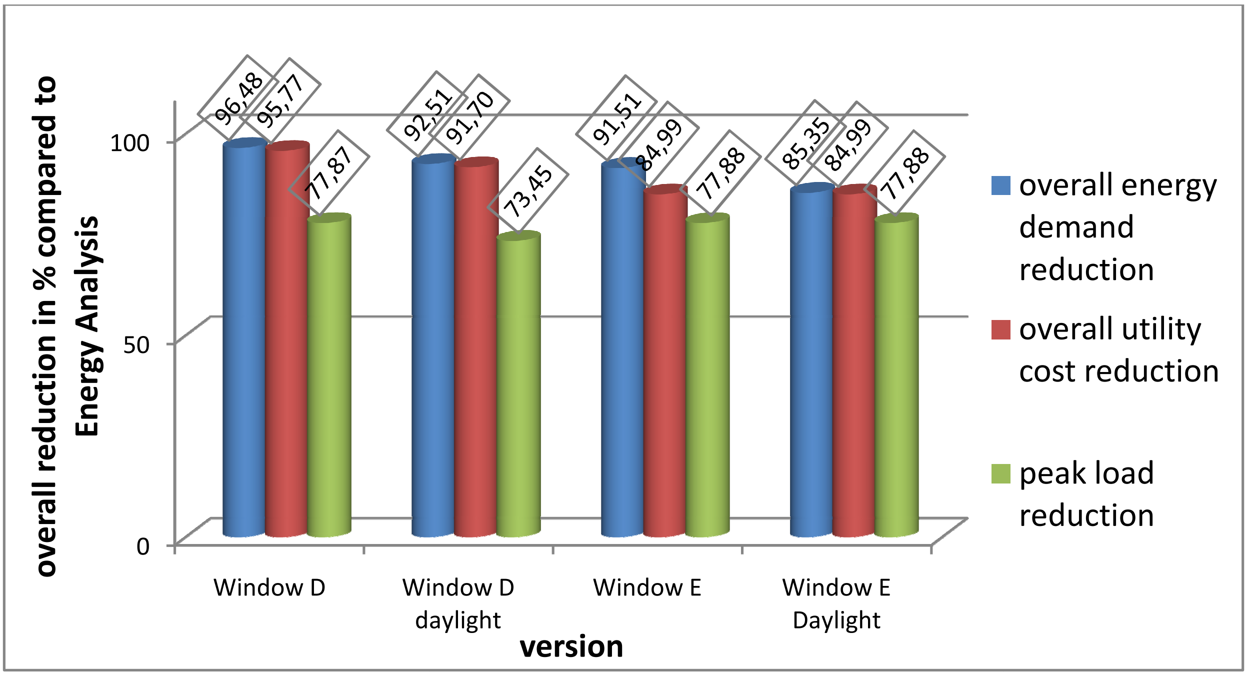


Figure 73: Daylight measures, overall reduction

Considering the overall demand compared to the Energy Analysis and the overall utility cost reduction Window E is only advisable with daylight control.

4.4.6 Overall Insulation Measures

Before any further optimizations have been tested the overall insulation measures have been combined. Since it is assumed that, with all the implemented measures following in the next subchapter, the tightness will improve, the influence of the tightness is shown as well in this chapter.

4.4.6.1 Input

The following above simulated measures are realized in this simulation, once with the same tightness as in the energy analysis and once with improved tightness.

- Window E
- Floor B
- Roof B
- Cool Metal Roofing
- Daylight Sensor

In 4.3.1.7 Infiltration the natural infiltration for a very leaky building has been calculated. However, it is known that the tightness will improve while implementing the above described measures in the manner of insulating the roof, floor and openings and new windows. Yet, it is unknown to which extent the tightness will improvesimulations since it cannot be specified to which extend the exterior walls can be sealed. Therefore a still leaky building with an infiltration of 0.6 cfm/ft^2 (0.182 m³/m²min) at 0.3 inch of water (n_{75}-value) will be assumed for further, where all above mentioned measures have been taken. When calculating the natural infiltration, as explained in 4.3.1.7, it leads to an infiltration of 0.0706 cfm/ft^2 (0.0215 m³/m²min).

4.4.6.2 Results

First of all the influence of the infiltration on the energy demand and peak load will be shown. Afterwards details on the outcome are listed, since the overall measures are implemented in further simulations.

The following Figure 74 and Figure 75 depict the percentage of energy demand for the overall measures, with and without changes in infiltration. Thereby it has to be mentioned that the infiltration value only changes from very leaky to a leaky class. If it is possible to make the building tighter, the energy saving potential is higher than shown in the following two figures below.

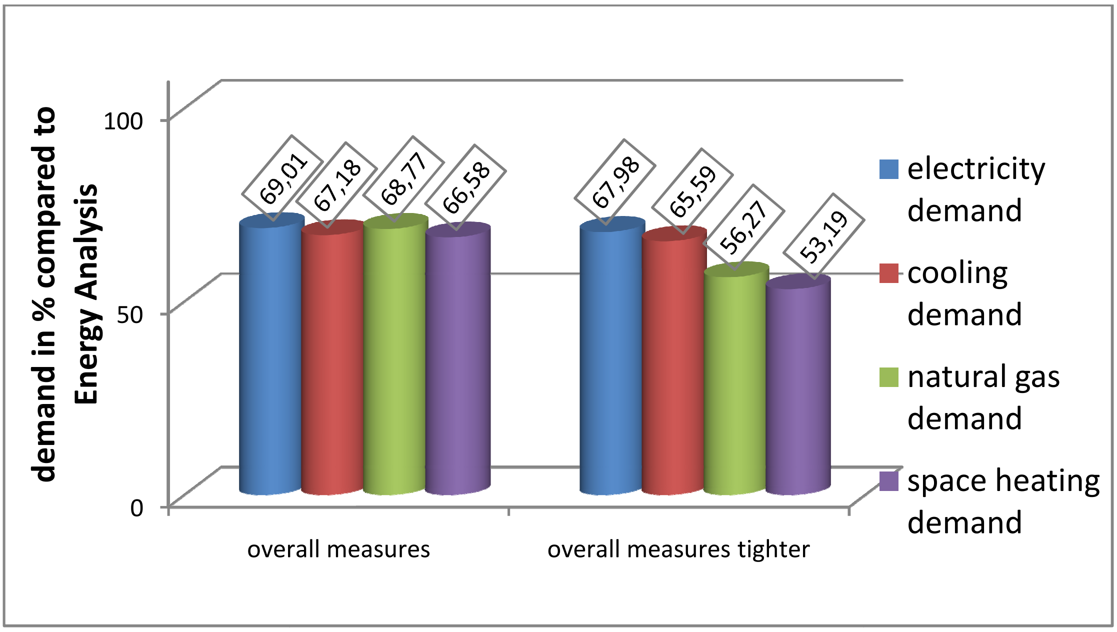


Figure 74: Building Tightness, demand reduction

The overall measures show significant improvement reducing energy demand over 30 percentage points in all four categories, although mostly minor adjustments have been made. Besides it has to be noted that it is very likely that by retrofitting the infiltration loss will be lessened. It is unknown how much improvement can be done regarding tightness due to the historic brick wall, further decrease of energy demand and peak load in all categories is conceivable though. 'Overall measures tighter' already shows significant advancement especially regarding space heating and therefore natural gas demand. Both declined by further 12.5 and 13.4 percentage points. Additional shrinkage is shown in Figure 75, illustrating the peak load reduction.

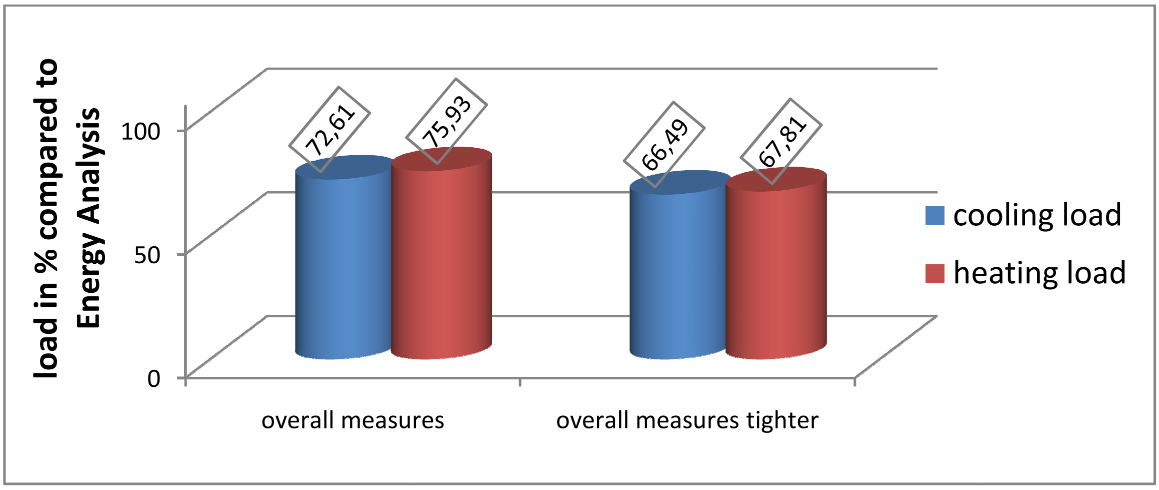


Figure 75: Tightness, peak load reduction

The above bar chart shows a reduction of 33.5 and 32.2 percentage points regarding cooling and heating load of the building compared to the Energy Analysis, although only minor measures have been applied. This leads to HVAC equipment which can be designed one third smaller than calculated in the Energy Analysis.

The following Figure 76 depicts the electricity cost reduction due to the overall measures compared to the initial calculation. The utility costs would be reduced by one third, keeping in mind that these results could be even lower, since the influence of peak demand on utility costs has to be considered. Moreover the bar chart shows the high influence of tightness on the peak load, especially on heating.

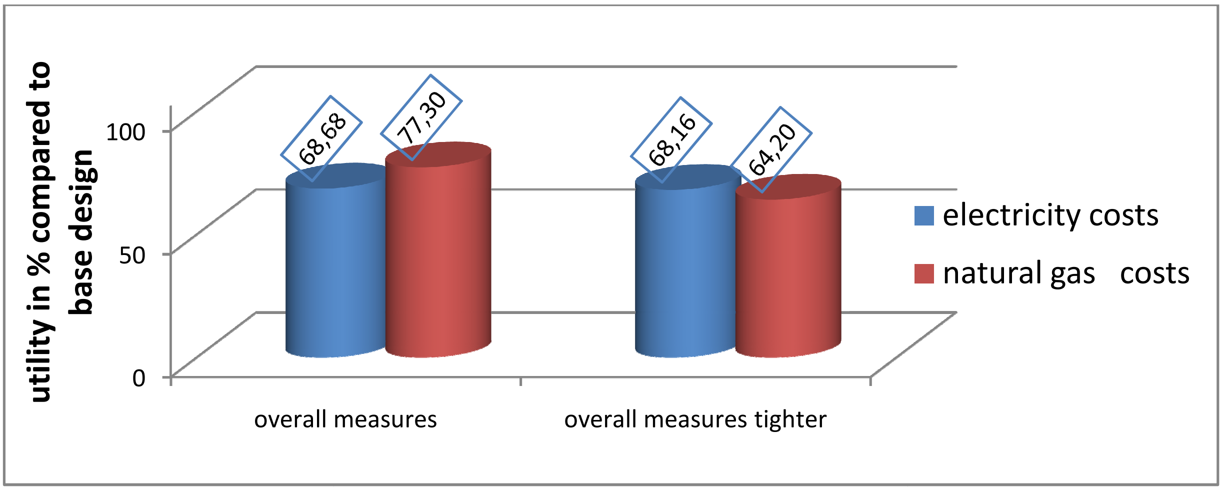


Figure 76: Tightness, utility costs reduction

Even the cooling demand decreases slightly. Further, the heating and cooling load can be improved by additional 8.12 % and 6.12 %. Only by reducing the infiltration of the building from 'very leaky' to 'leaky' the space heating load did decline from 1,643,000 BTU/h (481.5 kW) to 1,467,200 BTU/h (430 kW). Through finding ways to improve the tightness even more; the energy saving potential is much higher.

More details on the simulations were all overall measures, as described in 4.4.6.1 Input, have been implemented will be conducted as follows. However, the following Figure 77 illustrates the annual energy consumption by end use, also showing the following sectors for additional saving potentials.

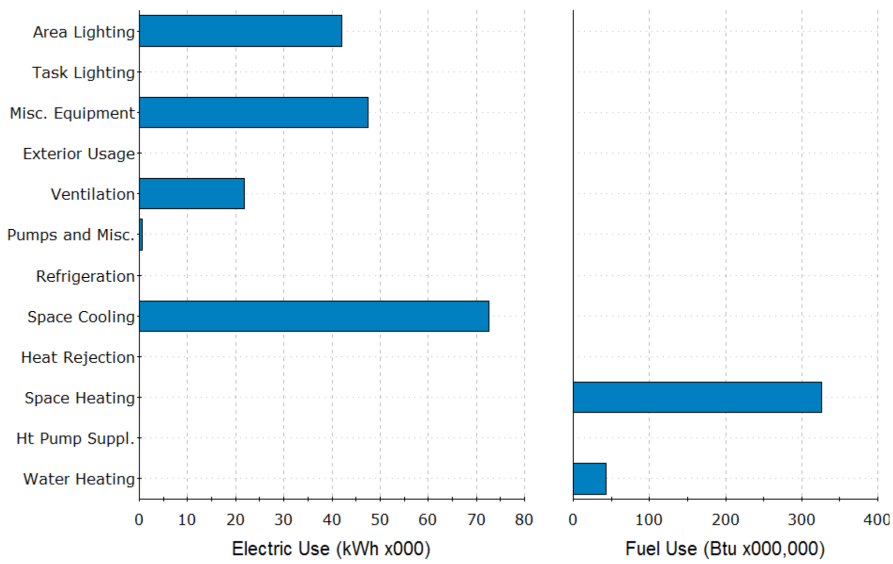


Figure 77: Overall measures with infiltration, annual energy consumption by enduse

Space cooling came down to 72.68 MWh and the space heating 325.94 MMBTU (95.52 MWh, leading to an overall demand reduction of 38 %. Also utility costs came down 34 %, as well as the peak load decreased to 67 % of the peak load result in the energy analysis.

The following Figure 78 and Figure 79 depict the monthly distributed energy demand and peak load. Thereby it can be seen that, after implementing the above measures, the peak load and months of high demands interact intensively. Thereby in the next chapter it has been tried to moderate the peak demand by looking at various HVAC systems.

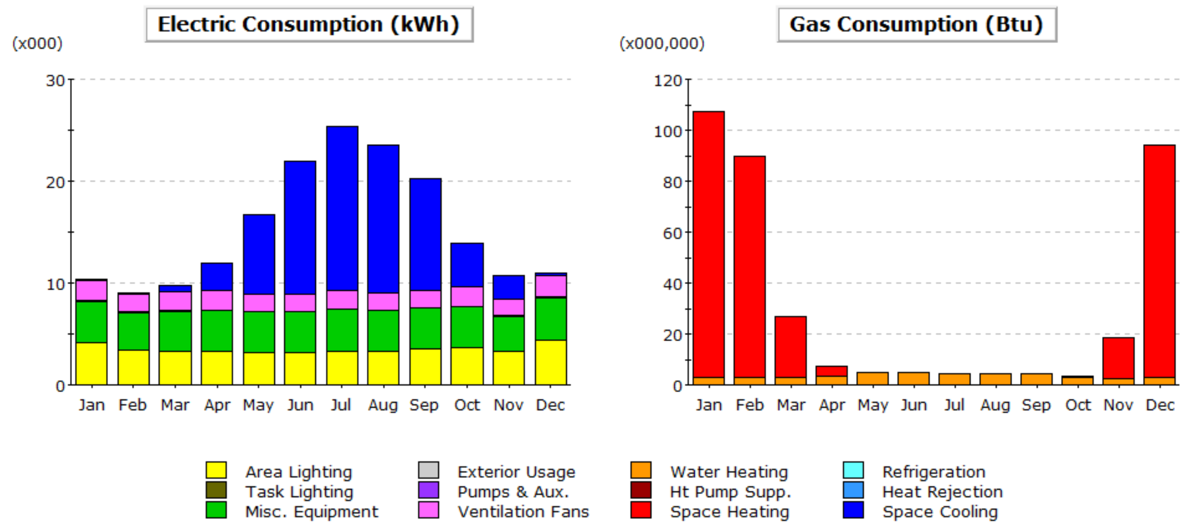


Figure 78: Overall measures with infiltration, energy demand monthly distribution

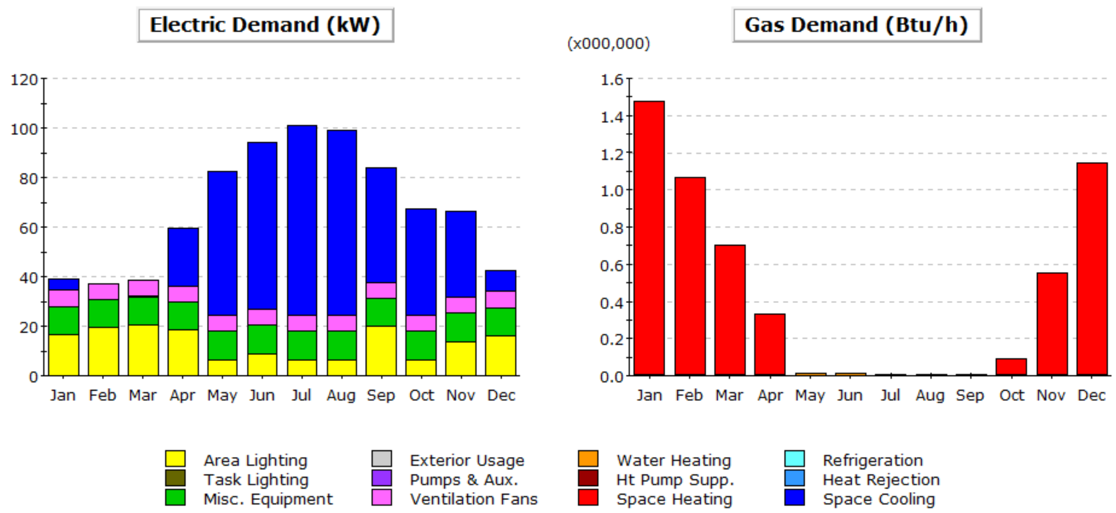


Figure 79: Overall measures with infiltration, peak demand monthly distribution

For the reason that the measures included here will be included in the later on following simulation, the following Table 13 sums up the outcomes.

Table 13: overall insulation measures, result summary

electricity	**Imperial units**		**SI units**	
electricity demand total	184470			
electricity demand per sqft	9,54659249	kWh/ft²	102,7587	kWh/m²
cooling demand total	72680	kWh		
cooling demand per sqft	3,76129637	kWh/ft²	**40,48627**	**kWh/m²**
natural gas				
natural gas demand total	369120000	BTU	108178,4	kWh
natural gas space heating	325940000	BTU	95523,58	kWh
space heating demand per sqft	19323,125	BTU/ft²	**53,21126**	**kWh/m²**
domestic hot water demand per occupant	187739,13	BTU/pers	55,02091	kWh/pers
annual utility costs				
electricty	25900	$		
natural gas	3871	$		
electricity per sqft	**1,34**	**$/ft²**	14,43	$/m²
natural gas per sqft	**0,20**	**$/ft²**	2,16	$/m³
HVAC system	**Imperial units**		**SI units**	
space cooling load	**76,66**	**kW**		
space heating load	1467200	BTU/h	**429,9939**	**kW**

4.4.7 HVAC System

The following subchapters show the simulated HVAC systems alternatively to the HVAC system estimated in the energy analysis. Thereby the aim has been to outline the potential without any alterations to the sizing such as duct sizing for example. The sizing has been done by the software.

4.4.7.1 Inputs

HVAC B

The following Figure 80 depicts HVAC system B in eQuest. Thereby the energy saving potential of an enthalpy wheel has been tested on the building. The placement of the enthalpy wheel is shown as 'heat recovery' in the schematic.

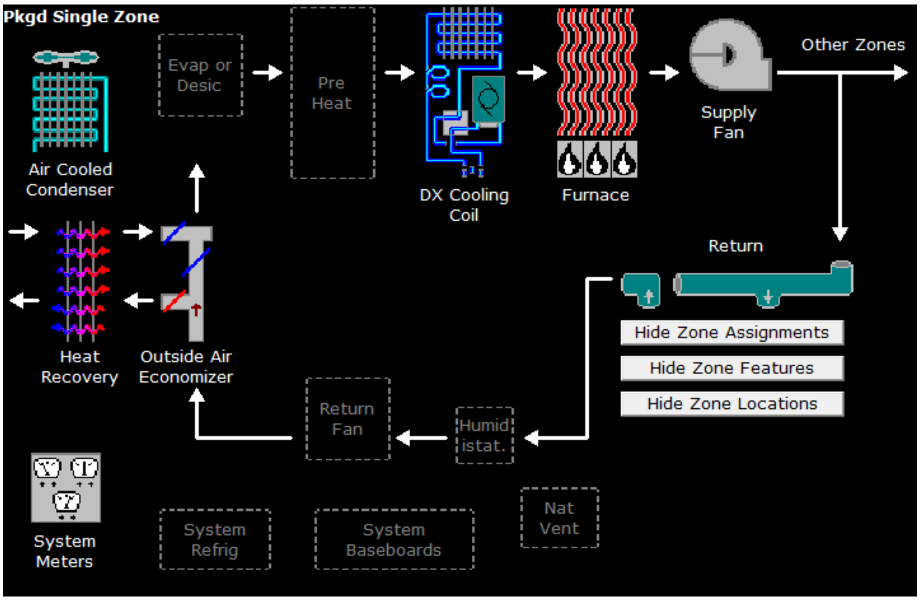


Figure 80: HVAC System B input

In doing so, no further changes have been implemented compared to HVAC system A. Additionally though, it has to be mentioned that the enthalpy wheel has only been operated while the fans are on during the operation time described in 4.3.1.6 Internal loads. Furthermore the efficiencies of the DOE2 calculator have been inherited, which leads to a sensible effectiveness of 0.76 and a latent effectiveness of 0.74.

HVAC C

The simulation of HVAC system C tests the energy saving potential of a sensible heat exchanger. The schematic is equivalent to the schematic illustrated in Figure 80, although the heat recovery element differs. The sensible heat exchanger operates only during fans are on as well. EQuest proposes a sensible effectiveness of 0.52 as a default value.

HVAC D

Due to the results of the evaluated energy saving potential of HVAC systems B and C, which is described further below, the simulation system D has been made similarly to HVAC system B. Thereby it possesses a enthalpy wheel as well, but it has been further tried to reduce the part of the outside air due to the high exterior humidity. Therefore the minimum outside air ratio has been set to 0.4 at every time when the outside air conditions do not exceed a 65 °F (18.33 °C) and an enthalpy of 30 BTU (31.65 kJ).

HVAC E

The following Figure 81 illustrates HVAC System E, having a solid desiccant unit with dehumidifier and indirect evaporative cooler, without regeneration preheat and integrated in a sensible cooling system.

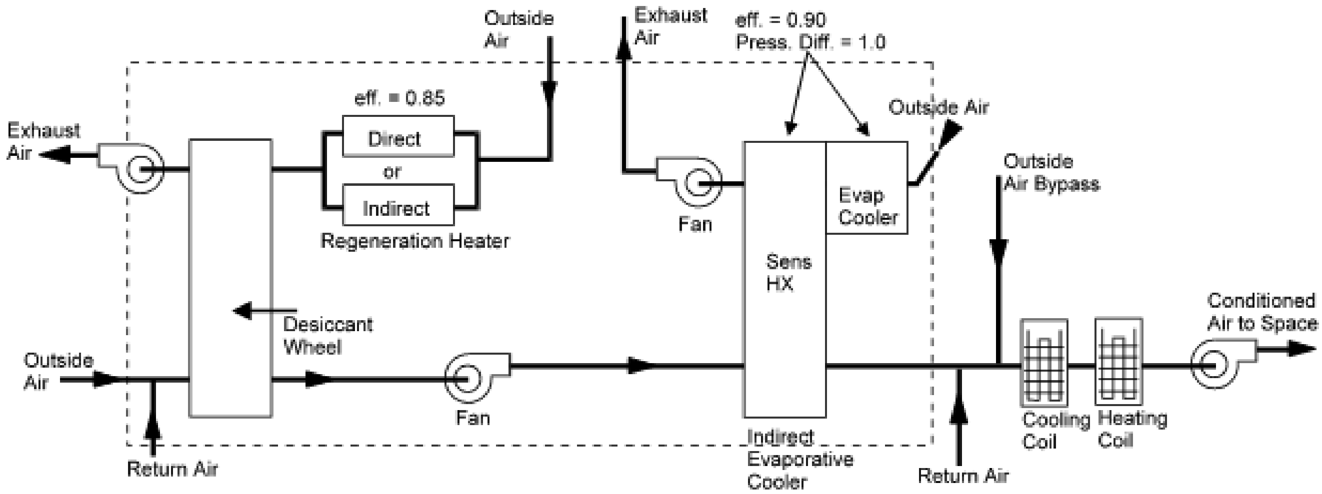


Figure 81: HVAC, System E [SW eQuest, 2014]

HVAC F

Allthough in this simulation the same solid descicant unit with dehumidification has been simulated as shown i as shown in Figure 81 a heat recovery has been added. Thereby it has been tried to see if the reduction in energy use can be further optimized while implementing the enthalpy wheel, as simulated in HVAC unit B.

4.4.7.2 Results

Various HVAC systems have been tested while mainly focusing on potential energy demand reduction, rather than on detailed planning. Thereby all simulations have been shown in reference to HVAC system A, specified in 4.3.1.2 Energy supply and do include all insulation measures from 4.4.6 Overall Insulation Measures. Figure 82 below illustrates the demand reduction for all of the potential efficiency enhancing measures.

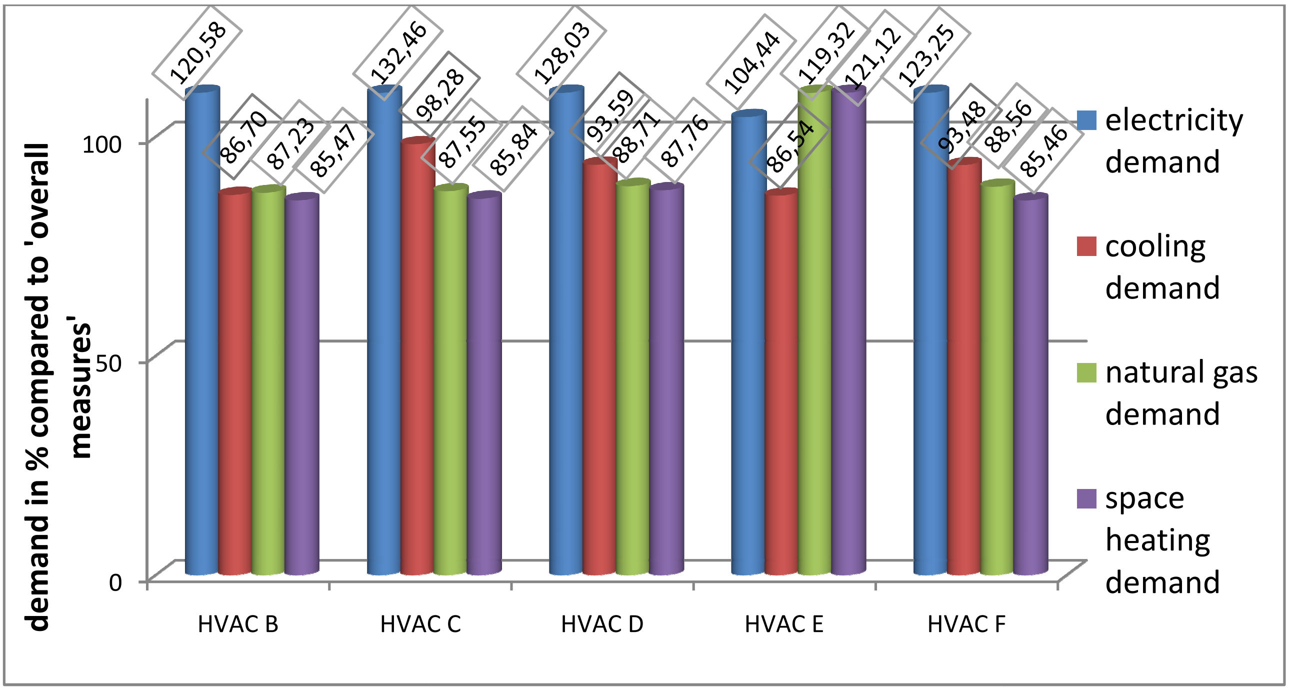


Figure 82: HVAC demand reduction

First of all starting with the results of HVAC system B, one can observe the rise in electricity demand, although the cooling demand is reduced at the same time. This escalation is due to the required additional ventilation due to the heat recovery wheel used in HVAC system B.

HVAC system A had an energy demand of 21.7 MWh electricity for ventilation. HVAC system B on the other hand had an energy demand of 48.5 MWh electricity for ventilation. Thereby it has to be noted that eQuest uses a default value for the fan efficiency of 0.53. By using ventilators with an efficiency of 64 % for example, 40 MWh electricity would be used for ventilation, which would come up to 1120 $ of savings per year at the electricity price, noted in 4.3.1.2 Energy supply. Furthermore it has to be mentioned that this number can be reduced while scheduling office times. In all HVAC systems office times between 6 am and 7 pm have been estimated. While only using some of the areas as an office and some of the area as an event space, control systems programmed with different schedules will get a decrease in ventilation energy. Moreover it has to be mentioned that enthalpy wheels when applied require careful engineering.

HVAC system C with a sensible heat exchanger shows 12 percentage points more of electricity demand compared to HVAC system B. Further the cooling demand is higher than the one of HVAC system B due to the sensible effectiveness. HVAC system D offers worse results than HVAC system B, as expected.

HVAC unit E shows a rise in natural gas demand compared to the others, since the air has to be pre-heated in order to make sure the desiccant wheel functions as wanted. Furthermore the room outtake air could not be connected properly to the cycle, shown in Figure 81: HVAC, System E [SW eQuest, 2014] on page 71. The following Figure 83 shows an example instead, where adaption of solar power is imagined, although it has to be noted that due to historic preservation solar power is not an option on the roof or near the area, since the space is occupied.

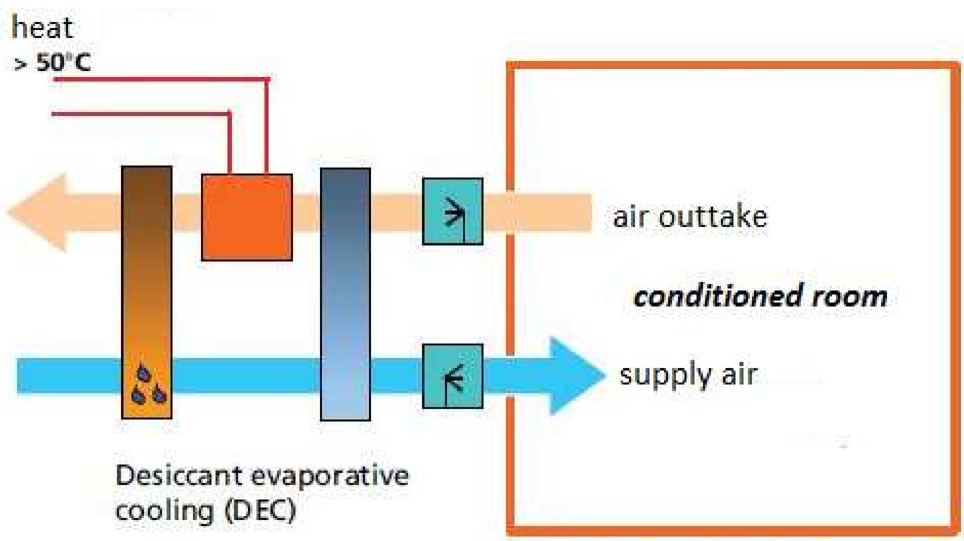


Figure 83: Example Desiccant and Evaporative Cooling Unit, [I Frauenhofer ISE, 2014]

HVAC system F shows similar results to HVAC system B, although more components are included.

Figure 84 below depicts the utility costs of all HVAC systems tested.

Looking at the utility costs it can be observed that in general the annual utility costs would rise in simulated measures. Thereby it has to be mentioned that the influence of peak load reduction is not included in this calculation, as already mentioned in chapters before.

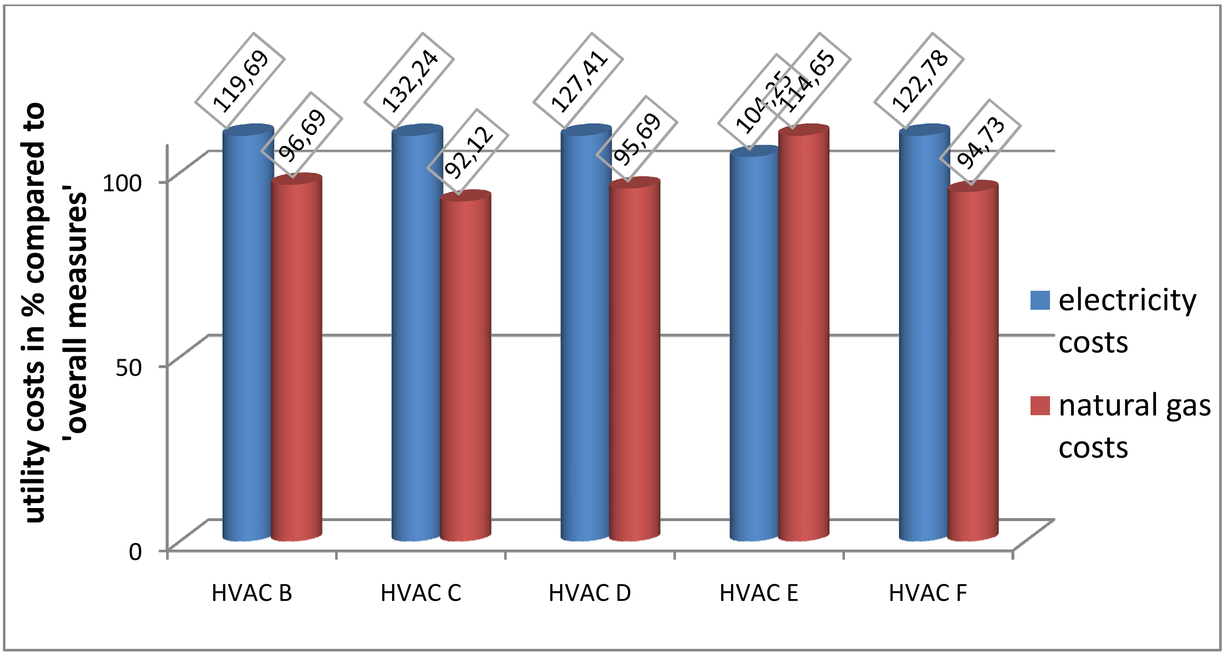


Figure 84: HVAC utility cost reduction

The following Figure 85 depicts the peak load reduction, were significant reduction can be observed in all variants. Hence the cutback of peak load demand would not only lower the real utility costs, but also lower other costs. For example, regarding HVAC unit B the peak load concerning cooling and heating are both 15 to 18 percentage points lower. Thus the HVAC equipment can be sized smaller.

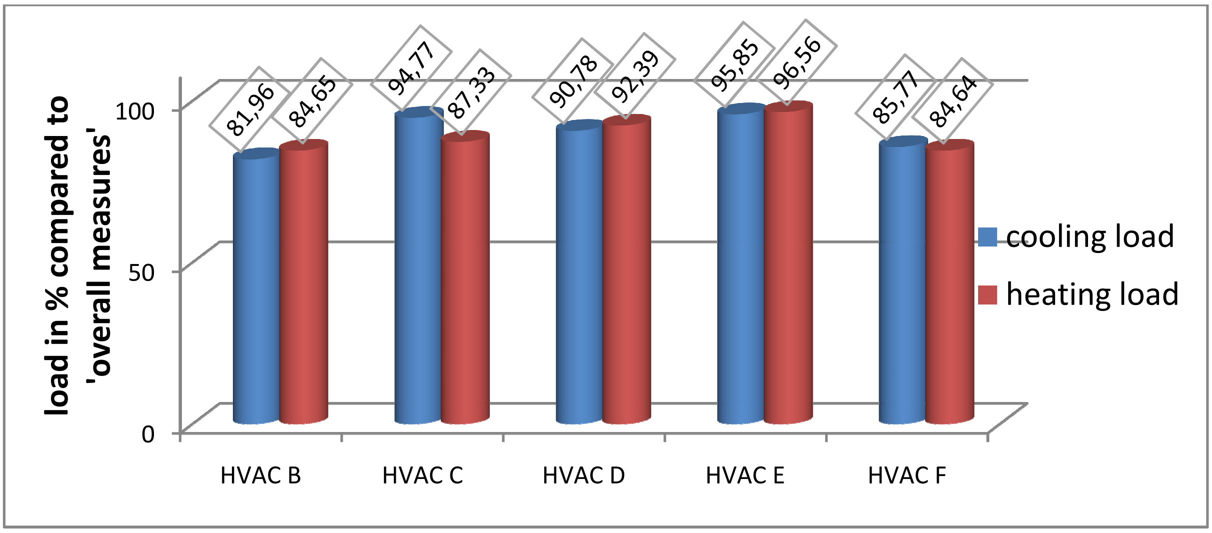


Figure 85: HVAC, peak load reduction

4.5 Economic Analysis

For evaluating the financial feasibility for the simulated measures the net present value method has been used calculating the pay off period. Thereby the yearly cash flow has been discounted to the present value. Equation 4 below shows the used formula.

Equation 4: discounting of the annual cash flow, [P BWL 3, p152, 2006]

$$Co = CF * (\frac{1}{1+i})^n$$

Co= present value of cash flow

n years

i= rate

CF cash flow every year

Hence some information concerning costs was not available some changes and assumptions have been adapted to the calculation. Since the building has to be renovated anyhow, the assumption has been made that only the additional costs would be considered for net present value calculation purposes. With this for example the price difference between the various windows is understood. Furthermore the yearly accumulated cash flow is given with the according amortization time.

The following components have been examined regarding net present value and compared to the energy analysis.

- Window B
- Window C
- Window D
- Window E
- Daylight sensors
- Floor B
- Floor C
- Roof B
- Roof C

- Roof C Cool Metal Roof
- Overall Measures

Afterwards the net present value of HVAC system B and HVAC system B with reduced fan power have been computed.

4.5.1 Development of energy prices

The United States Energy Information Administration [I EIA, 2014] did make an estimate on future development of natural gas and electricity price. However, these values might vary slightly from state to state, besides additional charges are unknown and will vary from state to state as well. Anyways yearly growths of the price in percentage, outlined in 1 Introduction, have been used as source for the net present value calculation. Starting on page 2, Figure 3 and Figure 4 illustrate the forecasted slope. Thereby an average yearly growth of 0.4 % for the natural gas price and 1.7 % for the electricity price has been predicted.

4.5.2 Inflation

The inflation has been researched in order to discount the savings to net present value day. The following Figure 86 depicts the inflation measured by the annual growth rate of the gross domestic product of the United States published by [I World Bank, 2014] starting 1961 until now.

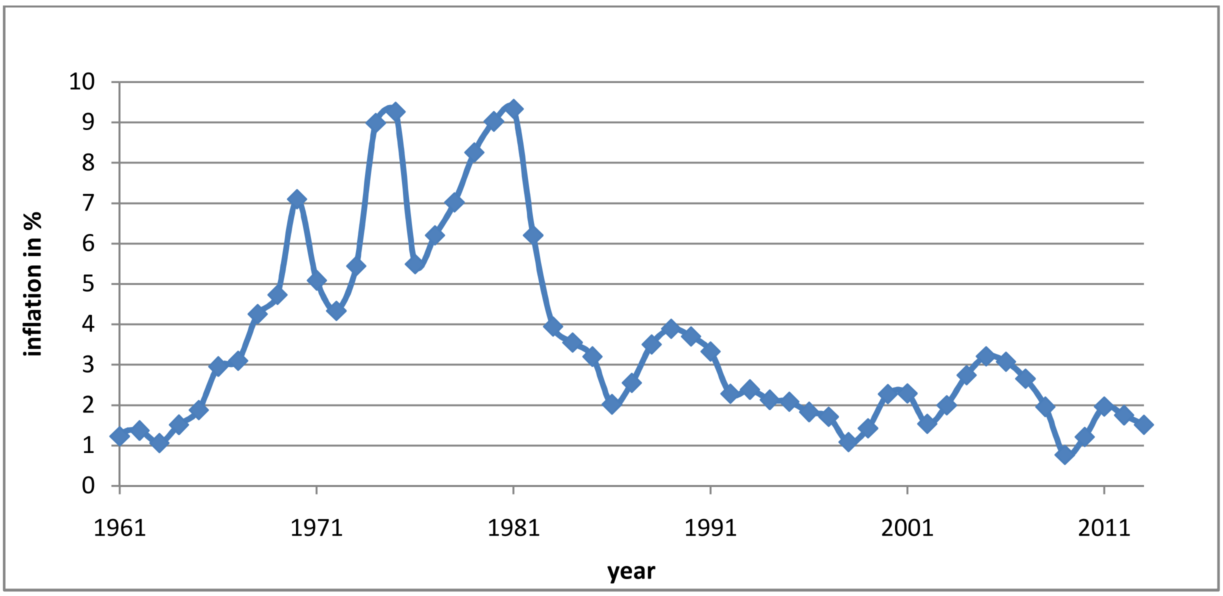


Figure 86: Inflation as measured by the annual growth rate of the GDP implicit deflator [I World Bank, 2014]

In order to define the inflation for net present value calculating purposes it has been decided to compute an inflation mean value from the past. Thereby it has been noticed that the high inflation between 1970 and 1983 would distort the inflation mean value for the economic analysis due to a huge boom in economic during those years. For this reason Table 14 below illustrates the inflation mean value for various periods.

Table 14: mean value of inflation regarding different periods

period	Inflation mean value
1960-2013	3,4695
1990-2013	2,1203
2000-2013	2,0668

Since the difference of the 2nd and 3rd regarded period is not that high, it has been decided to regard the period between 1990 and 2013 for calculating the present value of the annual cash flow.

4.5.3 Financing

Since financing remains unknown yet and might come from other projects, funding or will go in hand with the planed arena on the site no interests on credits have been considered.

4.5.4 Results

The following subchapters show the net present value dependent on the year, which is connected to the amortization time. When the additional costs per simulation variant are known the amortization time can be directly read from the tables. Thereby the additional costs of each variant are compared to the costs of retrofitting according to 'Energy Analysis'. Though, it has to be noted that the results are calculated with respect to the assumptions made in 4.3 Energy Analysis.

4.5.4.1 Windows and daylight sensor

Table 15 below illustrates the net present value and amortization depending on each year. It has to be mentioned that the peak load reduction is not included in this calculation.

Table 15: Windows, net present value dependent on year

accumulated net present value in $						
years	**Window B**	**Window C**	**Window D**	**Window E**	**Window D daylight sensor**	**Window E daylight sensor**
5	10781,49	11247,04	26273,99	17377,33	40916,52	46696,56
10	21255,04	22159,44	51908,17	34299,59	80894,50	92396,28
15	31434,10	32752,58	76924,06	50784,25	119961,53	137123,09
20	41331,26	43040,84	101342,01	66847,74	158143,94	180900,11
25	50958,31	53037,67	125181,34	82505,57	195466,89	223749,74
30	60326,30	62755,66	148460,41	97772,36	231954,45	265693,68

In general, due to price difference in gas and electricity, windows reducing electricity demand show a higher net present value and therefore a shorter amortization time. Looking at the results of the accumulated net present value of the windows, one can see that Window D would show the best results compared to the other windows. By implementing daylight sensors though, Window E shows better results.

4.5.4.2 Floors

Due to only little improvement of energy demand regarding Floor B no significant results can be seen in the economic analysis, although it has to be noted that measure 'Floor B' notably enhances condensate issues. Floor C, as mentioned in 4.4.3 Floor, does not redeem.

4.5.4.3 Roof

Three Roof types have been tested on the subject of net present value, which is shown in Table 16.

Regarding the outcome, it has to be mentioned that Roof C in comparison to Roof B shows much better humidity and condensate results. Further significant differences are shown between Roof C with and without 'cool metal roofing' coating.

Table 16: Roof, net present value dependent on year

years	accumulated net present value in $		
	Roof B	**Roof C**	**Roof C CMR**
5	21691,91	22301,49	23291,95
10	42554,57	43741,92	45692,79
15	62636,37	64371,93	67254,58
20	81982,18	84238,41	88025,54
25	100633,57	103384,85	108050,38
30	118629,11	121851,55	127370,56

4.5.4.4 Overall Measures

Table 17 below illustrates the net present value and estimated amortization time of the overall measures described in 4.4.6 Overall Insulation Measures.

Table 17: Overall measures, net present value dependent on year

year	accumulated net present value of the overall measures in $
5	68516,28
10	135044,20
15	199672,40
20	262483,80
25	323556,00
30	382961,75

4.5.4.5 HVAC

The calculation of the net present value has been done for HVAC system B with and without reduced fan power. The results showed no cost effectiveness, although it has to be mentioned that the peak load reduction would have considerable impact on the outcome in this case. Furthermore due to peak load reduction it can be said that the sizing of the other HVAC components is influenced strongly as well.

4.6 Design proposal

A basic engineering design proposal has been made to depict the design approach which has been made to meet various criteria which come in place in this building such as historic preservation, utility cost reduction, the comfort of the occupants and the energy consumption of the building.

The detailed design will cover the structural engineering and the detailed architectural design, following up later on [O Shonka, 06th June, 2014]. Furthermore in this chapter the proposed improvements will be described and summed up. The detailed information for each structure has already been outlined in 4.4 Simulation of energy efficiency measures.

4.6.1 Design

The basic design has been drawn in ArchiCAD [SW ArchiCAD, 2013] and is shown as follows. The plans are attached in Appendix, whereas the details of roof, wall, and floor structure are depicted simplified. The construction details are illustrated in the following chapters.

4.6.1.1 Exterior

The following figures, Figure 87, Figure 88 and Figure 89 depict the exterior of the design proposal. The elevator can be seen in all of these figures as an extension of the tower in the 3rd floor. The position of the elevator is optimal to make the Boiler and Engine Room accessible from the main entrance although the floor level of the first floor has been increased due to flood elevation. Further it provides access to the tower and the engine Room as the floor levels differ.

In order to meet the requirements of the historic preservation it is important that the elevator and the passage cannot be observed from the front view at east elevation. While realizing the project it is important to make the passage and the elevator appear different than the rest of the building for one to distinguish between the historic building and the supplements. Additionally one should not interfere with the original building as much as possible. Therefore the elevator could be moved farther away from the building in the final design [O Harrise, 6th June, 2014].

Figure 87: Design exterior view 1

As the original entrance will be restored, it will be used as the main entrance, which is depicted in Figure 88. [O Shonka, 21th April, 2014]

Figure 88: Design exterior view 2

In the following Figure 89 the passage can be seen, which connects the third floor of the Engine and the Boiler Room. This passage provides accessibility to the 3rd floor of the boiler room through the elevator at the main entrance.

Figure 89: Design exterior view 3

The following chapters follow with detailed pictures illustrating a 3D view of the several buildings.

4.6.1.2 Engine Room

The following Figure 90 depicts the main entrance area in the engine room from the interior. The elevation has to be increased due to flood elevation (as described in 4.1 Building Description) and the elevator provides access to all floors, being a double door elevator. As the flood elevation is slightly above the lower edge of the windows, a distance of at least 1 foot is proposed between the floor and the windows, which will be overseen by Jason Carangelo ([O Carangelo, 10th June, 2014]).

Figure 90: Main entrance interior

Figure 91 and Figure 92 illustrate the atrium in the engine room. This will be used for events and gives optimal view of the historic structure and stucco. Further it provides daylight for the meeting spaces on the second floor and the kitchen and reception on the first floor.

Figure 91: Engine room entrance area interior 1

Figure 92: Engine room entrance area interior 2

The balcony on the second floor provides a view of the atrium area, which can be seen in Figure 93 and Figure 94.

Figure 93: Engine room balcony 1

Figure 94: Engine room balcony 2

The glass area in front of the meeting spaces of the second floor, shown in Figure 95, Figure 96 and Figure 97, provides daylight to the meeting spaces. The glass should be covered with a foil in order to provide privacy at the meetings, which is not depicted in the 3D renderings.

Figure 95: Engine room, break room 2nd floor 1

Figure 96: Engine room, break room 2nd floor 2

Figure 97: Engine room, meeting room 2nd floor

The following renderings Figure 98, Figure 99 and Figure 100 illustrate the open design of the third floor. The original roof provides daylight to the meeting spaces and offices using interior glass areas. In order to have enough privacy in the meeting and office spaces the interior windows should be either covered with a foil or above 6` - 8” (2 m 2 cm) high. The steel trusses should be exposed, although they will slightly differ from the original structure as scissor trusses ([O Shonka, 24th April, 2014]) will be implemented. The vertical windows in the original roof structure are minor shed by the overhangs of the top roof.

Figure 98: Engine room, 3rd floor 1

Figure 99: Engine room, 3rd floor 2

Figure 100: Engine room, 3rd floor 3

4.6.1.3 Boiler Room

The Design in the Boiler Room will be very similar to the design for the Engine Room shown in 4.6.1.2, although the engine room is the main exposed room and event area due to the terracotta stucco on the interior of the brick walls 4.1Building Description. The atrium area, depicted in Figure 101 and Figure 102, is providing daylight to the meeting spaces in the second floor on two sides. Thereby the glass is intended to be covered with a foil as mentioned before.

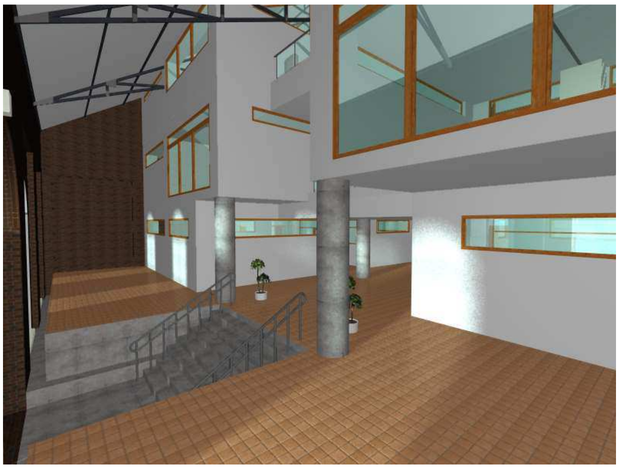


Figure 101: Boiler room entrance area interior 1

Figure 102: Boiler room entrance area interior 2

In the middle of the second floor a crucial corridor has been designed, which can be implemented as an open meeting space as shown in Figure 103 below.

Figure 103: Boiler room 2nd floor hallway

Figure 104 shows the third floor of the Boiler Room, which is very similar to the third floor of the engine room. Furthermore the passage coming from the Engine Room can be seen in this figure. Figure 105 illustrates an example of a meeting space for the third floor, whereas the realization of the indirect daylight design can be objected. The interior glass facing the sloped roof is intended to further provide daylight to the atrium area as well as provide a view downstairs without allowing the occupants in the entrance area a glance into the meeting rooms. Although the glass area of the meeting rooms and office spaces in the second floor are covered by a foil, the third floor meeting spaces provide a much more private space for meetings and conversations.

Figure 104: Boiler room 3rd floor

Figure 105: Boiler room 3rd floor meeting space

4.6.1.4 Tower

In the tower the heights of the rooms are basically planned to stay original accept for the dropped ceilings, as the floors would otherwise go through the stucco above the window. On the first floor of the tower two offices and an installation room are planned. An example can be seen in Figure 106.

Figure 106: Tower 1st floor office

As events will take place in the building, the second and third floor have been converted to a bar or café with observation deck. The following Figure 107 shows an example for the second floor of the tower. The spiral staircase lets room for the tables to get the view over the area. As mentioned in 4.6.1.1 Exterior the elevator is attached on the outside and makes the third floor wheelchair accessible.

Figure 107: Tower 2d floor bar and café

Figure 108 shows the observation deck. Since the original design of the building left the third floor of the tower open without access, the frames of the glass area should be as thin as possible and the glass should be without spacers in between in order to keep the original look.

Figure 108: Tower 3rd floor observation deck

In case the windows in the observation deck should be possible to open, French windows can be implemented with a glass railing or something similar keeping historic preservation in mind [O Harrise, 6th June, 2014].

4.6.2 Roof

The proposed roof structure is depicted in Figure 58 on page 52, which possesses a 1/2 ft (15.2 cm^2) thick layer of mineral wool, a ventilated air layer in order to remove moisture on the outside and wooden spruces. If the insulation would be installed in between the existing metal trusses, moisture issues would occur due to thermal bridges. Therefore it is advised to connect the illustrated roof structure to the historic metal trusses on the outside.

Regarding the roof it strongly depends on the additional costs if the roof with double insulation is financially feasible. Mainly important is the water vapor permeable foil with an sd-value of 0.15, hence it showed the best humidity results, as described in 4.4.4 Roof.

4.6.3 Floor

The floor elevation will be increased to 13 feet (3.95 m) above sea level As the focus of this proposal lays on the energy design the proposed floor structure is only valid for this. Figure 52 on page 48 depicts the proposed floor structure, showing the best economic results.

Above the existing gravel and concrete the floor level has to be increased, therefore a fill is assumed to be in between a stabilization structure. Above the fill an expanded polystyrene foam board provides the necessary insulation to meet the code requirements and low water vapor permeability as already outlined in 4.4.3 Floor. Furthermore a foil with a water vapor diffusion resistance factor of 10^5 or a water vapor diffusion-equivalent air layer thickness (sd-value) of 20 is necessary.

4.6.4 Windows and Daylighting

The window type preferred in order to serve historic preservation would be Window E [O Harrise, 6th June, 2014]. This window type, which has been described already in 4.4.2.1 Inputs, is a double pane window, being as thin as a single pane window. The following Figure 109 depicts the window from [P Pilkington, 2011].

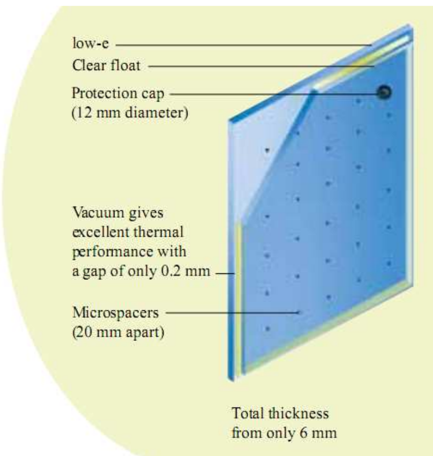


Figure 109: Design Proposal Pilkington Spacia

Thereby simulations and economic analysis have shown that Window E itself shows only better results than the other simulated windows, if daylight sensors will be implemented. For this reason and historic preservation this is finally proposed to the City of Savannah. If this is neglected in historic preservation windows, similar to Window D, or with a higher solar heat gain coefficient, though still serving energy code requirements, are recommended.

4.6.5 HVAC

The best HVAC variant, system B having an enthalpy wheel is proposed although the economic analysis did not show sufficient results. This proposal is due to the significant peak load reduction of over 18 and 15 % compared to the insulated retrofit. Therefore other HVAC system components will be designed smaller, and peak load demand charge will decrease as well.

5 Conclusion and Summary

The energy analysis and simulations have been done for a representative municipal building in this area. Thereby historic preservation was a major topic which contributed to the boundary conditions of the simulations. Therefore the outcome and design proposal focus on similar historic municipal buildings in the South Atlantic.

Regarding the windows it has been found that the solar heat gain coefficient (SHGC) plays a major role, next to the u-value. Results showed that the balance between reducing solar heat gain and lessen heat loss through windows should be right, if the solar heat gain coefficient is significantly low, heating demand rises, which has been shown by Window D. It reduced the costs due to price differences between natural gas and electricity, but a rise in heat demand could be observed.

Since historic preservation has been a key factor it has been decided to propose a window equivalent to a double pane window, though having a slightly worse solar heat gain coefficient but showing even better results by applying daylight sensors.

Daylight sensors in general show essential improvements at decreasing energy demand and peak loads. By that all kinds of daylight sensors are an option. A proposed sensor would be one depended on presence of occupants, hence it could be used for controlling HVAC units and lightening systems especially in the event area and meeting spaces.

Furthermore while working on the design it has been tried to work with indirect day lighting in order to reduce electricity demand due to artificial lighting and enhance user satisfaction and comfort. Certainly this only applies for similar buildings being retrofitted; hence it hardly produces additional costs, if it is planed from the beginning.

Regarding the roof construction, mineral roof has been used for insulation despite common practice in this area, due to ecological and installation reasons. Therefore in order to reduce relative humidity in the mineral wool, a semi - impermeable foil has been used.

The historic roof consists of metal. Therefore the external appearance will be metal as well. Thereby 'cool metal roofing' coating does makes sense, although the simulation did not show. The reason for this is the initial emissivity chosen in Energy Analysis, since the original data of the metal roof are unknown.

The peak load reduction should not be underestimated. Although the decrease is not shown in the fall of the utility costs during simulations, the peak load mainly contributes to the overall costs. The peak load decrease reduces the investments costs of the HVAC components and cooling and heating equipment as well as the annual utility costs. Therefore an enthalpy wheel, recovering heat and dehumidifying, should seriously be considered.

When looking at other municipal buildings in the South Atlantic further measures have potential. For example external shading devices such as outside blinds would show serious improvement. Further it can be thought of changing the number of windows, although it has to be noted that this has to be done wisely since it raises the solar heat gain. If planed sustainably it can reduce annual electricity costs due to lighting.

Furthermore, wall insulation on the interior has been neglected due to the historic stucco on the inside. This energy efficiency enhancing measure has major potential as well.

Looking at future questions in this field some issues did remain unresolved, since they did not apply at this project due to various reasons, historic preservation for example. Cooling supported by solar thermal collectors would be interesting to apply in this area. This would mainly reduce electricity costs, being higher costs in this field, as described.

6 Literature

6.1 Publications

[P ASHRAE 55-2010, 2010]	American Society of Heating, Refrigerating and Air-Conditioning Engineers, ASHRAE 55-2010 'Thermal Environmental Conditions for Human Occupancy' ISSN 1041-2336, © 2010
[P ASHRAE 55-2004, 2004]	American Society of Heating, Refrigerating and Air-Conditioning Engineers, ASHRAE 55-2004 'Thermal Environmental Conditions for Human Occupancy'
[P ASHRAE 90.1-2010, 2010]	American Society of Heating, Refrigerating and Air-Conditioning Engineers, ASHRAE 55-2010 'Energy Standards for Buildings except Low-Rise Residential Buildings' ISSN 1041-2336, © 2010
[P ASHRAE Handbook, 2009]	American Society of Heating, Refrigerating and Air Conditioning Engineers 'Handbook of Fundamentals', Inch Pound Edition, 2009
[P Bachner, 2013]	Bachner, D., MSc. "Assessment of characteristic official buildings in the City of Savannah with respect to the thermal insulation performance of the building envelope and its optimization potential" Master Thesis Wels, January 2013

[P Brychta, M., 2013] DI Brychta, M.
‚Dynamic Thermal Simulations‘
17.12.2013

[P BWL 3, 2006] ‘Betriebswirtschaftslehre 3’
1st Edition
Mainz Schulbuchverlag, Vienna 2006

[P Cleary N, 2011] ‚Refrigeration and HVAC- Part 1‘
Noel Cleary
ITT Dublin, 2011

[P EIA, 2014] United States Energy Information Administration n
‘Annual Outlook 2014’
published April 2014

[P energy star, 2013] Energy Star
‘Energy Star Product list’
Excel file
list posted on May, 2013

[P eQuest Overview, 2014] eQuest
Overview
‘eQuest… the quick energy simulation tool’
page 15, 2014

[P Felder & Associates, 2014] Felder & Associates
Historic Structure Report
14th March, 2014

[P Fernandes et al., 2010] Fernandes et al, F.M.,
Ancient Clay Bricks,
ISBN: 978-90-481-2683-5
Springer, Netherlands, 2010

[P Georgia Power, 2014] Georgia Power- Southern Company
'Full Service to governmental institutions service G17'
March, 2014

[P Hindrichs U. D., Daniels K., 2007] *Dirk U. Hindrichs, Klaus Daniels*
‚Plus minus 20°C/40° latitude – Sustainable building design in tropical and suptropical regions'
Edition Axel Menges Stutgart/London
SCHÜCO, o.0. 2007

[P Hirsch, 2009] Hirsch, James J. and Associates
'Building Energy Use and Cost analysis Program -Volume 4: Libraries and Reports'
Berkley, California
March 2009

[P Lstiburek, J., 2002] J. Lstiburek, Ph.D P.Eng. Member ASHRAE
'Moisture Control for Buildings'
published February 2002, ASHRAE Journal

[P Lstiburek, W., 2004] W. Lstiburek, Ph.D P.Eng. Member ASHRAE
Smart Building Applications
'Understanding Vapor Barriers'
published August 2004, ASHRAE Journal

[P ONV, 2001] Österreichisches Normungsinstitut
Austrian Standards Institution
'Katalog für wärmeschutztechnische Rechenwerte von Baustoffen und Bauteilen'
published 1st December, 2001

[P Pacific Northwest, 2009] Pacific Northwest, National Laboratory
`Infiltration Modeling Guidelines for Commercial Building Energy Analysis`
Gwori, K. et al
September, 2009
page 12f.

[P Persily et al, 1985] Persily, PHD, A.K. and Grot, PHD, R.A.
'The air tightness of office building envelopes'
Proceedings of the ASHRAE/DOE/BTECC conference on the thermal performance of exterior envelopes of buildings III
Clearwater Beach, FL, 1985

[P Pilkington, 2011] Pilkington Building Products North America
'Vaccum Glazing – Pilkington Spacia'
Brochure
June 2011

[P Pilkington Ltd., 2012] Pilkington Group Limited
'Global Glass Handbook- Architectural Products'
2012

[P Reichl et al, 2004] Reichl, C., Mann, M., Haider, G.
'Pedestrian comfort analysis in large scale urban building projects'
Arsenal Research, 2004

[P Riccabona, 2003] Arch. Dipl.-Ing. Dr. techn. Riccabona, Christof
'Baukonstruktionslehre 4 – Bauphysik'
7th Edition, ISBN978-3-7068-3910-5
Manz Verlag, o.O, 2003

[P SCAD, 2014] Savannah College of Art and Design
Waterworks Booklet
Winter 2014

[P Spracher L., 2014] Luciana M. Spracher,
"City of Savannah Waterworks Pumphouse"
Bricks and Bones Historical Research
© City of Savannah, February 2005

[P Tamara, Shaw, 1976] Tamura, G.T. and C.Y. Shaw
'Studies on exterior wall air tightness and air infiltration of tall buildings'
1976

[P UC Berkley, 1981] Energy and Environment Division,
Building energy Simulation Group
Lawrence Berkley Laboratory
"DOE-2 Engineers Manual",
Solar Energy Group, Energy Division
University of California, 1981

6.1 Internet resources

[I Building Science A, 2014] Building Science
'BSD-012: Moisture Control for New Residential Buildings'
http://www.buildingscience.com/documents/digests/bsd-012-moisture-control-for-new-residential-buildings
access in May 2014

[I Building Science B, 2014] Building Science
'BSD-012: BSD-106: Understanding Vapor Barriers'
http://www.buildingscience.com/documents/digests/bsd-106-understanding-vapor-barriers?topic=doctypes/digests
access in May 2014

[I Corrugated Metal, 2014] Corrugated Metals, A Division of Mechanical Metals
'Corrugated Metal Panels'
http://www.corrugatedmetal.com/corrugated-metal-panels/
access in March 2014

[I DOE, 2010] U.S. Department of Energy
'Guidelines for selecting cool roofs building technologies program'
http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/coolroofguide.pdf.
access on 21th June, 2014

[I EIA, 2014] U.S Energy Information Administration
'Annual Energy Outlook – Table Browser'
http://www.eia.gov/oiaf/aeo/tablebrowser/#release=AEO2014ER&subject=3-AEO2014ER&table=3-AEO2014ER&region=1-0&cases=ref2014er-d102413a
access in August 2014

[I Energy Models A, 2014] Energy Models
'Approved LEEED simulation software packages'
http://energy-models.com/blog/list-approved-leed-simulation-software-packages
access in March 2014

[I Energy Models B, 2014] Energy Models
'Introduction to eQuest Energy Modeling'
http://energy-models.com/training/equest/introduction
access in March 2014

[I Energy Models C, 2014] Energy Models
'How to model Solar Heat Gain coefficient in eQuest'
http://energy-models.com/forum/how-model-shgc-equest
access May 2014

[I Engineering ToolBox, 2014] The Engineering ToolBox
'Densities of Miscellaneous Solids'
http://www.engineeringtoolbox.com/density-solids-d_1265.html
access in March 2014

[I Frauenhofer ISE, 2014] Frauenhofer ISE
graph,
http://www.green-therm-cool-center.de/text/13/de/kaelteerzeugung.html
access August 2014

[I Georgia Power, 2014] Georgia Power Natural Gas
'What will my Georgia Natural Gas Bill look like?'
https://onlygng.com/business/faq.asp#
access in August 2014

[I Google Maps, 2014] Google Maps
© Google 2014,
access on 20th June, 2014

[I International Code Council, C301, 2014] International Code Council
'Energy Conservation Code-Section C301 Climate Zones'
http://publicecodes.cyberregs.com/icod/iecc/2012/icod_iecc_2012_ce3_sec001.htm
access in March 2014

[I International Code Council, C402, 2014] International Code Council
'Energy Conservation Code- Building envelope requirements'
http://publicecodes.cyberregs.com/icod/iecc/2012/icod_iecc_2012_ce4_sec002.htm
access in March 2014

[I MIT, 2014] Massachusetts Institute of Technology
'Data useful in heat and mass transfer'
http://web.mit.edu/2.51/www/data.html#c
access in March 2014

[I MIT Energy Club, 2007] MIT Energy Club: Units & Conversions Fact Sheet
Massachusetts Institute of Technology
published 2007
http://www.mitenergyclub.org/assets/2008/11/15/Units_ConvFactors.MIT_EnergyClub_Factsheet.v8.pdf
access online on 18th June 2014

[I NREL, 2008] National Renewable Energy Laboratory
National Solar Radiation Data Base
TMY Data from Station 722070: Savannah Intl AP
http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/by_state_and_city.html, © 2008
online, Access on March 16th, 2014

[I National Park Service, 2014] National Park Service
U.S. Department of the Interior
'Roofing for Historic Buildings'
http://www.nps.gov/tps/how-to-preserve/briefs/4-roofing.htm#historic
access in March 2014

[I Pacific Power, 2014] Pacific Power
'Understanding your electricity charges'
https://www.pacificpower.net/bus/ayu/uyec.html
access in March 2014

[I TRNSYS, 2014] Trnsys Demo version
http://trnsys.com/demo/
access in March 2014

[I USBGC, 2014] United States Green Building Council
'Energy Modeling for LEEED Projects'
http://www.usgbc.org/Docs/Archive/External/Docs3478.pdf
access in March 2014

[I U-value, 2014] U-wert.net UG
www.u-value.net
access in March 2014 until June 2014

[I Wolfram Alpha, 2014] Wolfram Alpha
Climate Savannah Georgia
http://www.wolframalpha.com/input/?i=climate+savannah+georgia
access on 21th June 2014

[I World Bank, 2014] The World Bank- Data
'Inflation – GDP Deflator (annual %)'
http://data.worldbank.org/indicator/NY.GDP.DEFL.KD.ZG
/countries/1W-US?display=graph
access August 2014

6.2 Oral Sources and Emails

[O Carangelo, 10th June, 2014] Jason Carangelo
Building Inspections Administrator
Development Services Department, City of Savannah
Email,
31401 Savannah, 10th June, 2014

[O Harrise, 6th June, 2014] Ellen Harrise, LEED A.P., AICP
Director of Urban Planning and Historic Preservation
Metropolitan Planning Commission
Meeting,
City Hall, 2 E Bay St, 31401 Savannah, 6th June, 2014

[O Knight, 23rd April, 2014] Christina Knight
Accounting, City of Savannah
Email
23th April, 2014

[O Marr, 6th March, 2014] Garrison Marr
Sustainable Development Administrator, City of Savannah
Introduction
Thomas Gamble Building, 3 E Bay St, 31401 Savannah,
6th March, 2014

[O Lanier, 27th May, 2014] Clay Lanier
Regional Sales Manager, Pilkington North America, Inc.
Email
27th May, 2014

[O Saxon, 23rd April, 2014] Kimberly Saxon
Accounting, City of Savannah
Email
23th April, 2014

[O Shonka, 13th March, 2014] Peter Shonka
Assistant City Manager, City of Savannah
Water Works Building Tour,
31401 Savannah, 13th March, 2014

[O Shonka, 24th April, 2014] Peter Shonka
Assistant City Manager, City of Savannah
Meeting,
City Hall, 2 E Bay St, 31401 Savannah, 24th April, 2014

[O Shonka, 06th June, 2014] Peter Shonka
Assistant City Manager, City of Savannah
Meeting with Jason Carangelo,
City Hall, 2 E Bay St, 31401 Savannah, 6th June, 2014

6.3 Software

[SW ArchiCAD, 2013] ArchiCAD™ 16 International
Architectural 3D Modeling Software
GRAPHISOFT Deutschland GmbH
Educational Version, © 2013

[SW eQuest, 2014] Quick Energy Simulation Tool
© James J. Hirsch,
portion © University of California and Autodesk Inc.
Version 3.65, 2014

7 Register

7.1 Table of Figures

Figure 1: Rise in energy consumption in United States [P EIA, Appendix A2, 2014] 1
Figure 2: Energy use in commercial sector [P EIA, Appendix A5, 2014] 2
Figure 3: Energy Prices, Commercial Natural Gas, United States, [I EIA, 2014] 2
Figure 4: Energy Prices, Commercial Electricity, United States, [I EIA, 2014] 3
Figure 5: climate zones within the United States [P Lstiburek, J., 2002] 5
Figure 6: Temperatures in January [P Hindrichs U. D., Daniels K., p49, 2007] 6
Figure 7: Temperatures in July [P Hindrichs U. D., Daniels K., p49, 2007] 6
Figure 8: Precipitation over the year [P Hindrichs U. D., Daniels K., p 52, 2007] 7
Figure 9: Temperature distribution Savannah, Georgia [I Wolfram Alpha, 2014] 7
Figure 10: Relative humidity Savannah, Georgia [I Wolfram Alpha, 2014] 8
Figure 11: condition changes in h,x-diagram, [P Hindrichs U. D., Daniels K., p33, 2007] 10
Figure 12: acceptable range of temperature and humidity in air, [P ASHRAE 55-2004, p5, 2004] 11
Figure 13: Radiation transmission of standard window glass [P Hindrichs U. D., Daniels K., p 242, 2007] 12
Figure 14: transmission of different glass types over wavelength [P Hindrichs U. D., Daniels K., p 242, 2007] 12
Figure 15: humidity impact on exterior building components [P Hindrichs U. D., Daniels K., p 220, 2007] 13
Figure 16: vapor diffusion through exterior building component [P Hindrichs U. D., Daniels K., p 220, 2007] 14
Figure 17: Vapor Barrier Flow Chart for Zone 1-to 4 [P Lstiburek, W., p49, 2004] 14
Figure 18: cooling demand savings example dependent on the orientation [P Hindrichs U. D., Daniels K., p 223, 2007] 15
Figure 19: cooling demand savings example dependent on the insulation [P Hindrichs U. D., Daniels K., p 223, 2007] 15
Figure 20: cooling and heating demand savings example dependent on the insulation [P Hindrichs U. D., Daniels K., p 223, 2007] 15

Figure 21: savings in annual cooling energy demand in % for various solar absorption coefficients in different climates [P Hindrichs U. D., Daniels K., p 223, 2007] 16
Figure 22: electricity charge divisions, [I Pacific Power, 2014]..19
Figure 23: Location Waterworks Building [I Google Maps, 2014] 21
Figure 24: Building Context Map [P Felder & Associates, II p 19, 2014.................................22
Figure 25: On-site visit front entrance...24
Figure 26: On-site visit, roof construction 24
Figure 27: On-site visit, wall construction 24
Figure 28: On-site visit, windows 1...25
Figure 29: On-site visit, windows 2...25
Figure 30: On-site visit, windows 3...25
Figure 31: On-site visit, closed openings 1 25
Figure 32: On-site visit, closed openings 2 25
Figure 33: On-site visit, altered opening..26
Figure 34: On-site visit, Interior Stucco [P Felder & Associates, 2014] 26
Figure 35: Energy Analysis, Model drawn in [SW eQuest, 2014] 27
Figure 36: Trend of natural gas costumer charge rate, City of Savannah, [O Knight, 23rd April, 2014] 29
Figure 37: Trend of natural gas commodity charge rate, City of Savannah, [O Knight, 23rd April, 2014]..30
Figure 38: Average yearly electricity rate, city of Savannah, [O Saxon, 23rd April, 2014]. 30
Figure 39: electricity rate, 6 years, monthly fluctuation, [O Saxon, 23rd April, 2014]. 31
Figure 40: electricity rate trend city of Savannah, [O Saxon, 23rd April, 2014]. 31
Figure 41: Energy Analysis, Floor structure, [P Felder & Associates, III p21, 2014], [O Shonka, 13th March, 2014]...34
Figure 42: Energy Analysis, air conditioning, depicted in [SW eQuest, 2014]........................38
Figure 43: Energy Analysis, simulation result, annual energy consumption by enduse 38
Figure 44: Energy Analysis, simulation result, energy consumption in sectors 39
Figure 45: Energy Analysis, simulation result, electricity and gas consumption....................39
Figure 46: Energy Analysis, simulation result, electricity and gas peak demand...................40
Figure 47: Openings, structure input...42
Figure 48: Windows, Energy Demand Reduction 45

Figure 49: Windows, Peak Load Reduction 45
Figure 50: windows, utility costs reduction 46
Figure 51: Windows, overall percentage of demand 47
Figure 52: Floor B input....48
Figure 53: Floor C input....49
Figure 54: Floor, Energy demand reduction 49
Figure 55: Floor, peak load reduction....50
Figure 56: Floor, utility cost reduction....50
Figure 57: Floor overall demand reduction 51
Figure 58: Roof B input, drawn in [I U-value, 2014] 52
Figure 59: Roof B, relative humidity in summer and winter, without foil, drawn in [I U-value, 2014] 52
Figure 60: Roof B, relative humidity in summer and winter, with vapor barrier, drawn in [I U-value, 2014]....53
Figure 61: Roof B, relative humidity in summer and winter, with moisture variable vapor check, drawn in [I U-value, 2014] 54
Figure 62: Roof B, relative humidity in summer and winter, [I U-value, 2014]....55
Figure 63: Roof C input 56
Figure 64: Roof B, relative humidity in summer and winter, without foil, drawn in [I U-value, 2014] 57
Figure 65: Roof, energy demand reduction....57
Figure 66: Roof, Utility cost reduction....59
Figure 67: Roof, peak load reduction....59
Figure 68: Roof, overall demand reduction 60
Figure 69: Daylight measure, restrictions....61
Figure 70: Daylight measures, demand reduction....62
Figure 71: Daylight measures, peak load reduction 63
Figure 72: Daylight measures, utility cost reduction 63
Figure 73: Daylight measures, overall reduction 64
Figure 74: Building Tightness, demand reduction 65
Figure 75: Tightness, peak load reduction....66
Figure 76: Tightness, utility costs reduction 67

Figure 77: Overall measures with infiltration, annual energy consumption by enduse 67
Figure 78: Overall measures with infiltration, energy demand monthly distribution 68
Figure 79: Overall measures with infiltration, peak demand monthly distribution................68
Figure 80: HVAC System B input 70
Figure 81: HVAC, System E [SW eQuest, 2014] 71
Figure 82: HVAC demand reduction 72
Figure 83: Example Desiccant and Evaporative Cooling Unit, [I Frauenhofer ISE, 2014]........73
Figure 84: HVAC utility cost reduction...74
Figure 85: HVAC, peak load reduction...74
Figure 86: Inflation as measured by the annual growth rate of the GDP implicit deflator [I World Bank, 2014] 76
Figure 87: Design exterior view 1 81
Figure 88: Design exterior view 2 81
Figure 89: Design exterior view 3 82
Figure 90: Main entrance interior...82
Figure 91: Engine room entrance area interior 1 83
Figure 92: Engine room entrance area interior 2 83
Figure 93: Engine room balcony 1 84
Figure 94: Engine room balcony 2 84
Figure 95: Engine room, break room 2nd floor 1 84
Figure 96: Engine room, break room 2nd floor 2 84
Figure 97: Engine room, meeting room 2nd floor 84
Figure 98: Engine room, 3rd floor 1..85
Figure 99: Engine room, 3rd floor 2..85
Figure 100: Engine room, 3rd floor 3..85
Figure 101: Boiler room entrance area interior 1...86
Figure 102: Boiler room entrance area interior 2...86
Figure 103: Boiler room 2nd floor hallway 86
Figure 104: Boiler room 3rd floor 87
Figure 105: Boiler room 3rd floor meeting space..87
Figure 106: Tower 1st floor office...87
Figure 107: Tower 2d floor bar and café 88

Figure 108: Tower 3rd floor observation deck 88
Figure 109: Design Proposal Pilkington Spacia 89

7.2 Table of Tables

Table 1: conversion table [I MIT Energy Club, 2007] 4
Table 2: Overview of the accepted experienced temperature conditions as a function of wet bulb temperature with a maximum air velocity of 0.15 m/s [P Cleary N, 2011] according to ASHRAE 55-2010, 2010]. 10
Table 3: Thermal Envelope Requirements according to Energy Conservation Code, Climate Zone 2A [I International Code Council, C402.2, 2014], [I International Code Council, C402.1, 2014] according to [P ASHRAE 90.1-2010, p 27, 2010] 16
Table 4: Window Requirements according to Energy Conservation Code, Climate Zone 2A [I International Code Council, C402.3, 2014] 18
Table 5: On-site visit data 23
Table 6: condensation analysis, temperatures [P Bachner p6, 2013] [I Wolfram Alpha, 2014] 28
Table 7: Construction Materials for Energy Analysis, [I MIT, 2014], [P Fernandes et al, chapter III p 6, 2010], [P ONV, chapter 31, p12, 2001], [P Riccabona, p329, 2003]....................32
Table 8: gross floor area, energy analysis 32
Table 9: Wall thickness, energy analysis 34
Table 10: Energy Analysis, Percentage of Area 36
Table 11: Energy Analysis, HVAC systems and assigned Zones 37
Table 12: energy analysis, key results 40
Table 13: overall insulation measures, result summary 69
Table 14: mean value of inflation regarding different periods 77
Table 15: Windows, net present value dependent on year 78
Table 16: Roof, net present value dependent on year 79
Table 17: Overall measures, net present value dependent on year 79

7.3 Table of Equations

Equation 1: shading coefficient, [I Energy Models C, 2014], [P Hindrichs U. D., Daniels K., 2007] 18
Equation 2: Energy Analysis, calculation of natural ventilation [P Pacific Northwest, p12, 2009], ... 36
Equation 3: Energy Analysis, calculation of natural ventilation, [P Reichl et al, 2004, p4], [P Pacific Northwest, p12, 2009], [P Persily et al, p125, 1985],.. 37
Equation 4: discounting of the annual cash flow, [P BWL 3, p152, 2006].............................. 75

8 Appendix

Number	Name
8.1	Design plans
8.2	Plans in historic structure report
8.3	Windows and doors input
8.4	Simulation result summary
8.5	Simulation reports