FACHHOCHSCHUL-MASTERSTUDIENGANG

Öko-Energietechnik

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

ALS DIPLOMARBEIT EINGEREICHT

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von

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Prof. (FH) Dr. Peter Zeller

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Georgia Tech Savannah

City of Savannah

DECLARATION OF ACADEMIC INTEGRITY

I declare that this master thesis is my own work and that all sources and papers that I have used have been properly cited in the references. No other sources or external help was used.

This paper has neither been submitted to another examination board in the same or similar version nor has it been published.

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Daniela Bachner

Wels, 30 January 2013

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It is my desire to convey my special thanks to Garrison Marr for taking the extra burden of involving me into his projects, letting me take a look into the daily business and never getting tired of supporting and guiding me. You are the reason that I had an unforgettable and successful time in Savannah!

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And thanks to all the strong people around me – my family and friends – who never get tired of supporting me.

ABSTRACT

Reducing costs is an essential target in all economic sectors and so it is for the public sector. One way of addressing cost reduction is to reduce the energy consumption. The City of Savannah in the United State of Georgia is a pioneer in setting environmental targets. By joining the Georgia Energy Challenge in 2008 the city government committed itself to reduce the city's overall energy consumption by 15 percent by 2020 (on the basis of 2007). It also implemented ambitious energy efficiency standards for its neighborhood development programs. In November 2012 the Savannah International Clean Energy Conference took place for the first time offering a platform to discuss clean energy opportunities.

In conjunction with the Clean Energy Conference cooperation between the University of Applied Sciences Upper Austria and the City of Savannah, Georgia, was established giving students the possibility to work on a research project with the City of Savannah. The major task of the project was to do energy assessments for the city's buildings most in need. The energy assessments were done in cooperation with Mike Brown from Enterprise Innovation Institute, Georgia Institute of Technology.

In the first step the buildings energy consumption was analyzed by means of monitoring software and those buildings with the highest energy consumption related to the building's area were determined. Buildings that had not been subject to an assessment yet were proposed and finally two fire stations were selected for an assessment. One of them was a construction from the 1950s and the other one was built in 2011. This allowed a direct comparison between an old and a new station.

For these two buildings the energy consumption was analyzed in detail. An on-site visit has been executed to collect information about the building's structure, mechanical equipment, operation modes and appliances. This information was entered into the software eQUEST 3.64 from James J. Hirsch to simulate the buildings energy consumption patterns. Even though the building envelope and the mechanical system interact with each other and neither one can stand alone, the

main focus was put onto the building envelope in this paper. Improvement measures were defined and their impacts and payback periods were quantified.

The most suitable retrofit measures of the building envelope are the installation of weather-stripping around the garage doors and the installation of storm windows on single-pane windows, the replacement of exterior wooden doors and the substitution of double-pane wood-frame windows with insulating panels. With these measures 6.027 kWh/year of energy – or 8% of the yearly consumption – can be saved. The implementation costs amount to $5.236, which will payback within a period of 5,84 years.

General recommendations for the construction of new buildings were made that include a deliberate building orientation, the implementation of insulation in wall and roof constructions or the use of reflective roof coating. Many opportunities to reduce the energy consumption of buildings were discussed. Due to relatively low energy prices most recommendations are not economically feasible for retrofits. The implementation of energy-efficient measures in new constructions, however, should be adopted with a blanket coverage.

CONVERSION TABLE

Table 1: Conversion Table - Metric and IP System [MIT Energy Club, 2007]

Massachusetts Institute of Technology

Units & Conversions Fact Sheet

Derek Supple, MIT Energy Club
http://web.mit.edu/mit_energy
Latest Update: 4/15/2007

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

ºF = 1.8 • ºC + 32
ºK = (ºF – 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 = 10bar = 9.87atm = 145psi
1atm = 1.0132 bar = 760 mmHg
= 14.696 psi = 10.33 ton/m^3

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 kgm²/s² = 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

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

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

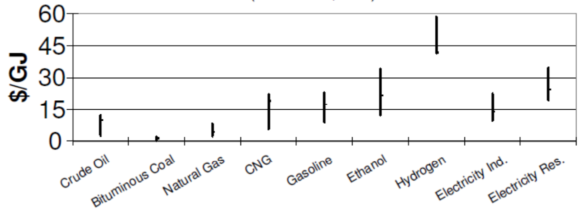
Crude Oil = 6.119 GJ/bbl = 5.8 mmBtu/bbl = 39.7 mmBtu/ton
= 145.7 MJ/gal = 38.5 MJ/L = 43.8 MJ/kg (GJ/ton)
Gasoline = 121.3 MJ/gal (= 32.1 MJ/L = 43.1 MJ/kg = 115 mBtu/gal)
Diesel = 135.5 MJ/gal (= 35.8 MJ/L = 42.8 MJ/kg = 128 mBtu/gal)
Biodiesel = 124.8 MJ/gal (= 33.0 MJ/L = 37.5 MJ/kg = 121 mBtu/gal)
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)

API Gravity = (141.5/[Density in g/cm^3 at 60 ºF]) - 131.5
Light Crude API > 31.1º; Heavy API < 22.3º; Bitumen API ~ 8º

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/m²

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

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Even though all calculations were made with USCS units (United States Customary System Units), which are commonly used in the United States, this paper is in SI units as they are internationally used. As the conversion table on page VI is taken from the Massachusetts Institute of Technology (MIT) Energy Club, the table uses the American punctuation system, where [.] is a comma and [,] is the thousands separator. In the following paper, however, [.] stands for the thousands separator and [,] for a comma.

TABLE OF CONTENTS

1. PREFACE

Saving energy is not only an environmental aspect. Much more it is an economical issue in times of economic turbulences. Navigating through turbulent financial times is an almost insurmountable task for many companies but also for public administrations. In these times saving costs cannot be achieved by dismissing evermore employees considering that unemployment figures rise continuously and that empty treasuries are unable to maintain social security. Other ways to reduce costs have to be found and one of them is certainly saving energy. Already during the first oil crisis in the 1970s this attempt was made, however, it faded away, but in recent years saving energy became a major issue again.

The world is confronted with declining energy resources and increasing environmental struggles. Many scientific papers draw a picture of soon depleting energy resources. It is very likely that energy prices will continue to rise as they did in the recent past. Preparing for high energy costs and hence uncertain economic situations is therefore very important for both private and public entities. A very efficient way to do this so, is to reduce energy consumption. Using less energy to achieve the same results leads to reduced costs. But it also leads to less dependence from others. If a country manages to reduce its energy consumption, it is easier to meet its energy needs on its own and to balance its foreign trade.

Especially when taking into account the narrow means of many municipalities, conserving energy is a necessary measure and it is one of the rare ways how city administrations can reduce costs and benefit in the future. There is a variety of areas that can be addressed to save energy without reducing comfort, such as traffic lights, pumps, and furthermore the energy consumption of buildings. This is especially true for commercial buildings that are only occupied during daytime.

The City of Savannah tries to follow this path and to position itself as a leader in energy efficiency and conservation as well as renewable energy technology. Therefore, in November 2012 the Savannah International Clean Energy Conference took place for the first time bringing together specialists in all those fields to discuss about future energy supply and Georgia's position in this development. As part of the conference the energy consumption of Savannah's buildings was analyzed, benchmarked and ways to reduce the building's energy consumption were identified in form of a student research project in cooperation with the University of Applied Sciences Upper Austria and the Georgia Institute of Technology.

Therefore, this paper deals with the identification and the quantification of feasible improvement measures of official buildings in places with hot and humid climate such as Savannah, Georgia.

The paper is divided into 8 chapters. In the following chapter 2 the project location, Savannah, is depicted. Chapter 3 focuses on the energy supply and consumption in the United States and the world. In chapter 4 general information and fundamentals of physics are discussed. Chapter 5 presents construction principles in the United States. The calculation procedure and analysis method are described in chapter 6, while chapter 7 depicts the final results. Finally, chapter 8 contains conclusions and recommendations for future projects.

2. THE CITY OF SAVANNAH

The city of Savannah is located in the southeast of the United State Georgia around 25 kilometers from the Atlantic shore, see Figure 1. In the following paragraphs the history of the city will be summarized.

Figure 1: Map USA [Delta Vacations, 2012]

2.1. Brief history

Savannah was founded in 1733 when English settlers under General James Edward Oglethorpe arrived and established the state of Georgia, named after the British king George II. Those settlers were sent to the new world to establish a buffer zone between the British colony in South Carolina and the Spanish territories in present-day Florida as well as a prospering new colony that would produce agricultural goods and ores. [Porter & Prince, 2011, page 10f].

As nearby Charleston in South Carolina prospered, Savannah allowed slavery for the first time by the mid-18th century and became wealthy soon after. The main products were cotton, rice and indigo, which were shipped mainly to Great Britain.

Settlers in coastal Georgia suffered from numerous catastrophes such as the yellow fever, fires and the civil war, see [Porter & Prince 2011, page 13].

2.2. Present

Today Savannah is the fourth largest city in Georgia. It plays an important role due to its large seaport, which is the fourth largest in the nation [City of Savannah, 2012]. Its preserved architecture makes it a major tourist attraction with more than 12 million tourists visiting each year. The gross domestic product of Savannah in 2010 was $12,93 million [Bureau of Economic Analysis, 2012].

The 2010 U.S. census lists a population of 136.286. The following table shows the composition of the city's population.

Table 2: Savannah – Facts and data [US Census Bureau, 2012]

Total population, 2010	**136.286**
Persons per square mile, 2010	**1.321,2**
Female persons, percent, 2010	**52,1%**
White persons, percent, 2010 (a)	**38,3%**
Black persons, percent, 2010 (a)	**55,4%**
High school graduates, percent of persons age 25+, 2006-2010	**83,5%**
Bachelor's degree or higher, pct of persons age 25+, 2006-2010	**23,3%**
Housing units, 2010	**61.883**
Homeownership rate, 2006-2010	**47,4%**
Median value of owner-occupied housing units, 2006-2010	**$144.900**
Households, 2006-2010	**52.615**
Persons per household, 2006-2010	**2,43**
Per capita money income in past 12 months (2010 dollars) 2006-2010	**$19.836**
Median household income 2006-2010	**$33.316**
Persons below poverty level, percent, 2006-2010	**23,8%**
Total number of firms, 2007	**13.722**

2.3. Politics

Savannah has a democratic government, which is lead by the 65th mayor of Savannah, Edna Jackson, since 2011. She is the first African-American woman in this position. The city government consists further of eight alderman from six city districts [City of Savannah, 2012].

2.4. Building structure

Today the City of Savannah has approximately 146 buildings [Marr, 2012] that belong to the city's properties. As the different departments of the city administer their buildings separately, no general records are available. More than 1300 electric meters [Marr, 2012] measure the energy consumption of the city, which is available as an excel file from the utility company.

2.5. Heritage regulations

Savannah's city center, the Savannah Historic District, is under protection through the National Historic Preservation Act. Therefore, the outward appearance of the buildings is subject to conservation and any modification must meet a guideline from the U.S. Department of Interior.

However, as the selected buildings for the energy assessments were not subject to historic preservation, the regulations did not play an essential role for the development of improvement opportunities and are not listed in this paper.

2.6. Climate

Savannah is a city in the Southeast of the United States, located at a latitude of 32°08'N and a longitude of 081°12'W at an elevation of 14 meters [Climate-Charts, 2010]. As it is located on the Savannah River just 25 kilometers away from the river's estuary mouth, the climate is influenced strongly by the sea. The U.S. Department of Energy (DOE) has published the following Figure 2 displaying the different climate zones of the United States.

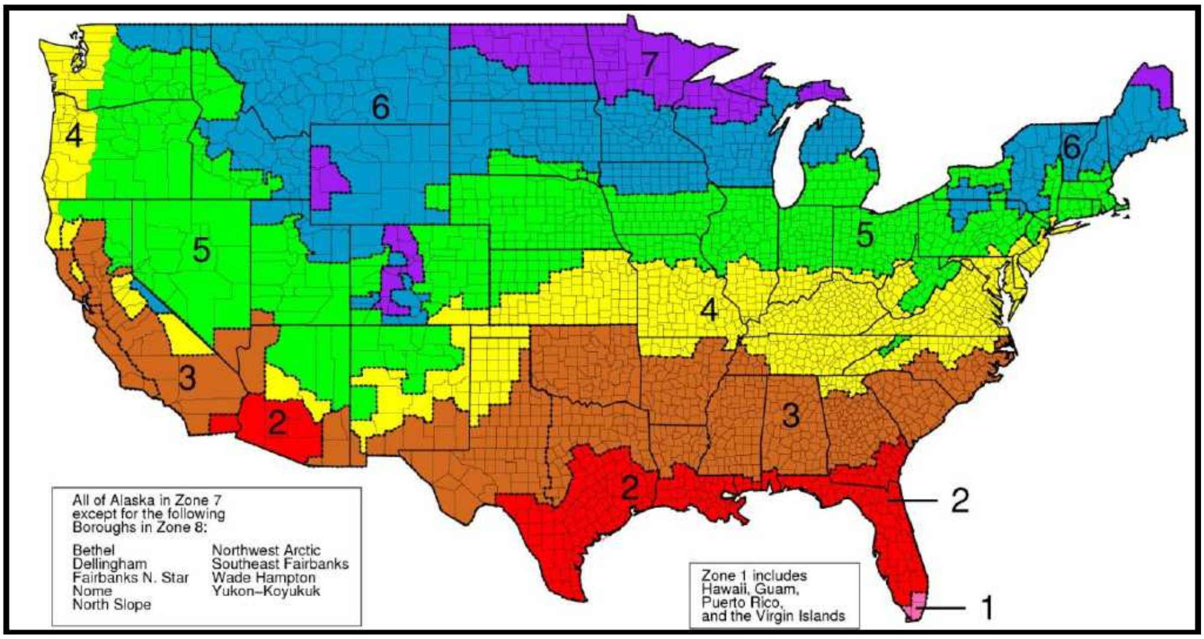


Figure 2: Climate Zones United States [DOE, 2010]

The Savannah area shows a hot and humid climate (2) with an average temperature of 27 °C (80 °F) in summer and 10 °C (50 °F) in winter [Wolfram Alpha, 2012]. A hot and humid climate is defined by "one or both [of] the following conditions: (1) a 67°F [19,5 °C] or higher wet-bulb temperature for 3000 or more hours during the warmest six consecutive months of the year; (2) a 73°F [23 °C] or higher wet-bulb temperature for 1750 or more hours during the warmest six consecutive months of the year" [ASHRAE Handbook, 2001, page 24.4].

Figure 3 shows the average temperature during the course of the year for Savannah, Georgia, whereas the minimum and maximum temperatures, which have been reached, are displayed as a light blue background.

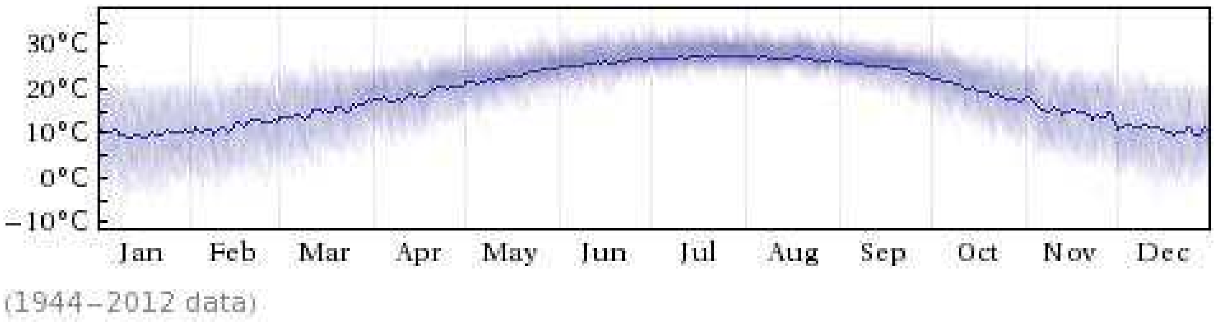


Figure 3: Average temperature for Savannah [Wolfram Alpha, 2012]

Characteristics of this climate are the moderate temperatures in winter and high amount of rainfall in the summer months as shown in Figure 4, which cause high humidity levels.

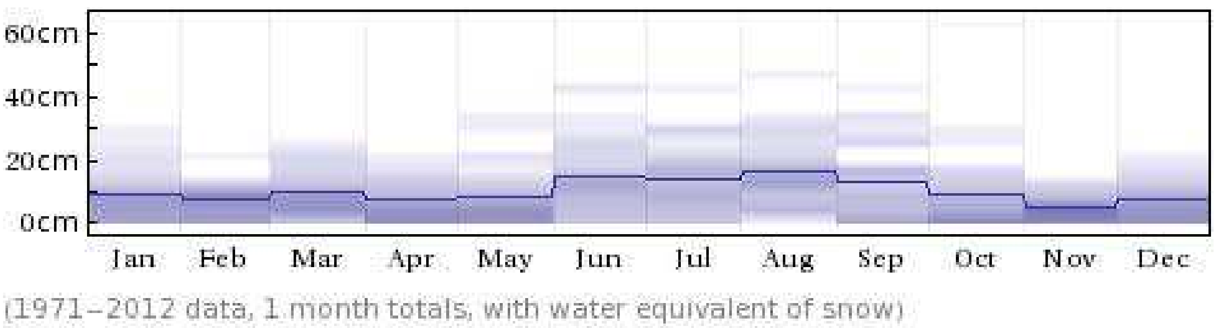


Figure 4: Average Precipitation for Savannah [Wolfram Alpha, 2012]

The climate has immense effects on constructions. The hot and humid climate is characterized by an intense solar radiation and high moisture levels [DOE, 2012A]. There is a minor need for heating, however a tremendous cooling load. Air-conditioning with dehumidification is essential in summer.

3. Energy Supply and Consumption

Energy is THE driving force in world economy. The need for energy is enormous and production is continuously increasing, as can be seen in Figure 5. Only in the late 1970s and beginning 1980s a light slowdown could be noticed after the second oil crisis in 1979, as well as in 2008 when a severe economic and financial crisis hit the world. As we are recovering from that crisis it is likely that energy production keeps going up unless governments succeed in implementing policies to increase energy efficiency, that means generate welfare and at the same time use less energy.

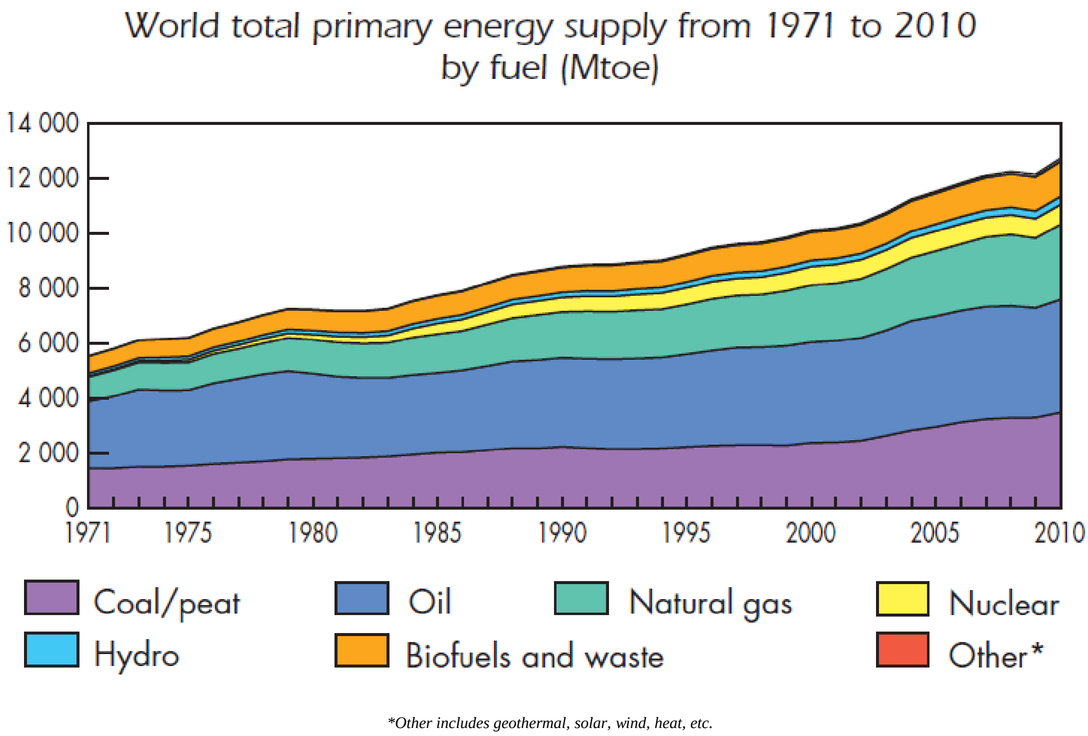


Figure 5: Energy supply by fuel source 1971-2010 [IEA, 2012]

Figure 5 above shows the development of the total energy supply from 1971 to 2010. A continuous increase since the 1970s can be seen, where several areas of reduced increase occurred. So in the early 1970s, the beginning of the 1980s as well as in 2008 the energy supply reduced slightly for a short period of time.

Fossil fuels including coal/peat, oil and natural gas increased over the whole period and have a share of roughly 80% of the total energy supply.

The United States is the largest economy in the world and has long been the largest energy consumer. Data from the U.S. Energy Information Agency states the total energy consumption of the year 2010 amounted to 97,3 Quadrillion Btu [EIA, 2012A]. This is equivalent to 28.517 TWh (compare Conversion Table, page VI). Only in 2010 China overtook the United States in terms of energy consumption [Enerdata, 2012].

As stated in the latest Key World Energy Statistics of 2012 of the International Energy Agency, the United States is not only the second largest producer of natural gas and the third largest producer of crude oil, providing 19,2 % respectively 8,6 % of world production of gas and crude oil, but it is also the world's largest net importer of crude oil and the fourth largest net importer of natural gas. It imported 513 Mt crude oil in 2009 and 55 bcm natural gas in 2010 compared to 74 bcm in 2009 [IEA, 2012, page 11ff] and [IEA, 2011, page 14]. The reduction in natural gas imports is caused by increased domestic production from shale gas.

Units used to express energy contents:

Btu	British thermal unit, 1 Btu = 1.055.056 J It is the energy required to raise the temperature of 1 pound of water by one degree F [Southface, 2012, page 85]
Mt	Megaton
bcm	Billion cubic meters, 10^9 m^3
Mtoe	Megaton of oil equivalent, 10^6 toe; toe is a unit for energy 1 toe = 41,87 MJ

The U.S. is furthermore a net exporter of coal and the world's largest producer of nuclear power, producing 30,4 % of total nuclear energy in 2010. It also generates the largest amount of electricity with 4.354 TWh in 2010 and holds the world's second largest installed hydro power capacity and generates 6,5 % of its electricity with hydro power. The United States has the world's largest refining capacity and is the largest producer of oil products, producing 802 Mt (20,9 % of world production) in 2010. The following paragraph compares the energy production by fuel type of the world, shown in column 1, in the United States, shown in the central column, and the energy production in the European Union in column 3.

WORLD	US	EU
In 2010 crude oil continued to be the predominant source of energy, taking up 33 % of total energy production. Other fossil fuels amounted to 27 % in the form of coal and 21 % as natural gas. Nuclear fuels amounted to 6 %. The total share of renewable energy sources in the world's production was 13%. The world's energy production in 2009 amounted to 12.717 Mtoe [IEA, 2012, page 6].	The energy supply in the United States in 2010 was dominated by fossil fuels. The share of crude oil was 37 %, while natural gas amounted to 25 % and coal to 21 %. Nuclear energy amounted to 9 % of total energy supply and renewable energy sources had a share of 8 % as displayed in Figure 7 [EIA, 2011, page 37]. The U.S. Energy Information Agency states that the total primary energy supply of the United States was 2.163 Mtoe in 2009 [IEA, 2011A].	The numbers about the energy production of the European Union for 2010 show that 28 % of the energy generated in the EU is from nuclear. Fossil fuels amount to 51 % of total production, where 20 % comes from coal, 19 % from gas and 12 % from crude oil. Another fifth of the energy production is generated from renewable energy sources. The European Union produced 837 Mtoe in 2010, which are 47,58 % of its energy demand of 1.759 Mtoe. [European Commission, 2012, page 16ff]

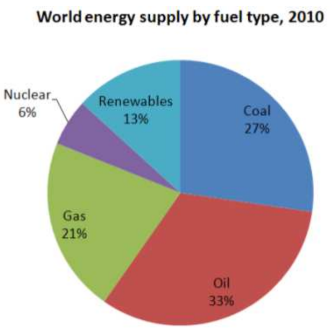
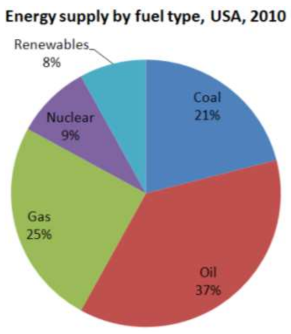
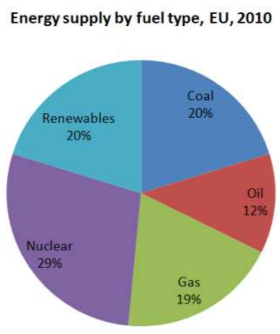

		

Figure 6: World Energy Production by Fuel in 2009, [European Commission, 2012]	**Figure 7: Energy Production U.S. in 2010, [EIA, 2011]**	**Figure 8: Energy Production EU-27 in 2010, [European Commission, 2012]**

The graphs below display the energy consumption and show a slightly different picture. It shows that oil is the most important energy source worldwide amounting to 41 % of the total energy consumption, while energy in form of coal and gas together amount to one quarter of the total energy consumption. Energy in form of electricity, which is transformed from other sources amounts to 18%. Biofuels, waste and others (geothermal, solar, wind, heat, etc.) represents 16% of the total energy consumption [IEA, 2012, page 28].

The United States and the European Union show an almost identical fuel mix in terms of total energy consumption. In both more than one third of the energy is consumed in form of oil and one fourth in form of natural gas. Coal has a smaller share in the European Union compared to the United States while nuclear energy is more important in the EU. Renewable energy sources sum up to 8% of the total energy consumption in the US and 10% in the EU, see [European Commission, 2012, page 18] and [EIA, 2012A, page 3].

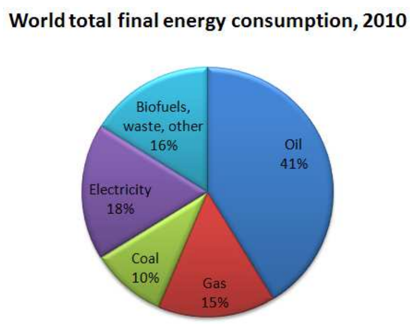


Figure 9: World total energy consumption, 2009 [IEA, 2012]

The yearly world energy consumption amounts to 8.677 Mtoe [IEA, 2012, page 28]. The deviation compared to the energy supply is caused by transformation losses and the use of oil in the petrochemical industry.

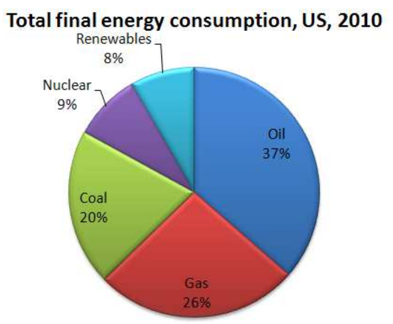


Figure 10: Total energy consumption, US, 2010 [EIA, 2012A]

The United States consumed 97,3 Quadrillion Btu or 2.451 Mtoe in 2011. This is 125 percent of what has been produced in the U.S in 2011. 18,7 percent were imported from outside [EIA, 2012A, page 3].

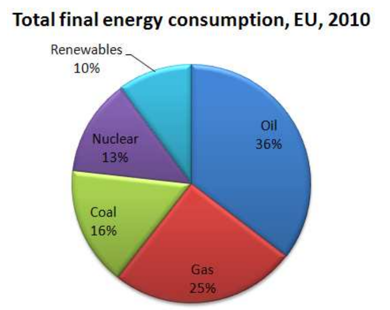


Figure 11: Total energy consumption, EU, 2010 [European Commission, 2012]

1.759 Mtoe of total energy was consumed in the European Union in 2010 [European Commission, 2012, page 18].

As this paper deals with the energy consumption in the building sector, the following paragraph displays the shares of energy consumption of the different sectors.

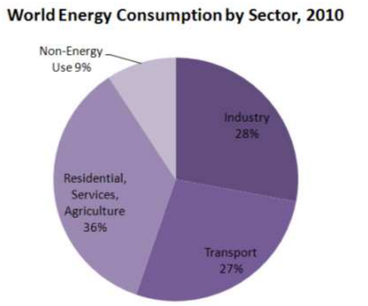


Figure 12: World Energy Consumption by Sector, 2010 [IEA, 2012]

The largest energy consumers worldwide are industry with 28% and the transport sector with 27% of total energy consumption. As the International Energy Agency IEA does not differentiate between residential and services, those sectors together consume 36% of the overall energy consumption. Non-Energy Use totals 9% of consumption [IEA, 2012, page 34].

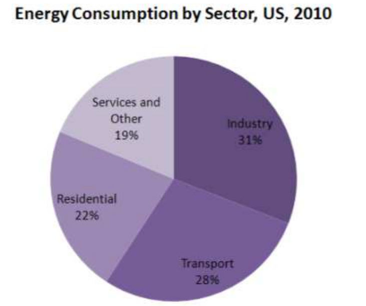


Figure 13: Energy Consumption by Sector, US, 2010 [EIA, 2012A]

The biggest amount of energy is consumed by the industrial sector in the United States. 31% are used there. The second biggest consumer is the transportation sector with 28%. Residential (22%) and Commercial (18%) consume somewhat smaller amounts of energy [EIA, 2012A, page 38]. Around 41% of total energy consumption is used for buildings, see [DOE, 2012B].

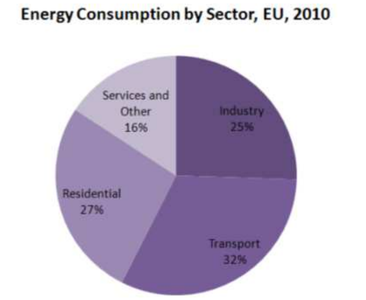


Figure 14: Energy Consumption by Sector, EU, 2010 [European Commission, 2012]

In the European Union the biggest consumer is the transportation sector with 32% of total energy consumption. Industry is only on third position with 25% after the residential sector (27%). Services and others consume 16% of the total energy used in the EU [European Commission, 2012, page 15].

Figure 15 below summarizes the energy flow in 2011 within the United States. The supply amounted to 107,66 Quadrillion Btu. 10,36 Quadrillion Btu (9,6 %) were exported and 97.30 Quadrillion Btu were consumed domestically.

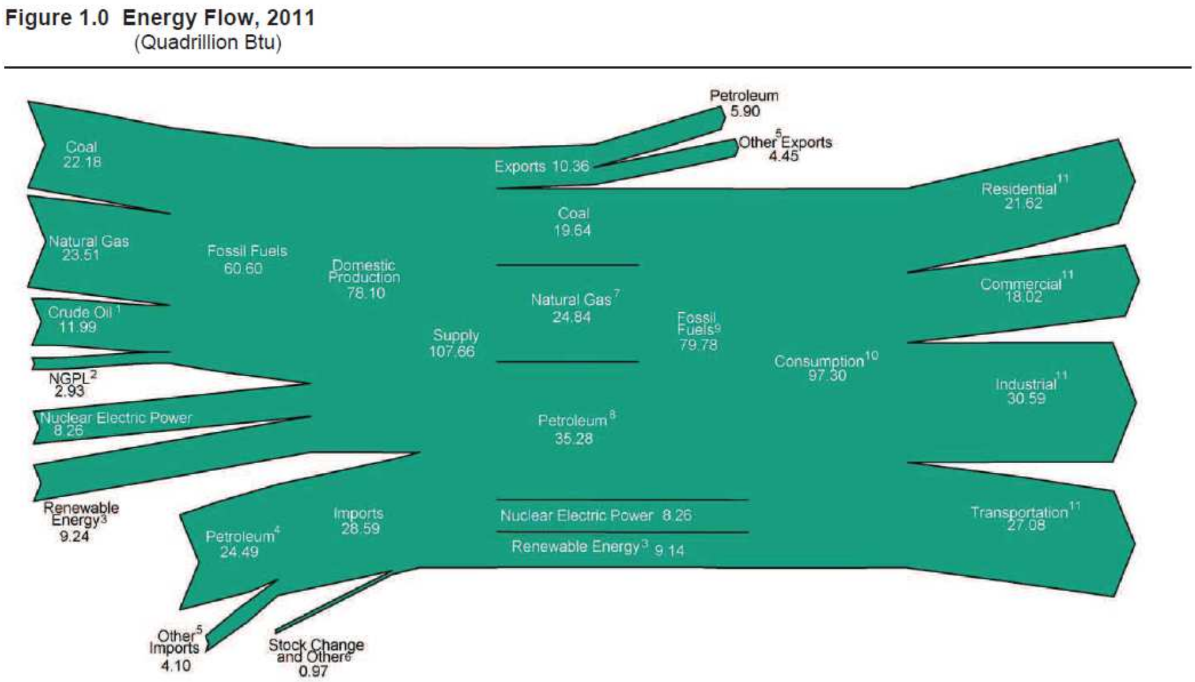


Figure 15: Energy Flow 2011 [EIA, 2012B]

The American economy is mostly dependent on fossil fuels, which make up 74,18% of the total supply. By far the most important energy source is petroleum. Similar to a lot of other countries, the U.S. is dependent on energy imports, which represent 26,56 % of its energy supply as displayed in Figure 15.

Like in most other countries also in the United States the demand for energy increased steadily. Since the late 2000s a slight reduction of energy consumption can be seen. Figure 16 shows the primary energy production and consumption as well as imports and exports in the period from 1949 to 2011.

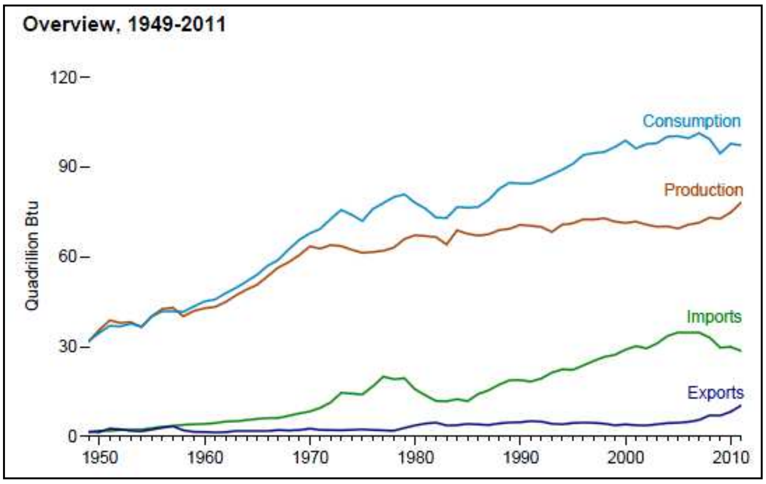


Figure 16: Primary Energy in the US, 1949-2011 [EIA, 2012A]

At the same time of the energy consumption reduction a dramatic decrease in energy prices is visible. This might be caused by the financial crisis of 2008. However in the last two years of the analyzed period increasing energy prices for crude oil, fossil fuel composite and coal are displayed in Figure 17 below.

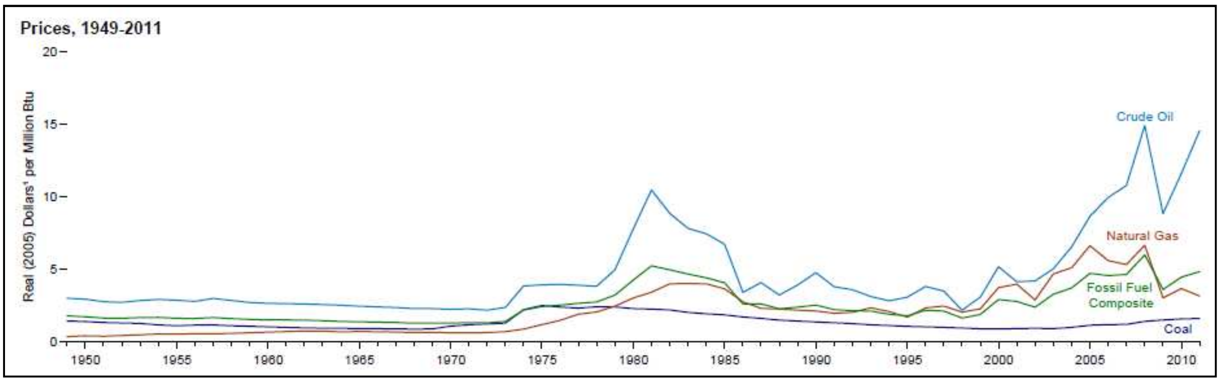


Figure 17: Energy Prices US 1949-2011 [EIA, 2012A]

Over the past years the U.S. federal government has achieved notable success in establishing policies that strengthen the use of renewable energy sources, cleaner energy technologies and reduce greenhouse gas emissions such as the Energy Policy Act, EPAct 2005. A slight reduction in energy consumption is already visible. In the near future one will see if this reduction is caused by effective policies or if it was caused by the recent economic crisis in the United States.

4. GENERAL INFORMATION

This chapter summarizes physical and technical background information that has been necessary to complete this work. Not only physics on heat transfer and resistance are treated but also principles of buildings simulation.

4.1. Heat transfer

To be able to describe heat loss and heat gain in buildings it is essential to understand the principle laws of heat transfer. In the following section heat transfer is explained.

Heat is thermal energy, whereas “mechanical, kinetic, potential, electrical, magnetic, chemical, and nuclear” [Çengel, 2003, page 6] are other forms of energy. When total energy E of a system is described all the above are taken into account. Heat is denoted by the letter Q. It is described in [Çengel, 2003, page 9] as

$$Q = \int_0^{\Delta t} \dot{Q} dt \qquad (4.1.1)$$

where

$\dot{Q}$ ... $Heat\ transfer\ rate\ \left[\frac{J}{s}\right]$

dt ... $time\ interval\ [s]$

Every energy transfer is caused by a potential difference and the urge of a system to reach an equilibrium state. In case of thermal energy a temperature difference causes the energy transfer from the system with the higher temperature to the one with a lower temperature. Heat is “transferred from one system to another as a result of temperature difference” [Çengel, 2003, page 17]. As “the temperature difference is the *driving force* for heat transfer” [Çengel, 2003, page 2], there can never be energy transferred between two mediums of the same temperature.

"The rate of heat transfer per unit area normal to the direction of heat transfer is called heat flux, and the average heat flux is express as

$$\dot{q} = \frac{\dot{Q}}{A} \qquad \left(\frac{W}{m^2}\right) \tag{4.1.2}$$

where A is the heat transfer area. […] [H]eat flux may vary with time as well as position on a surface" [Çengel, 2003, page 10]. The "rate of heat transfer in a certain direction depends on the magnitude of the temperature gradient (the temperature difference per unit length or the rate of change of temperature) in that direction. The larger the temperature gradient, the higher the rate of heat transfer" [Çengel, 2003, page 2f]. There are three ways how thermal energy can be transferred from one system to another: **conduction, convection and radiation.**

"[T]he heat conducted to the outer surface of the wall of a house in winter is convected away by the cold outdoor air while being radiated to the cold surroundings" [Çengel, 2003, page 13], as displayed in Figure 18 below, where heat is transferred through a wall to the exterior surface by conduction ($\dot{Q}_1$) and from the surface to the outside air by convection ($\dot{Q}_2$) as well as to other objects in the surrounding by radiation ($\dot{Q}_3$) [Çengel, 2003, page 14].

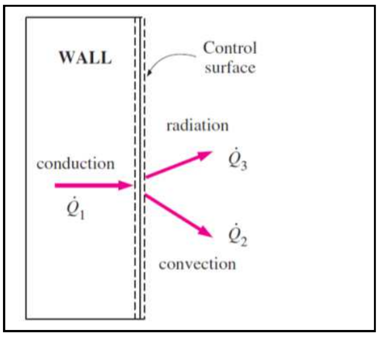


Figure 18: Heat transfer through wall [Çengel, 2003, page 14]

Heat transfer is an essential mechanism influencing a building's construction. It is responsible for loss and gain of thermal energy of a system and is therefore directly connected with the total energy consumption of a building. Energy efficient homes are designed with respect to the minimization of heat loss in winter and heat gain in summer, see [Çengel, 2003, page 3]. To be able to reduce the energy consumption the understanding of heat transfer is important.

4.1.1. Conduction

"Conduction is the transfer of kinetic energy between particles" [ASHRAE Handbook, 2001, page 3.1]. Particles of higher energy transfer their energy to those particles of less energy. "Conduction can take place in solids, liquids, or gases" [Çengel, 2003, page 17]. The rate of heat conduction depends on the material properties, the area and the thickness of the layer as well as the temperature difference, as can be seen from the formula for heat conduction, see [Çengel, 2003, page 18], which is shown in Formula 4.1.1.1 below.

$$\dot{Q}_{cond} = kA\frac{T_1 - T_2}{\Delta x} = -kA\frac{\Delta T}{\Delta x} \qquad [W] \qquad (4.1.1.1)$$

where

$k \ldots Thermal\ conductivity\ [\frac{W}{mK}]$

$A \ldots Area\ [m^2]$

$\Delta T \ldots Temperature\ difference\ [°C]$

$\Delta x \ldots Thickness\ [m]$

The thermal conductivity k describes the ability of a material to conduct heat, see [Çengel, 2003, page 19]. It is the material's "conductance for a standardized unit thickness" [Watson & Labs, 1983, page 43].

According to Formula 4.1.1.1, the "rate of heat conduction […] is proportional to the temperature difference across the layer and the heat transfer area, but is inversely propor- tional to the thickness of the layer" [Çengel, 2003, page 18].

4.1.2. Convection

Convection is the process of energy transfer between a solid and the adjacent fluid as a result of the combination of conduction and fluid motion. “The faster the fluid motion, the greater the convection heat transfer” [Çengel, 2003, page 25].

Convection can occur as natural convection, if it is caused by fluid motion due to density differences and gravity or as forced convection in case of an externally driven fluid motion. Natural convection is typically much lower than forced convection, see [Çengel, 2003, page 26] and [ASHRAE Handbook, 2001, page 3.11ff].

The rate of convection heat transfer can be calculated according to Newton’s law of cooling as shown in Formula 4.1.2.1, see [Çengel, 2003, page 26].

$$\dot{Q}_{conv} = hA_s(T_s - T_\infty) \qquad [W] \qquad (4.1.2.1)$$

where

h … Convection heat transfer coefficient $[\frac{W}{m^2}]$

A_s … Surface area, convection $[m^2]$

T_s … Temperature at surface $[°C]$

T_∞ … Unaffected temperature of fluid $[°C]$

“The convection heat transfer coefficient h is not a property of the fluid. It is an experimentally determined parameter whose value depends on all the vari- ables influencing convection […]” [Çengel, 2003, page 26].

4.1.3. Radiation

Radiation is the third basic mechanism for energy transfer. It "is distinguished from con- duction and convection in that it does not depend on an intermediate material as a carrier of energy […]" [ASHRAE Handbook, 2001, page 3.6f]. Energy is "emitted by matter in the form of *electromagnetic waves* (or *photons*) as a result of the changes in the electronic configurations of the atoms or molecules" [Çengel, 2003, page 27].

When dealing with heat transfer, thermal radiation that is caused by the temperature of the emitting matter is considered. The Stefan-Boltzmann law states the "maximum rate of radiation that can be emitted from a surface at an ab- solute temperature T_s" [Çengel, 2003, page 27] for an idealized surface called blackbody as pointed out in Formula 4.1.3.1.

$$\dot{Q}_{emit,max} = \sigma A_s T_s^4 \qquad [W] \qquad (4.1.3.1)$$

with

$\sigma = 5{,}67 * 10^{-8} \frac{W}{m^2 K^4} \quad \ldots Stefan - Boltzmann\ constant$

$A_s \ldots Surface\ area\ [m^2]$

$T_s \ldots Surface\ Temperature\ [K]$

For real surfaces the radiation is less than the blackbody radiation, which can be described with Formula 4.1.3.2 below.

$$\dot{Q}_{emit,max} = \varepsilon \sigma A_s T_s^4 \qquad [W] \qquad (4.1.3.2)$$

with

$\varepsilon \ldots Emissivity$

The emissivity and the second important radiation property, the absorptivity α, both depend on the temperature and the wavelength of the radiation, compare [Çengel, 2003, page 28].

4.2. R-value, U-factor

The system used in the United States to describe the insulation value of a material is different compared to that used in Europe. The following chapter explains the American system in detail and points out the most important figures.

The R-value is the thermal resistance of a material to heat flow. “Under steady-state conditions, the mean temperature difference between two defined surfaces of material or construction that induces unit heat flow through a unit area” [ASHRAE Handbook, 2001, page 23.1f] is the thermal resistance. The R-value of a flat, homogeneous material can be determined by dividing the thickness by the conductivity of the material, as shown in Formula 4.2.1.

$$R = \frac{L}{k} \qquad (4.2.1)$$

where

$L \dots Thickness\ of\ material\ [m]$

$k \dots Thermal\ Conductivity\ [\frac{W}{mK}]$

The thermal resistance is measured in $\frac{°F ft^2 hr}{Btu}$ in the U.S., while in Europe the unit $\frac{m^2K}{W}$ is used. Materials with a high thermal resistance are effective insulators, as the “[t]hermal resistance is a measure of the effectiveness of thermal insulation to retard heat flow” [ASHRAE Handbook, 2001, page 23.3].

The total thermal resistance of a construction element from the inside surface to the outside surface can be calculated as follows in Formula 4.2.2, see [ASHRAE Handbook, 2001, page 23.8]:

$$R = R_1 + R_2 + R_3 + R_4 + \dots + R_n \qquad (4.2.2)$$

where

$R_1, R_2, \dots, R_n =$ Individual resistances of the layers

To receive the overall resistance of a construction element, the resistances of the air films have to be added, as shown in Formula 4.2.3, see [ASHRAE Handbook, 2001, page 23.8]:

$$R_T = R_i + R + R_o \qquad (4.2.3)$$

where

$R_i, R_o =$ Resistance of the inner and the outer air film

$R_T =$ Overall resistance to heat flow of a construction

When calculating the resistances of inhomogeneous construction elements, the fractions of the individual structures inside the element have to be accounted for and included in the calculation.

The U-factor is called thermal transmittance. It is “the rate of heat flow per unit area under steady-state conditions from the fluid on the warm side of a barrier to the fluid on the cold side, per unit temperature difference between the two fluids” [ASHRAE Handbook, 2001, page 23.1f]. The U-factor is the inverse value of the R-value, as shown in Formula 4.2.4 [ASHRAE Handbook, 2001, page 23.8]. Therefore also the unit is the inverse of the R-value, namely $\frac{Btu}{°Fft^2hr}$ respectively $\frac{W}{m^2K}$.

$$U = \frac{1}{R_T} \quad (4.2.4)$$

The thermal transmittance of materials can be calculated analytically as well as measured in laboratory equipment, see [ASHRAE Handbook, 2001, 25.1]. The figure below displays the calculation procedure for the total thermal resistance of a wall with two layers and the inner and outer air film.

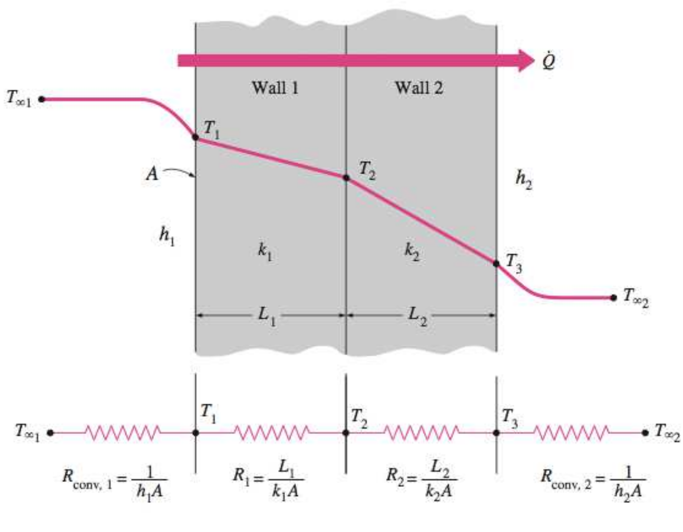


Figure 19: Thermal resistance network [Çengel, 2003, page 133]

4.3. Sensible heat, latent heat,

Sensible heat: Energy in form of temperature. Heat can be transferred in form of temperature changes by convection and radiation, see [Çengel, 2003, page 649].

Latent heat: Latent heat is energy in form of moisture, which means energy is transported by vaporization of water.

4.4. Temperature

Dry-bulb temperature: The dry-bulb temperature is the temperature of air. It is measured by a regular thermometer, see [Southface, 2012].

Wet-bulb temperature: The wet-bulb temperature is measured with a thermometer that's "bulb is covered by a wick that has been thoroughly wetted with water". In air the water evaporates from the wick and reaches an equilibrium temperature called the wet-bulb temperature, see [ASHRAE Handbook, 2011, page 6.13].

Dew-point temperature: is the temperature at which the water vapor in the air starts to condense, that means the partial pressure of water vapor is equal to the saturation vapor pressure. The dew-point temperature correlates with the relative humidity of air, see [ASHRAE Handbook, 2011, page 6.13]

4.5. Moisture

Moisture is problematic for buildings, as it not only reduces the performance of insulation materials but also accelerates the degradation of building materials, see [ASHRAE Handbook, 2001, page 23.11f]. These effects can be reduced significantly with the application of vapor retarders in the building structure.

"A vapor retarder retards water vapor diffusion but does not totally prevent its transmission. […] Conditions on the inside and outside of buildings vary continually", and therefore the requirements change continuously. The effectiveness of a vapor retarder depends on “its vapor permeance, installation, and location within the insulated section. The vapor retarder is usually located at or near the surface exposed to the higher water vapor pressure.” [ASHRAE Handbook, 2001, page 23.16]. In a hot and humid climate this is usually the summer-warm side of the insulation, where the thin vapor retarder sheet or coating is mounted, see [ASHRAE Handbook, 2001, page 23.16].

Permeance describes the water vapor transmission through a material of a specific thickness and is expressed in perms $\frac{grains}{h\,ft^2\,in_{Hg}}$, see [ASHRAE Handbook, 2001, page 23.15].

4.6. Building simulation

Building simulation is a helpful tool for analyzing the behavior of future buildings during the design phase and to evaluate the effects of proposed improvement measures. Many different software tools are available, such as eQUEST, Energy Plus, TRNSYS, ANSYS Fluent, etc.

The basic principle of these tools is the solution of numerical energy equations and transport equations with a computer. The physical laws of energy transfer and fluid dynamics build the foundation of building simulation. Information about the building such as location, building materials, operation schedules and mechanical equipment and appliances have to be entered.

eQUEST 3.64

Models can be set up with or without a wizard. For quantitative simulations the Schematic Design Wizard is available, while the Development Design Wizard is for detailed simulations.

Steps with the Development Design Wizard

The data input is divided into several sections. All sections that are necessary for a particular project are accessible from a project navigator. The sections are defined as Project&Site, Building Shell, Internal Loads, Water-Side HVAC, Air-side HVAC, and Utility&Economics.

After finishing the data input in the wizard, one can change from the so-called Wizard Data Edit to Detailed Data Edit. All input data is listed in form of tables and can be changed here individually. After finishing the data edit, the simulation can be performed. A simulation summary as well as a detailed results list is available.

Difficulties:

- The Occupancy/Lighting/Equipment schedule profiles cannot be changed freely.
- The data input in the detailed interface is structured unclearly and not saved, when input modes are changed again.
- No detailed inputs about the insulation quality or wall constructions can be made (limited possibilities) in the wizard.
- With the help of the wizard the software is easy to use and results can be generated quickly. However, for such complex buildings as the fire stations, where not only conditioned living area exists but also slightly conditioned garage area, a simulation only provides reliable results if a large amount of data is input. In-depth knowledge about the software is necessary.

5. CONSTRUCTION PRINCIPLES IN THE U.S.

The construction practice in the United States differs significantly from that of other regions in the world. This chapter points out characteristics of buildings in the U.S. and lists typical constructions.

The history of American architecture began in the 16^{th} century with the arrival of the first settlers and the establishment of colonies. Due to massive immigration from all parts of the world, today's architecture is as diverse as the country's population. For example, the Spanish influence can still be seen today in architecture that has remained in the Southwest, whereas an English influence is noticeable in the Northeast of the United States.

With the independence of the United States from Great Britain in 1776 the cultural independence, based on science, arts, and architecture became vital and reached its height before 1900. In that period most of the federal buildings were constructed and styles referring to antique Roman and Greek designs were used widely [American Architecture, 2012], see also [Morrison, 1987] and [Wood et al., 2000].

Today the picture of American settlement structure is divided into a variety of styles and building types. Independent from one's personal taste, there are three main construction types that can be filtered out:

- Steel constructions, as in most skyscrapers
- Masonry buildings, as applied in many townhouses
- Wood frame constructions, as in most residential buildings

The following paragraphs will describe all of the above in more detail, paying special attention to its technical characteristics.

5.1. Walls

5.1.1. Steel constructions

The first “real” skyscraper was finished in 1885 in Chicago after an engineer called William Le Baron Jenney had invented the new load-bearing steel framework with structurally independent exterior walls. Before, buildings were predominantly made of stone and were limited in height due to the load bearing behavior of stone. Some years earlier elevators for passenger transportation were developed, which allowed people to enter upper levels of a high-rise building easily. In the late 19th and early 20th century high-rise buildings started their triumph around the world, see [McNeil, 2002].

Figure 20: Steel-framed skyscraper [McNeil, 2002, page 898]

Today’s high-rise constructions are predominantly steel structures as in Figure 20.

5.1.2. Masonry constructions

Masonry is one of the oldest building materials in use. Many ancient advanced civilizations such as the Egyptians or Sumerians used masonry constructions to build houses, see [Hendry & Khalaf, 2001, page 1]. According to [Hendry & Khalaf, 2001, page 9] it has been the most important construction material for centuries until the first high-rise steel structures came up at the end of the 19th century.

Masonry units can be made out of stone, marble, clay, concrete, and recycled products. Mortar is used to bond units together. While some of those materials run through an energy-intensive production process, others can be used unmodified, see [Hendry & Khalaf, 2001, page 12f].

Common masonry wall types are solid walls (single leaf, bonded, etc.), cavity walls, veneered walls and reinforced walls. In Figure 21 and Figure 22 solid masonry wall types are displayed.

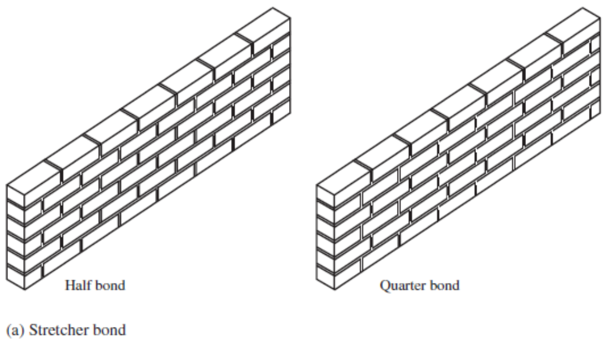


Figure 21: Single leaf walls [Hendry & Khalaf, 2001, page 68]

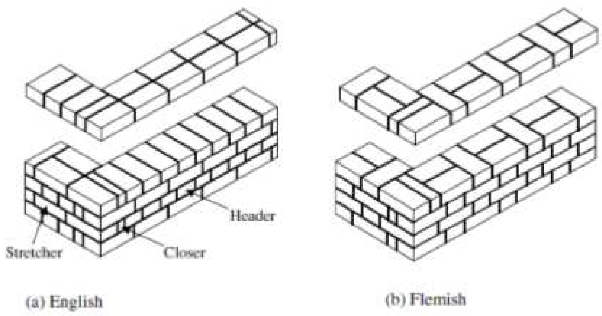
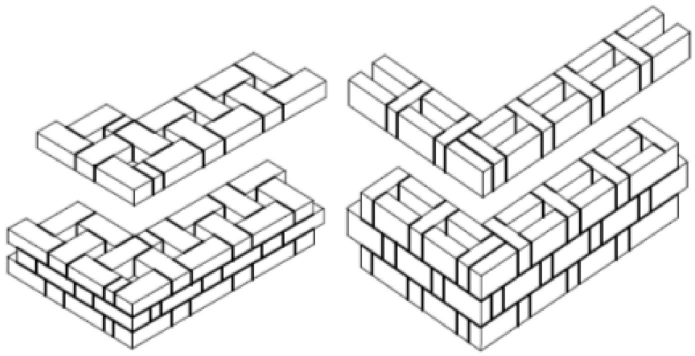


Figure 22: Brick Masonry Bonds [Hendry & Khalaf, 2001, page 69]



(e) Quetta (reinforcement not shown) (f) Rat-trap

Figure 23: Brick Masonry Bond with Cavities [Hendry & Khalaf, 2001, page 69]

As any construction element, masonry has to meet certain requirements: it must bear the construction's loads, it must prevent wind and liquid water from entering the construction, and it must be durable and withstand the weather and other forces, see [Hendy & Khalaf, 2001, page 9].

According to [Hendry & Khalaf, 2001, page 18] the advantages of masonry constructions are its structural performance, its low maintenance requirements and durability. Masonry can be used for flexible wall designs, such as curves. However, the construction work for masonry constructions has to be done on-site completely and a new construction needs time to desiccate. Therefore, other construction forms, such as prefabricated houses, became more popular over time, especially in the residential sector, see [Hendry & Khalaf, 2001, page 11]

5.1.3. Wood constructions

Timber frame constructions have been the state-of-the-art construction type in America from the 18th until today. Wood has always been an important construction material for humans, see [Harper, 2004, page 7.1]. A research paper from the Faculty of Architecture of the Middle East Technical University in Ankara, published in their biannual Journal in December 2009, states that "An overwhelming majority of residential buildings --single and multiple residence, one to three stories-- in the U.S., as well as a significant number of nonresidential --institutional, commercial and office-- buildings are balloon frame construction, or its derivative, western platform framing" [Turan, 2009, page 176]. This is consistent with the author's observations in the United States.

Braced framing

The braced framing method developed from carpenter's practice to use more standardized materials and a faster construction practice. It is also called "Plank-and-Beam Construction" and is probably the oldest method of framing, see [Miller et al., 2004, page 191]. It was characterized by the use of "heavy timber posts at the corners […] and often with intermediate posts between" [Miller et al., 2004, page 191].

Balloon frame technique

The balloon frame construction technique was probably invented by George Washington Snow in Chicago in 1832 as described by Jandl, 1983, see [Jandl, 1983, page 36]. It is characterized by minimal lumber use and has developed out of the earlier braced frame construction practices that needed skilled workers to jointly fit together the separate parts. It is believed that a shortage in lumber around Chicago combined with a fast population of the western plains, where there were no trees for timber supply lead to the development of a new construction practice. Whole houses were prefabricated in factories and erected on-site, see [Jandl, 1983, page 37].

The characteristics of the balloon frame technique are that studs extend "in one piece from the foundation to the roof. […] The joists are nailed to the studs and supported by a ledger board set into the studs" [Miller et al., 2004, page 190] of 2 by 4 inches, that rested on large sills of 8 inches square. Studs were placed periodically every 16 inches and doubled on the corners. Connections were typically realized as plug-in connection. “Above the sills […] had a ledger, or ribbon, at each level running horizontally across the long side of the building” [Jandl, 1983, page 38]. A balloon frame construction got its stability from the interaction between the continuous studs, tied together by the ledger and stiffened by floor boards and 1-inch thick boards that were fixed horizontally to the inside of the studs or to the outside as sheathing. The fixation of the parts was achieved by nailing except of the base, where the fixation was made with mortises and tenons, see [Jandl, 1983, page 39].

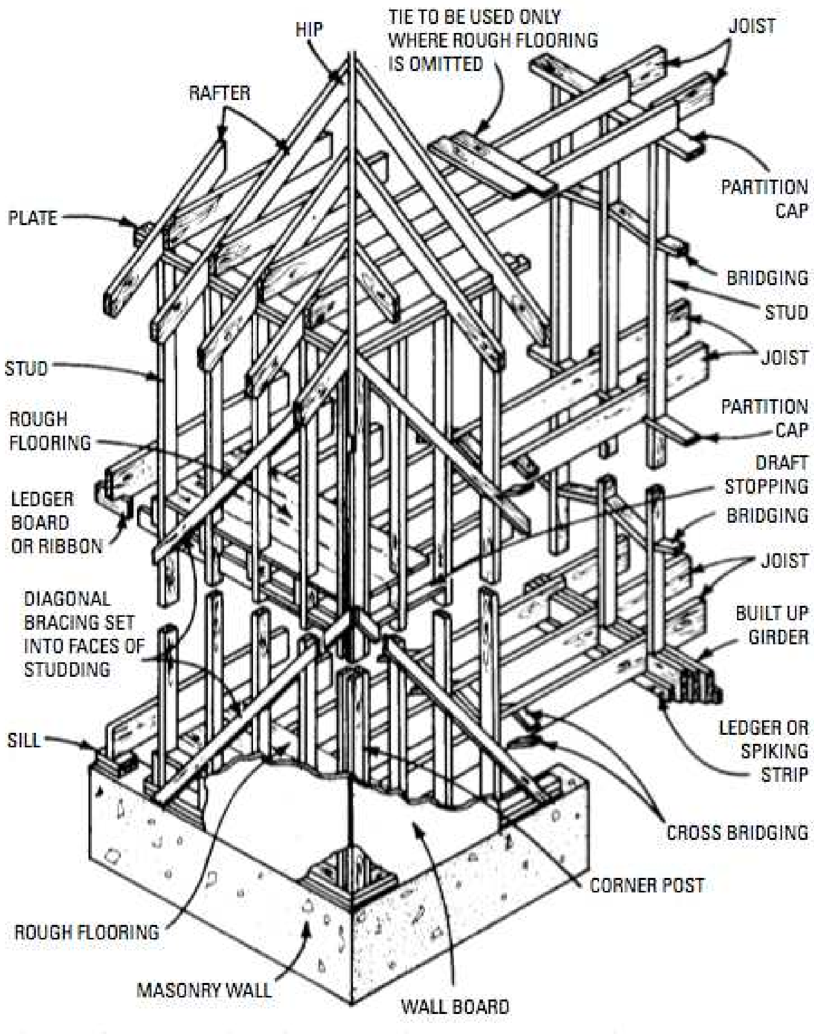


Figure 24: Details of balloon frame construction, [Jandl, 1983, page 47]

Balloon framing was commonly used until “sometime between 1874 and 1887” [Jandl, 1983, page 44].

Western framing

Independent platforms are constructed. Therefore it is also often referred to as platform framing. The platforms are supported by the ones below, see [Miller et al., 2004, page 192]

In the residential sector wood structures dominate the building sector. This might be caused by the quick erection of such construction and their costs. However, most municipal buildings are massive masonry buildings. The following paragraphs explain why fire regulations have a determining influence on the type of construction.

Fire regulations

Fire regulations are very important as so many buildings in the United States are made of timber and many cities suffered from severe fires in the past. Therefore, fire regulations are of particular importance in the construction industry. Buildings can be divided into five categories depending on their fire resistance as of the NFPA 220 [NFPA 220, 2012]:

> **Type I Fire Resistive**
>
> Type I fire-resistive construction is a type in which structural elements are of an approved noncombustible or limited combustible material with sufficient fire-resistive rating to withstand the effects of fire and prevent its spread from story to story.

Main materials used for this category are concrete, enclosed steel and cement often with spray-on fire protection coatings. Type I constructions are found in the public buildings sector, such as high-rise buildings or sporting arenas, where it is important that a fire cannot spread.

> **Type II Non-Combustible**
>
> Type II noncombustible construction is a type in which structural elements do not qualify for Type I construction and are of an approved noncombustible or limited combustible material with sufficient fire resistive rating to withstand the effects of fire and prevent its spread from story to story.

This type of buildings can be subject to steel deformation and collapse due to the missing fire-restrictive coatings of steel. Typical applications of such buildings are warehouses, churches, schools, small cultural centers, and malls.

Type III Ordinary (Exterior protected)

> This type of construction is commonly referred to as ordinary construction or brick and joist construction and is a highly predominate and common construction type.

Ordinary construction uses masonry for its load bearing parts frequently. Therefore, a certain fire resistance of the building envelope is achieved. However, the building interior contains combustible materials such as wood in floors, walls and ceilings. This type can be found in older apartment buildings from the late 19th and the early 20th century.

Type IV Heavy Timber

> Heavy Timber (Type IV) Construction is characterized by masonry walls, heavy-timber columns and beams, and heavy plank floors. Although not immune to fire, the large mass of the wooden members slows the rate of combustion. Heavy timber construction can be used where the smallest dimension of the members exceeds 5.5 in. (14 cm).

Heavy timber constructions are naturally fire-resistant as the large wooden parts are charred but not consumed by fire. Typically, mills were constructed in this way.

Type V Wood Frame

> Buildings include wood frame buildings with standard dimensional lumber like 2”x 4” up to and including 2” x 12” lumber.

Due to the smaller diameter of the timber parts it is threatened by fire more rapidly than heavy timber constructions. Most of the present-day wooden singe-family homes in the United States are part this category.

5.2. Windows

Most windows in American residential buildings are sliding windows, which are to be opened by pushing the bottom pane upwards. These windows do not feature any differences in their U-factors compared to horizontally operable casement windows. However, in many cases those windows have increased infiltration rates due to their construction.

Figure 25: Example window [American Craftsmen, 2012]

Two parameters that describe the features of a window are the Solar Heat Gain Coefficient (SHGC) and the U-factor. In a hot and humid climate a windows should have a low SHGC (≤0,30) as well as a low U-factor (≤0,33) [Habitat Congress, 2006, page 32f] to reduce the solar gains.

5.3. Roofs

Roof types differ depending on the building's location und type of use. However, characteristic types are flat roofs and pitched roofs with asphalt shingles.

5.4. Construction principles for hot and humid climates

Buildings in a hot and humid climate zone require some basic considerations regarding the site and the building envelope to perform effectively and comfortably and still be cost-efficient. “The southeastern United States probably has the greatest potential for building failures of any region in the country. […] The hot, humid Southeast, however, faces a greater likelihood that moisture-related problems will occur. When moisture intrudes into a building’s envelope and its occupied space, mildew begins to grow […]”, stated in [DuBose & Odom, 2000, page XI], the right building design plays a crucial role also in Savannah. The early design phase of a building is the best opportunity to prevent misplanning and inadequate design, see [DuBose & Odom, 2000, page 17]. Major aspects to be considered are listed below.

<u>Tight construction</u>

As the hot and humid climate is characterized by high relative humidity levels (latent load) during summer months, the installation of a vapor retarder is essential. Not only does a correctly installed vapor retarder protect the construction from condensate, but it also reduces the moisture content transported indoors reducing the necessary operation of the dehumidification, see [DuBose & Odom, 2000, page 8]. A tight building envelope that works as an air barrier and prohibits unintended ventilation is necessary “to control air and moisture flow through the wall system” [DuBose & Odom, 2000, page 11] and prevents damage.

<u>Insulation</u>

Insulation is as important in a hot and humid climate as it is in a temperate or cold climate. Adequately installed roof insulation is important to reduce solar heat gain through the roof. Spray-foam insulation is easy to install and has a high insulation performance. A continuous insulation layer in the wall is also inevitable. Insulation values of walls are typically $R \geq 13$ and $R \geq 30$ in roofs in a hot and humid climate, see [Southface, 2012, pages 118-122].

Windows

"Windows should be selected to manage the quantity of heat loss and solar gain" [DOE, 2011, page 5.12]. Therefore, windows with a low Solar Heat Gain Coefficient and a low U-factor should be used in hot and humid climates, see 5.2 Windows.

Building orientation

As the east and west façade have a high solar heat gain during most of the year, those parts of the building should be small. The north and south façade, however, can be large, see [Sizemore et al., 1979, page 2f]. Large roof overhangs are essential on the south façade because it prevents solar radiation from entering the building. Additionally, the large roof area can be used for the installation of photovoltaic systems, see [DOE, 2011, page 5.10].

The lot should be equipped with trees and plants for shading purposes to "create a cool microclimate around the house" [Habitat Congress, 2006, page 18], see also [DOE, 2011, page 5.13].

5.5. Energy Efficiency Ratings

HERS – Home Energy Rating System

HERS is a standardized and internationally recognized system to rate a building's energy efficiency. It is voluntary, is performed by a certified HERS rater and was developed by RESNET in 2006. The rating system considers the whole house as one system consisting of the envelope, the mechanical systems and its appliances. The rating ranges from 0 to 250, where 100 equal the energy efficiency of an imaginary reference building constructed to meet the 2006 building code requirements. The lower the rating, the higher is the energy efficiency of the building, see [Resnet, 2012].

Figure 26: HERS Index [Resnet, 2012]

EarthCraft

The EarthCraft program is a green building certification program designed to address climate, energy and water issues unique to the Southeastern United States. It was first developed in 1999 as a partnership between the Greater Atlanta Home Builders Association and the Southface Energy Institute. It is a point-based certification and is available in five different disciplines that focus on the following development types: single-family homes, renovation, neighborhood development, multi-family homes and light commercial buildings, see [EarthCraft, 2012].

Figure 27: EarthCraft logo [EarthCraft, 2012]

EarthCraft standards represent additional guidelines adding to local building codes. The certification, which is performed by a third-party technical advisor, facilitates low energy consumption. The EarthCraft standard confirms a certain energy efficiency level of the building, – a minimum of 15% compared to traditional projects. The implementation of the stated efficiency measures is verified by means of a blower door test (maximum value of 7 ACH_{50}) and a duct leakage test (maximum 12% air leakage) and therefore facilitates a high indoor environmental quality with lower utility bills, see [Southface, 2012]. ACH_{50} indicates the air changes per hour in a building at 50 Pascal pressure difference.

LEED

The international LEED (Leadership in Energy and Environmental Design) certification is managed by the U.S. Green Building Council. The certificate can be acquired in Platinum, Gold, and Silver level based on the points a building achieves in the LEED rating system scale. It takes into account the construction site and the infrastructure around it, the water efficiency of the building, the energy use and atmospheric parameters, the use of materials and resources, the indoor environmental quality, innovation and design processes, and regional priority credits, see [USGBC, 2012].

Figure 28: LEED Certificate [USGBC, 2012]

6. METHOD

As stated in the Statistics Manual of the International Energy Agency basic energy information is not always available in the quality and currentness as needed [International Energy Agency, 2005, page 3]. This is also true for energy data in the City of Savannah. For two buildings a detailed analysis was performed and is described in the following subchapters.

6.1. Energy Assessment

An energy assessment is performed to determine a building's performance in terms of energy intensity and to evaluate possible improvements to increase the buildings energy efficiency, see [Sizemore et al., 1979, page 30]. The assessment was performed according to the outline for an energy analysis suggested by Sizemore M. and The American Institute of Architects in the book *Energy Planning for Buildings* already in 1979. Sizemore describes the differences between a simple "energy audit" and a more detailed and sophisticated "energy analysis". While an audit "consists of examining the building and its past utility bills", the energy analysis is "detailed enough to allow opportunities to be accurately identified, projections of costs and benefits to be made and methods of carrying out the work to be determined" [Sizemore et al., 1979, page 30f]. Only the energy analysis provides guidance for steps to be taken to improve a buildings performance. An energy audit can only provide key findings and general recommendations due to the limited data and is most often a "first step in any energy planning project" [Sizemore et al., 1979, page 30].

The energy analysis includes "a

- [D]etailed study of the building, its operation and use, its environ-ment and its equipment.
- Calculation of loads the building and its equipment must meet.
- An estimate of energy used by individual pieces of equipment in response to loads. Calculation of costs to provide this energy. [And the]

- Study of how the building performs in non-energy related areas" [Sizemore et al., 1979, page 41].

First, the city's consumption data was analyzed to give a general overview of the energy intensity of the buildings. Then, buildings were chosen for a profound analysis, including on-site visits, analyzes of equipment and operation schedules, simulations and measurements. Last, improvement opportunities were quantified and suggested. Some of the tasks suggested by Sizemore et al. could not be executed due to a lack of information or missing permissions. All the steps performed will be described in more detail in the following subchapters.

6.2. Building definition

To identify suitable buildings for an energy analysis, the consumption data was analyzed in the first step.

The consumption data for all electric meters of the city is provided by the utility company Georgia Power and extended monthly in a Microsoft Excel file called "Electric Master Data lite.xls".

The consumption data files for the years 2010, 2011 and 2012 had already been entered into utility tracking software, to be able to assess buildings that qualify for an assessment in terms of their energy consumption behavior. The software used was Portfolio Manager from Energy Star and UtilityTrac Plus from Johnson Control's Facility Dude, displayed in Figure 29 and Figure 30.

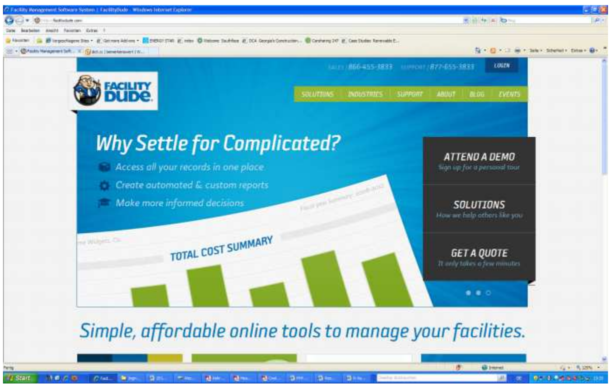


Figure 29: Facility Dude, Webpage [Facility Dude, 2012]

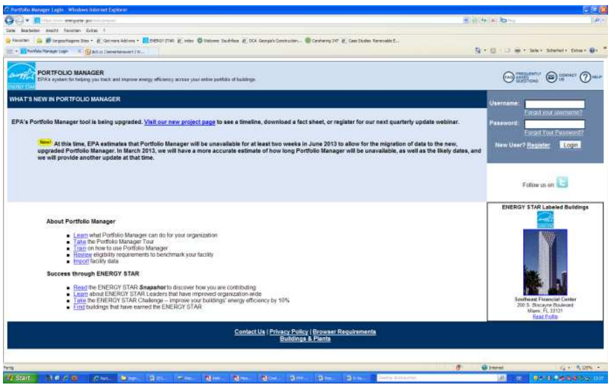


Figure 30: Energy Star Portfolio Manager, Webpage [Energy Star, 2012]

The buildings with the highest energy consumption per area were identified in both software tools. The buildings that appeared in both rankings were taken into consideration for an in-depth energy assessment. In Table 3 the results of the two software programs are shown. Especially service facilities such as fire stations and police departments have high area-specific energy consumptions. The same is true for the Hospitality Center, which is a tourist information center with a small square-footage, while the Civic Center is the main venue for events with a high attendance.

Table 3: Comparison of results Portfolio Manager and UtilityTrac Plus

Portfolio Manager (Energy Star)	UtilityTrac Plus (Facility Dude, Johnson Control)
1. Blackshear Basketball Complex	1. SCMPD 2
2. SCMPD[1] 2	2. Hospitality Center
3. Hospitality Center	3. Fire Station 9
4. Guy Minick RC	4. Civic Center
5. Fire Station 9	5. Visitor Center
6. Visitor Center	6. SCMPD 4
7. Dafflin Park Tennis Court	7. Delaware Center
8. Civic Center	8. Broughton Municipal Building
9. SCMPD 4	9. SCMPD 3
	10. Fire Station 14
	11. SCMPD Hq

Interestingly enough, the ranking in Portfolio Manager differed considerably from that of UtilityTrac Plus. The reason for this is probably due to the fact that UtilityTrac Plus was only used as a trial and not all buildings and facilities were entered into the software. However, this question could not be answered accurately as the Portfolio Manager account could not be accessed. The results from UtilityTrac Plus are listed in Appendix A and B.

[1] SCMPD… Savannah Chatham Metropolitan Police Department

Several top-ranked buildings were not considered for an energy assessment due to the following reasons. The necessary effort for the analysis of the Civic Center would have exceeded the possibilities and the timeframe of this project; therefore it was removed from the list. Furthermore all police departments were removed from the list, because it was not possible for a foreign student intern to investigate the police facilities.

The visitor center, the Broughton Municipal Building, as well as the Gamble Building have already been assessed in 2009 and the City Hall would not be comparable to any other building and it was therefore excluded. The Blackshear Basketball Complex and the Dafflin Park Tennis Court appear in the list due to their high lighting consumption. The relatively small area of the building itself leads to a high consumption per area. So they also did not qualify for an assessment. The buildings that finally qualified for an assessment due to their high energy consumption are listed below, see Table 4.

Table 4: List of buildings qualifying for an energy assessment, 17.07.2012

Building	**Address**	**Area [sq ft]**	**Consumption [MMBtu]**	**Total energy costs [$]**
Hospitality Center	1 West River Street	1.675	0,60	5.437,28
Fire Station 9	2235 Capital Street	2.500	0,85	8.458,49
Delaware Center	1815 Lincoln Street	12.000	2,86	25.543,81
Fire Station 14	480 Highland Blvd	2.788	0,53	5.624,06

Finally, the fire stations 9 and 14 were suggested for an in-depth energy assessment to the city officials and the Thrive Committee. However, the fire department did not give permission for those stations. It was more interested in receiving an energy assessment for the fire stations 8 and 11, so these two buildings were chosen.

6.3. On-Site visit

Two on-site visits in both buildings were executed.

Date of first visit:	08-15-2012, 10am – 1pm
Weather conditions:	Average Temperature: 27℃
[Wolfram Alpha, 2012]	Average Relative Humidity: 77%
Attendees:	Alex Heyward, Fire Department, City of Savannah
	Garrison Marr, Housing Department, City of Savannah
	Mike Brown, Georgia Tech
	Daniela Bachner, student
	Matthias Watzak-Helmer, student

Date of second visit:	11-10-2012, 8.30am – 11.30am
Weather conditions:	Average Temperature: 18℃
[Wolfram Alpha, 2012]	Average Relative Humidity: 78%
Attendees:	Garrison Marr, Housing Department, City of Savannah
	Mike Brown, Georgia Tech
	Robert Ballentine, Georgia Innovation Institute
	Daniela Bachner, student
	Matthias Watzak-Helmer, student

During the first visit general data about the building's size, the construction, window quality, as well as the operation schedule was collected by means of measuring and inspection. Information about the mechanical equipment, the lighting and the appliances was collected as basis for the analysis of the second student intern, Mr. Watzak-Helmer.

The second on-site visit provided additional information about the mechanical equipment and the insulation quality with an infrared camera. The infrared camera that was used was a FLIR.

No blower door test has been executed. While in Fire Station 8 it was not permitted due to its natural gas supply, a blower door test in Fire Station 11 was not possible as the size of the building exceeded the measurement range of the equipment.

Instead, data loggers were placed to measure the indoor temperature in different locations of both stations for further analysis of the mechanical equipment and operation. The recommended energy efficiency improvements were analyzed with the information collected during the on-site visits.

6.4. Building description

For two municipal service buildings energy assessments have been performed to receive general information about the building structure and to identify general improvement strategies that could be applied to many municipal buildings. Namely these two buildings were Fire Station 8 and Fire Station 11.

Fire Station 8

Fire Station 8 is an old service facility with the following data.

Year of construction:	1955
Address:	2428 Bee Road
	Savannah, GA, 31404
Orientation of entrance	West
Operation hours:	24/7, all year round
Occupation:	3 shifts with 3 fire fighters each

One half of the building is dedicated living area and sleeping area while the other half of the space is used as garage for the fire trucks.

Figure 31: Fire Station 8, Savannah, 19.10.2012

Construction materials

Walls:	Brick wall with airspace, 12 inch
Windows:	Double-pane windows with wood frame
	Single-pane windows with wood frame in entrance area

Doors:	Wood door with metal screen at entrance
	Wood door at back entrance
	Aluminum truck bay doors
Roof:	18° tilted wood construction with dark brown asphalt shingles
	4 inch mineral fiber insulation between joists with drop ceiling
Foundation:	Concrete slab

Table 5: Geometric data, Fire Station 8

Geometry	Station 8			
L	88,00	ft	26,82	m
B	62,00	ft	18,90	m
H	13,50	ft	4,11	m
Perimeter	348,28	ft	106,16	m
A floor	4.300	ft2	399,48	m2
A roof	4.998	ft2	464,28	m2
A walls	3.847	ft2	357,35	m2
N	871	ft2	80,94	m2
S	871	ft2	80,94	m2
E	1.052	ft2	97,73	m2
W	1.052	ft2	97,73	m2
Volume	43.692	ft3	1237,23	m3
A windows				
N	175,55	ft2	20,15%	
S	168,62	ft2	19,35%	
E	6,93	ft2	0,66%	
W	84,51	ft2	8,03%	

Figure 32 displays the layout of Fire Station 8 as from the Savannah Area Geographic Information System (SAGIS).

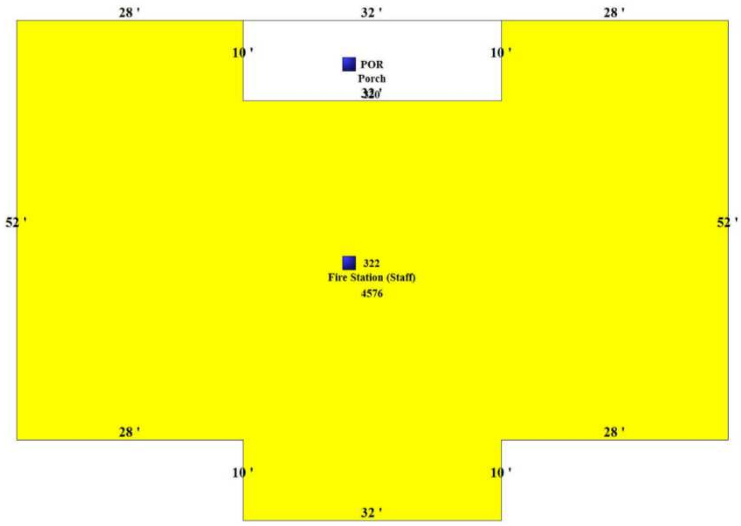
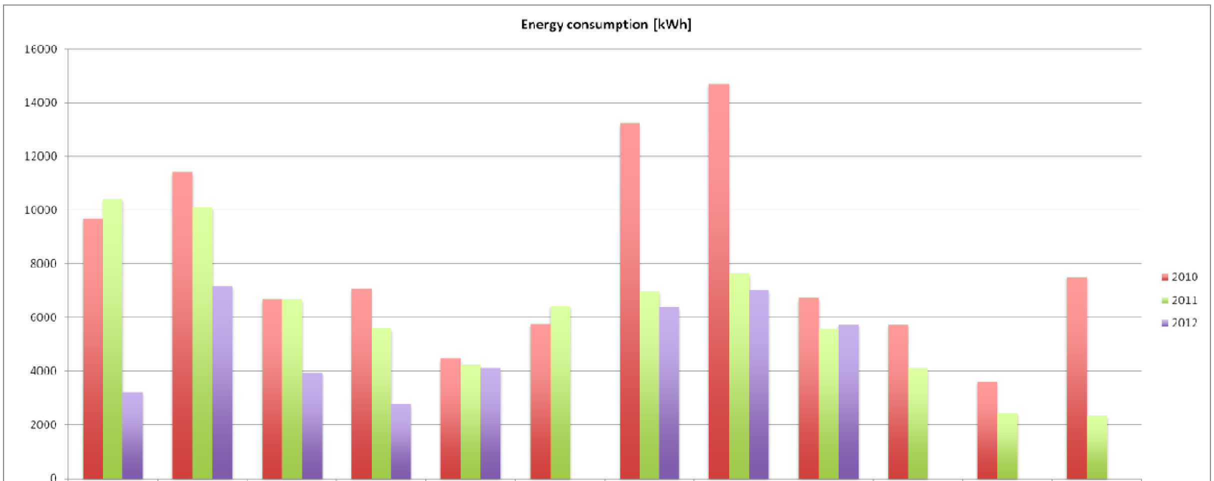


Figure 32: Layout, Fire Station 8 [SAGIS, 2012A]

Energy consumption data

Fire station 8 uses electricity and natural gas as energy sources. The consumption data for the years 2010, 2011 and 2012 is listed below.



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2010	9700	11402	6688	7073	4485	5768	13221	14716	6735	5745	3610	7531
2011	10436	10119	6688	5601	4260	6435	6969	7653	5572	4103	2454	2352
2012	3230	7184	3946	2800	4118	0	6386	7023	5757			

Figure 33: Electricity consumption 2010-2012 for Fire Station 8 [Electric Master Data Savannah]

Figure 33 displays the electricity consumption of Fire Station 8 for the years 2010 to 2012. The electricity consumption peaks in the heating period (December, January, February) and in the cooling period (July, August, September), while the consumption during the rest of the year is low. The electricity consumption declined substantially over the past years. This does not necessarily indicate sustainable energy savings. Possible reasons for this savings could be some load adjustments or simply weather variations, as this data is not weather-normalized. The maximum monthly consumption was reached in August 2010 with 14.716 kWh, while in December 2011 the minimum monthly consumption amounted to 2.352 kWh. A definite reason for this fact could not be figured out. Therefore, for all further calculations and simulations the consumption data of the year 2011 was used as baseline due to its relatively continuous behavior according to the seasons.

In the United States the price for electricity is a combination of energy and demand charges. The demand charge “is based on the single largest peak demand occurring anytime during a month. The demand charge is based on either the current month’s peak demand, and, in some rate structure cases, a previous summer month”

[Georgia Tech, 2011]. Therefore, the energy bill states the energy consumption as well as the peak demand of the billing month. As the City of Savannah does not receive energy bills from its utility but a Microsoft Excel file listing its electricity consumption data, the only available information about the energy rates was the monthly billing amount. No information about demand or energy charge was available. Figure 34 shows the monthly electricity price per kWh for the months from January 2010 to April 2012. The graph shows that the unit price for a kWh of electricity differs significantly from month to month. While energy is more expensive in periods with a high demand such as in summer, the unit price does not follow these fluctuations one-to-one. High unit prices are rather seen in months with low energy consumption such as April 2010 or September and October 2011. The dark blue line shows the increase of the average unit price over the period under observation.

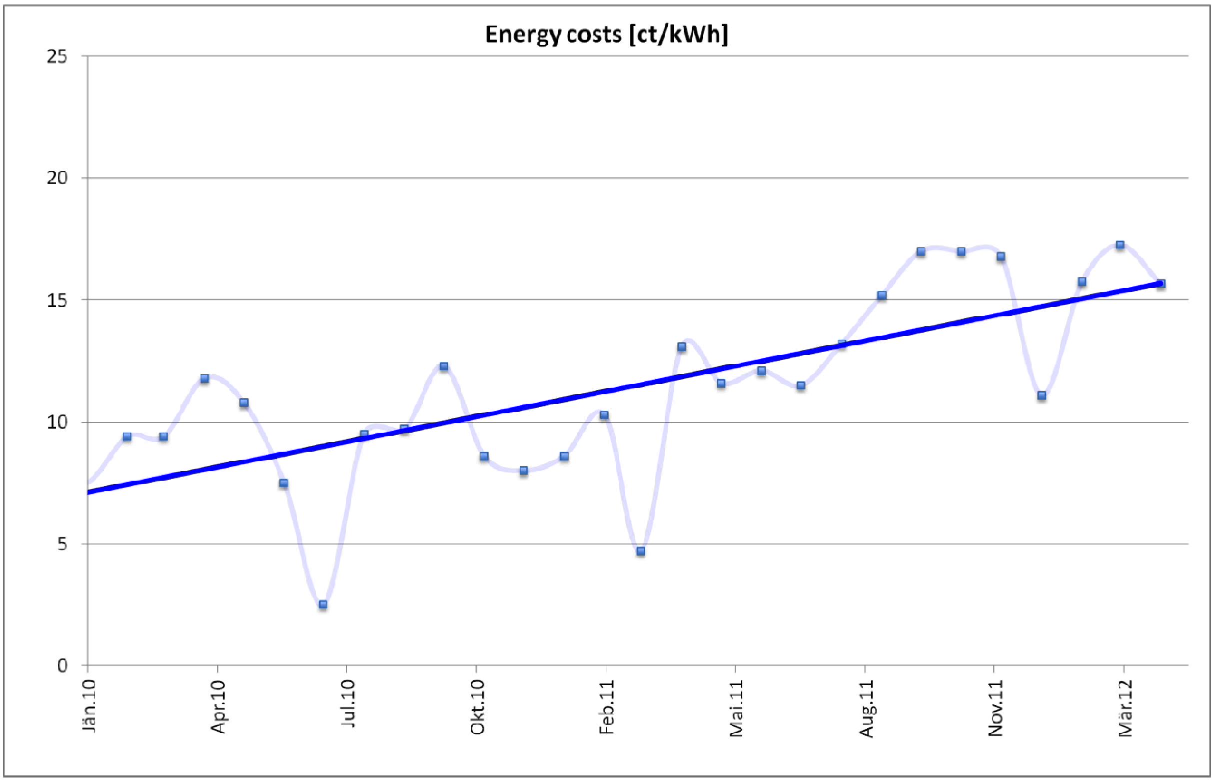


Figure 34: Energy costs in $/kWh, Fire Station 8 [Electric Master Data Savannah]

The electricity consumption data for the baseline year 2011 amounted to 72.642,00 kWh, which cost $7.858,51. This leads to unit costs of 10,8 ct/kWh, which was used for all calculations and simulations. The detailed list of the monthly energy consumption and the electricity prices is shown in Appendix C.

Natural gas consumption

Fire Station 8 uses natural gas for the kitchen range as well as for two 40.000 Btu/h gas furnaces. The consumption data of the year 2011 is displayed in Figure 35. The baseline consumption for cooking is between 2,2 and 2,5 MMBtu per month, while gas consumption is increased due to the need for heating from November to March. The costs for natural gas in Fire Station 8 range from $60 in summer to more than $200 in winter months with high heating demands. The total costs for natural gas in 2011 amounted to $1.039,20 for a total consumption of 78,7 MMBtu.

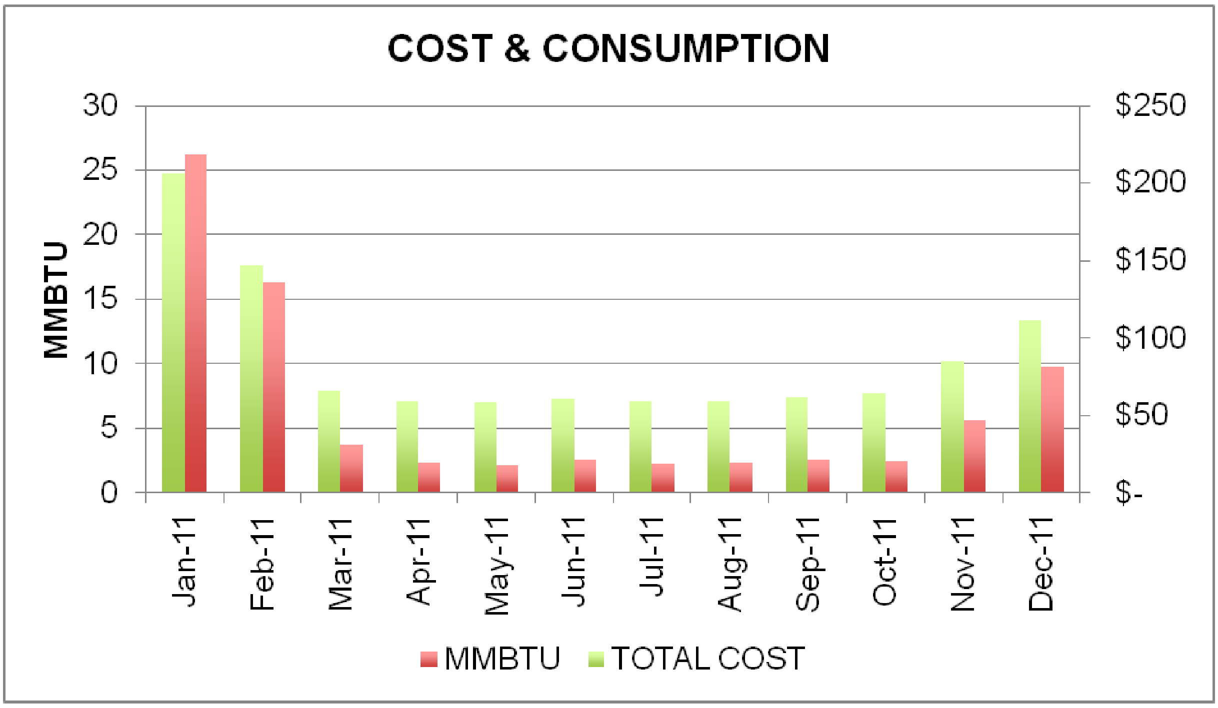


Figure 35: Natural Gas Consumption 2011, Fire Station 8

The consumption data and costs are listed in Appendix D.

Fire Station 11

Fire Station 11 is a newly constructed service facility with the following data.

Year of construction:	2011
Address:	11844 Apache Avenue Savannah, GA, 31419
Orientation of entrance:	Northwest
Operation hours:	24/7, all year round
Occupation:	2 shifts with 8 fire fighters each

Around one half of the building is dedicated living area, while the other half of the space is used as garage for the fire trucks. The living area is divided into a common room, bunkrooms, bathrooms, office space and storages. The truck bay has separate rooms for service works, a filling station and wardrobes.

Figure 36: Fire Station 11, Savannah, 19.10.2012

Construction materials

Walls:	CMU, 12 inch
Windows:	Double-pane windows with aluminum frame
Doors:	Aluminum doors with double-pane glazing
	Aluminum-frame truck bay doors with acrylic glazing
Roof:	Tilted metal construction with dark brown asphalt shingles
	Mineral fiber insulation with drop ceiling
Foundation:	Concrete slab

The measures of Fire Station 11 are listed in Table 6 below.

Table 6: Geometric data, Fire Station 11

Geometry	Station 11			
L	103,00	ft	31,39	m
B	87,00	ft	26,52	m
H	18,00	ft	5,49	m
Perimeter	396,00	ft	120,70	m
A floor	8.295	ft2	770,63	m2
A roof	11.672	ft2	1.084,32	m2
A walls	5.660	ft2	525,83	m2
NW	1.416	ft2	131,55	m2
SE	1.736	ft2	161,28	m2
NE	1.548	ft2	143,81	m2
SW	960	ft2	89,19	m2
V	115.200	ft3	3.262,12	m3
A windows				
NW	90,00	ft2	40,54%	
SE	44,01	ft2	19,82%	
SW	88,01	ft2	39,64%	
NE	0	ft2	0,00%	

Figure 37 displays the layout of Fire Station 11 as from the Savannah Area Geographic Information System (SAGIS).

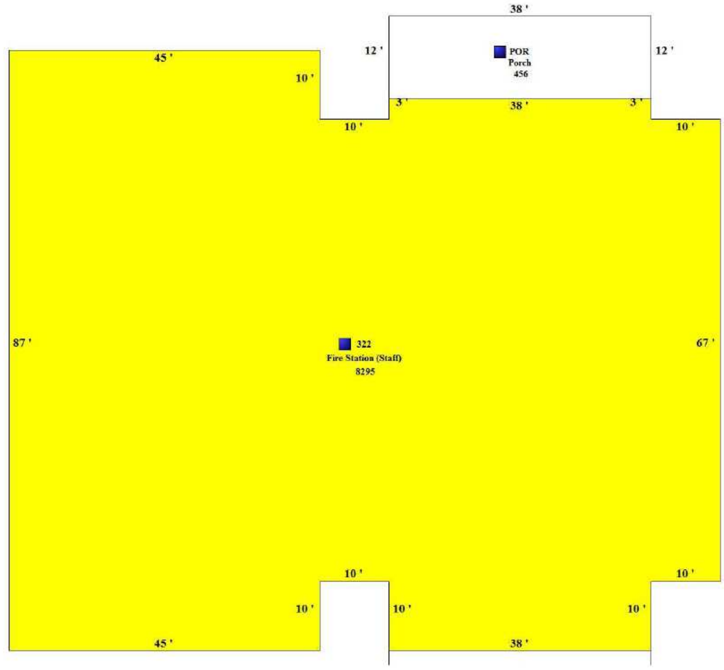


Figure 37: Fire Station 11 layout [SAGIS, 2012B]

Energy consumption data

Fire station 11 uses electricity as sole energy supplies. The consumption data is listed below.

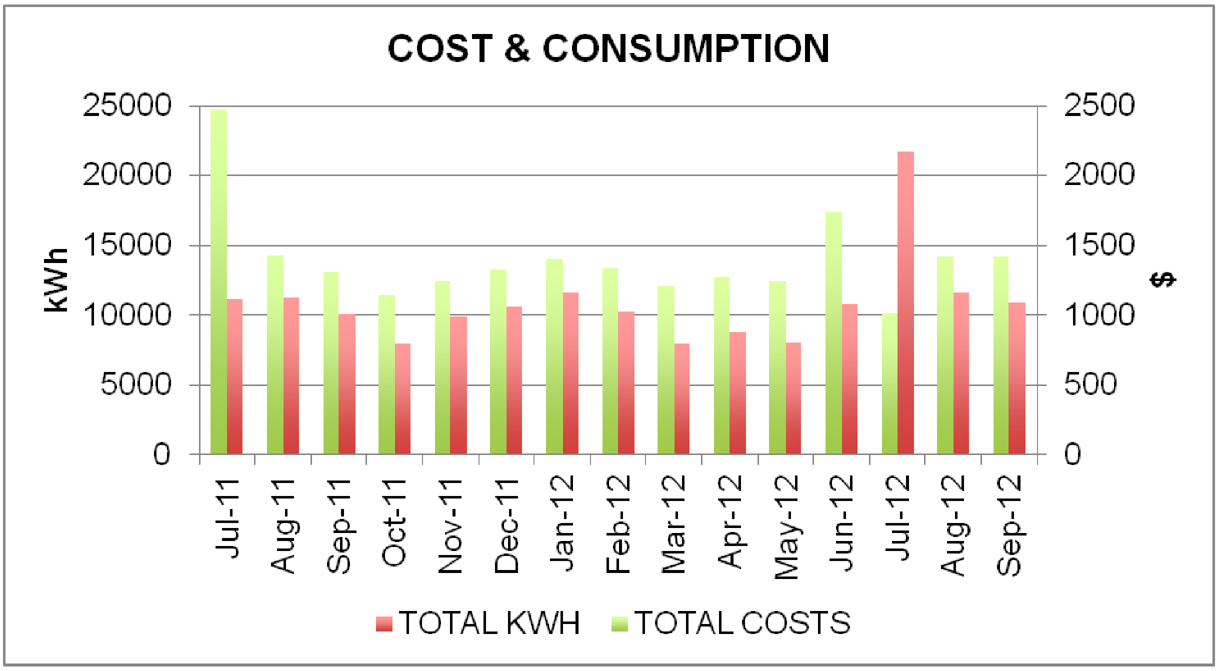


Figure 38: Electricity consumption and costs, Fire Station 11 [Electric Master Data Savannah]

Figure 38 shows the electricity consumption of Fire Station 11 from the opening of the station in July 2011 to the most recent available data in September 2012. The electricity consumption peaks in July 2012 with a usage of 21.680 kWh. Interestingly, the total costs of that month reached $1.015,07, which was less than in the other summer months in 2012. As the price and consumption data of July 2012 do not correlate with the other months, it is assumed that a billing mistake occurred there. The costs of the first month of operation peaked at $2.473,02 due to the initial operation costs. The electricity consumption was relatively constant over the first year of operation with slight peaks during the heating season as well as the cooling season. For the simulation the simulation period of 2011 was chosen and compared with the energy consumption data for the period of January to June 2012 and July to December 2011 to get consumption data for a whole year. Also for Fire Station 11 no detailed information about the composition of the total energy costs was available. Therefore the price per kWh was calculated from the total costs and defined with 0,135 ct/kWh. That price was used for further calculations. The consumption data and the electricity prices are shown in Appendix E.

6.5. R-Value Calculation

The R-values of the construction elements were calculated according to the ASHRAE Handbook 2001, Chapter 25.2. The thermal resistance of the individual materials was taken from the “Thermal and Water Vapor Transmission Data” [ASHRAE Handbook, 2001, Chapter 25.5] as well as from the “R-Value Table” of Colorado Energy [ColoradoENERGY, 2012]. As no inspection equipment for an internal analysis of the construction elements was available, typical structures appropriate to the construction period were used.

The R-values were calculated in the American unit $\frac{h\,ft^2\,F}{Btu}$ and converted to the internationally used unit $\frac{m^2 K}{W}$. The values for the construction elements of Fire Station 8 are listed in Table 7. The brick wall has an U-factor of $0{,}67\ \frac{W}{m^2 K}$, which is typical for walls from that period. The roof has an average U-factor of $0{,}39\ \frac{W}{m^2 K}$, with a framing factor of 9%. The U-factor of the double-pane windows is $2{,}84\ \frac{W}{m^2 K}$ and that of the doors is $2{,}19\ \frac{W}{m^2 K}$The foundation was estimated as a 6-inch concrete slab with an U-factor of $9{,}47\ \frac{W}{m^2 K}$.

Table 7: R-Values of construction elements in Fire Station 8

Wall				
Exterior film R	0,17	h.ft2.°F/Btu	0,03	m2.K/W
Brick 4" (100 lb/ft3)	0,96	h.ft2.°F/Btu	0,17	m2.K/W
Airspace	1,00	h.ft2.°F/Btu	0,18	m2.K/W
Mineral fiber 1,5"	4,68	h.ft2.°F/Btu	0,82	m2.K/W
Brick 4"	0,96	h.ft2.°F/Btu	0,17	m2.K/W
Interior film R	0,68	h.ft2.°F/Btu	0,12	m2.K/W
R-Value	**8,45**	**h.ft2.°F/Btu**	1,49	m2.K/W
U-factor	**0,12**	**Btu/h.ft2.°F**	**0,67**	**W/m2.K**

Roof					
Exterior air film	0,17	0,17	h.ft2.°F/Btu	0,03	m2.K/W
Asphalt shingles	0,44	0,44	h.ft2.°F/Btu	0,08	m2.K/W
Plywood 0.625in.	0,77	0,77	h.ft2.°F/Btu	0,14	m2.K/W
Wood Joist 2x6	6,88	0,00	h.ft2.°F/Btu	1,21	m2.K/W
Airspace	1,00	1,00	h.ft2.°F/Btu	0,18	m2.K/W
Mineral fiber 3.5"	0,00	10,92	h.ft2.°F/Btu	0,00	m2.K/W
Wood joist 2x6	6,88		h.ft2.°F/Btu	0,12	m2.K/W
Ceiling panel	0,47	0,47	h.ft2.°F/Btu	0,08	m2.K/W
Interior film down	0,92	0,61	h.ft2.°F/Btu	0,16	m2.K/W
R-Value	**17,53**	**14,38**	**h.ft2.°F/Btu**		**m2.K/W**
U-Factor	**0,07**		**Btu/h.ft2.°F**	**0,39**	**W/m2.K**

Window				
Double pane, wood frame	2,00	h.ft2.°F/Btu	0,35	m2.K/W
R-Value	**2,00**	**h.ft2.°F/Btu**	**0,35**	**m2.K/W**
U-Factor	**0,50**	**h.ft2.°F/Btu**	**2,84**	**W/m2.K**

Door				
Wood solid	2,60	h.ft2.°F/Btu	0,46	m2.K/W
R-Value	**2,60**	**h.ft2.°F/Btu**	**0,46**	**m2.K/W**
U-Factor	**0,38**	**Btu/h.ft2.°F**	**2,19**	**W/m2.K**

Floor				
6" concrete slab	0,60	h.ft2.°F/Btu	0,11	m2.K/W
R-Value	**0,60**	**h.ft2.°F/Btu**	**0,11**	**m2.K/W**
U-Factor	**1,67**	**h.ft2.°F/Btu**	**9,47**	**W/m2.K**

The R-values of the construction elements of Fire Station 11, which are displayed in Table 8, were calculated similarly as those of Fire Station 8. Again, the individual layers of the construction elements were estimated, as construction plans were not available. The wall has an U-factor of $0{,}76\ \frac{W}{m^2K}$ and the U-factor of the roof is $0{,}40\ \frac{W}{m^2K}$. The windows and doors are modern aluminum frame double-pane elements with U-factors of $2{,}05\frac{W}{m^2K}$. The slab foundation was estimated to be a 6-inch concrete slab with an U-factor of $9{,}47\frac{W}{m^2K}$ similar to that of Fire Station 8.

Table 8: R-values of construction elements in Fire Station 11

Wall					**Roof**					
Exterior air film	0,17	h.ft2.°F/Btu	0,03	m2.K/W	Exterior	0,17	0,17	h.ft2.°F/Btu	0,03	m2.K/W
CMU 12"	1,65	h.ft2.°F/Btu	0,29	m2.K/W	Asphalt shingles	0,44	0,44	h.ft2.°F/Btu	0,08	m2.K/W
Perlite expanded 3,5"	4,95	h.ft2.°F/Btu	0,87	m2.K/W	Plywood 0.625in.	0,77	0,77	h.ft2.°F/Btu	0,14	m2.K/W
Interior air film	0,68	h.ft2.°F/Btu	0,12	m2.K/W	Steel joists*	0,00	0,69	h.ft2.°F/Btu	0,12	m2.K/W
R-Value	**7,45**	**h.ft2.°F/Btu**	**1,31**	**m2.K/W**	Air space	1,00	1,00	h.ft2.°F/Btu	0,18	m2.K/W
U-Factor	**0,13**	**Btu/h.ft2.°F**	**0,76**	**W/m2.K**	Mineral fiber	10,92	0,00	h.ft2.°F/Btu	0,00	m2.K/W
					Steel joists	0,00	0,69	h.ft2.°F/Btu	0,12	m2.K/W
					Drywall 0.5in.	0,45	0,45	h.ft2.°F/Btu	0,08	m2.K/W
					Interior air film	0,92	0,92	h.ft2.°F/Btu	0,16	m2.K/W
					R-Value	**14,67**	**5,13**	**h.ft2.°F/Btu**	**2,51**	**m2.K/W**
					U-Factor	**0,07**		**Btu/h.ft2.°F**	**0,40**	**W/m2.K**

Window					**Doors**				
Double pane, aluminum frame	2,77	h.ft2.°F/Btu	0,49	m2.K/W	Double pane, aluminum frame	2,77	h.ft2.°F/Btu	0,49	m2.K/W
R-Value	**2,77**	**h.ft2.°F/Btu**	**0,49**	**m2.K/W**	**R-Value**	**2,77**	**h.ft2.°F/Btu**	**0,49**	**m2.K/W**
U-Factor	**0,36**	**Btu/h.ft2.°F**	**2,05**	**W/m2.K**	**U-Factor**	**0,36**	**Btu/h.ft2.°F**	**2,05**	**W/m2.K**

Floor				
6" concrete slab	0,60	h.ft2.°F/Btu	0,11	m2.K/W
R-Value	**0,60**	**h.ft2.°F/Btu**	**0,11**	**m2.K/W**
U-Factor	**1,67**	**Btu/h.ft2.°F**	**9,47**	**W/m2.K**

6.6. Simulation

The building simulation was executed with the simulation software eQUEST 3.64 from James J. Hirsch. The software was already explained in chapter 4.6. Building simulation.

For the simulation of the fire stations the Wizard Data Edit was used, as it is clearly structured and detailed enough for a basic simulation, but not as extensive as the Detailed Data Edit with its list format. The Building Creation Wizard leads through the data input screens step-by-step. It consists of four major input components, namely the Project/Site/Utility area, the Building Shell area, the Mechanical Equipment area and the Domestic Hot Water data, see Figure 39.

The floor plan of Fire Station 8 was created with the software ArchiCad 15 and input into eQUEST 3.64. So the building's measures were implemented automatically, see Figure 40. For both stations the construction elements were defined according to the structure listed in the R-value calculation in chapter 6.5. Furthermore, the operation schedule, displayed in Figure 41, and the equipment and appliances and their connected load are to be defined.

After finishing the data input, the simulation for the given period was started and the simulation results were available as an overview, illustrated in Figure 42, as well as a detailed report. The results for the baseline simulations of the fire stations are listed in chapter 7.

In the second step, changes for intended improvements were made on the baseline simulation. As the Measures M1-M3 would cause higher savings in reality than the simulation suggested, the software results are highly doubted. Therefore, only the results of the baseline cases are provided in the results chapter for both fire stations, as the Energy Efficiency Measure Wizard did not generate useful results for improvement measures. The input data for the simulation of both fire stations is listed in the Appendices F - L.

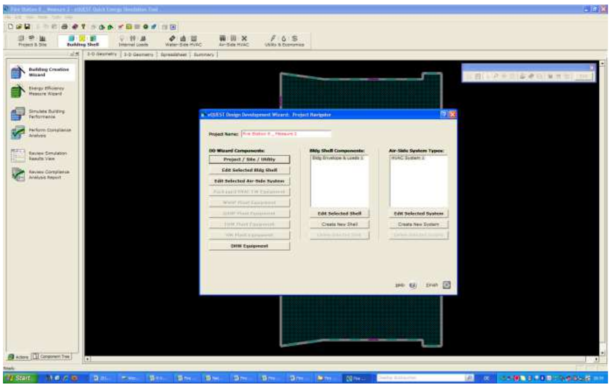


Figure 39: eQUEST - Design Development Wizard, Fire Station 8

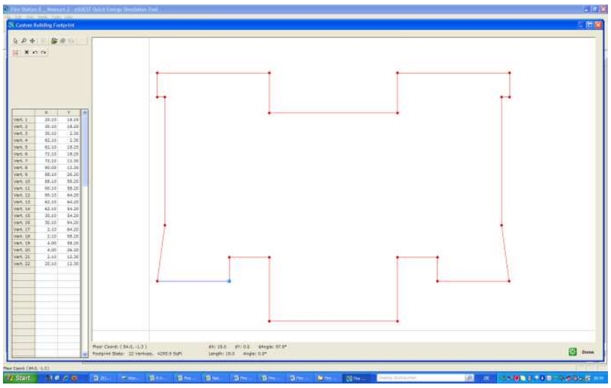


Figure 40: eQUEST - Building Footprint, Fire Station 8

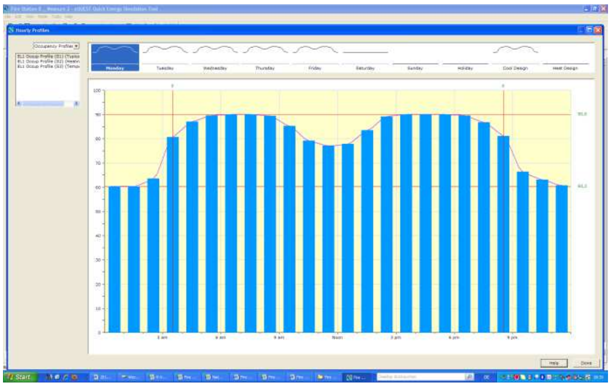


Figure 41: eQUEST - Operation Schedule input, Fire Station 8

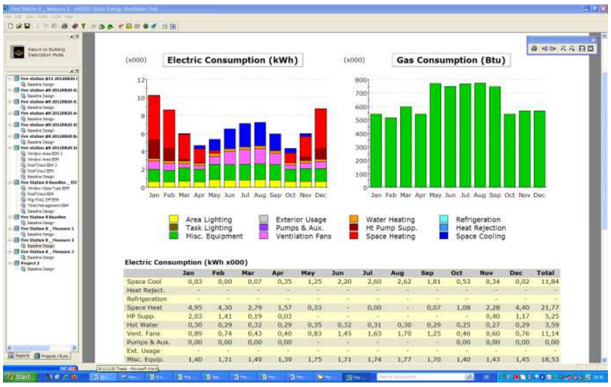


Figure 42: eQUEST - Results Overview, Fire Station 8

6.7. Calculation

During the on-site visits easy-to-implement and cost-effective measures were detected. Due to the limited available data, these improvement measures were analyzed by means of calculations instead of detailed simulation with software tools. The extracted measures and the quantifications are described below.

The anticipated measures for Fire Station 8 are listed below.

- Installation of storm windows on single-glazed windows at entrance
- Replacement of window panels with SIPs (Structural Insulated Panel)
- Installation of weather stripping/sealing around truck bay doors
- Installation of insulated exterior doors
- Installation of reflective roof

The anticipated measures for Fire Station 11 are listed below. As Fire Station 11 is a new construction from 2011, it was very unlikely that any of the possible efficiency measures would generate savings high enough to justify the investment.

- Installation of reflective roof

The following section describes the calculation procedure used for the quantification of the improvement measures for the fire stations. The calculations were performed according to ASHRAE Handbook of Fundamentals, 1981 as described in the procedure proposed by McGuiness et al. in the book *Mechanical and Electrical Equipment for Buildings, 1986,* 7th edition, with guidance from Michael Brown, PE, from Georgia Tech Enterprise Innovation Institute (EII). All calculation steps are listed in the Appendices M-LL. As these calculations are part of the energy assessment report for the City of Savannah the USCS unit system was used.

Weather-stripping around truck bay (garage) doors

Fire stations are equipped with large truck bay doors, which are difficult to seal. However, infiltration rates can be reduced significantly with weather-stripping around the perimeter of the doors. For Fire Station 8 energy savings due to weather-stripping was calculated following the approach described in McGuiness et al., 1986, Chapter 5 as listed in the Appendices M-O.

The main calculation steps are presented below. For both alternatives (weather-stripping and no weather-stripping) the infiltration rates were calculated and the latent heat loss in form of enthalpy differences for all temperature bins, as defined by [McGuiness et al., 1986], was quantified, see Appendix O. The annual energy savings and the associated cost savings and the simple payback period were determined.

Infiltration

$$\dot{m} = \dot{V} * P * \rho_{Air} \qquad \left[\frac{lb}{hr} * door\right] \qquad (6.7.1)$$

where

$\dot{V}$ ... $Air\ flow\ rate$ $\left[\frac{ft^3}{hr}\right]$

P ... $Door\ Perimeter$ $[ft]$

ρ_{Air} ... $Air\ Density$ $\left[\frac{lb}{ft^3}\right]$

Heat Loss, Infiltration

$$Q_{Loss} = \dot{m} * \Delta h * Annual\ Hours \qquad \left[\frac{Btu}{yr}\right] \qquad (6.7.2)$$

where

Δh ... $Enthalpy\ difference$ $\left[\frac{Btu}{lb}\right]$

Heating Energy Savings

$$E_{saved} = Q_{Loss} * Conversion \qquad \left[\frac{kWh}{yr}\right] \qquad (6.7.3)$$

<u>Annual Energy Cost Savings</u>

$$C = E_{saved} * C_{unit} \qquad \left[\frac{\$}{yr}\right] \qquad (6.7.4)$$

where

C ... $Cost$ [$]

<u>Simple Payback Period</u>

$$SPB = \frac{I}{C} \qquad [years] \qquad (6.7.5)$$

where

I ... $Investment$ [$]

Installation of storm windows

The installation of storm windows on the inside of existing single-pane windows at the west-facing entrance leads to a reduction of solar heat gain in summer and of heat losses in winter. The calculation follows the approach of ASHRAE Handbook of Fundamentals, 1981, Chapter 26. Only the main calculation steps are presented in this chapter. The complete calculation is presented in Appendices P-T. First, the conduction heat gain Q in $\frac{Btu}{yr}$ of the existing windows and the windows with the proposed storm windows were calculated.

Conduction Heat Gain

$$Q = \frac{A*CLTD}{R} \qquad \left[\frac{Btu}{yr}\right] \qquad (6.7.6)$$

where

$A \ldots Area\ [ft^2]$

$CLTD \ldots Cooling\ Load\ Temperature\ Difference\ [°F]$

$R \ldots Thermal\ Resistance\ \left[\frac{hr\ ft^2\ F}{Btu}\right]$

Heat Gain Reduction

$$\Delta Q_{cond,Gain} = Q_{current} - Q_{Storm\ window} \qquad \left[\frac{Btu}{yr}\right] \qquad (6.7.7)$$

Secondly, the solar heat gain Q in $\frac{Btu}{yr}$ for the yearly cooling load was determined for both options. Then the heat gain difference of the existing and the proposed system was determined as in Formula 6.7.7.

Solar Heat Gain

$$Q = A * SHGF * CLF * SC * Cooling\ hours \ \left[\frac{Btu}{yr}\right] \qquad (6.7.8)$$

where

$SHGF \ldots Solar\ Heat\ Gain\ Factor\ [\frac{Btu}{hr\ ft^2}]$

$CLF \ldots Cooling\ Load\ Factor\ [-]$

$SC \ldots Shading\ Coefficient\ [-]$

Heat Gain Reduction

$$\Delta Q_{solar,Gain} = Q_{current} - Q_{Storm\ window} \qquad \left[\frac{Btu}{yr}\right] \qquad (6.7.9)$$

Total Heat Gain Reduction

$$\Delta Q_{Total} = \Delta Q_{cond,Gain} + \Delta Q_{solar,Gain} \qquad \left[\frac{Btu}{yr}\right] \qquad (6.7.10)$$

The yearly energy savings W in kWh due to the reduced operation of the cooling units was calculated as follows.

Cooling Energy Reduction

$$W = \Delta Q_{total} * Conversion * Perf_C \qquad \left[\frac{kWh}{yr}\right] \qquad (6.7.11)$$

where

$$Conversion = \frac{1\ ton * hr}{12.000\ Btu}$$

$$Perf_C \ldots Cooling\ Performance\ \left[\frac{kW}{ton}\right]$$

For the quantification of conduction heat loss savings the deviation of conduction heat losses of the existing windows and the proposed storm windows during the heating period was calculated.

Conduction Heat Loss

$$Q = \frac{A * \Delta T * hrs}{R} \qquad \left[\frac{Btu}{yr}\right] \qquad (6.7.12)$$

where

$A \ldots Area\ [ft^2]$

$\Delta T \ldots Temperature\ Difference\ of\ Temperature\ Bin\ [°F]$

$hrs \ldots Annual\ Hours\ of\ Occurrence\ of\ Temperature\ Bin$

$R \ldots Thermal\ Resistance\ \left[\frac{hr\ ft^2\ F}{Btu}\right]$

Heat Loss Reduction

$$\Delta Q_{cond,Loss} = Q_{current} - Q_{Storm\ window} \qquad \left[\frac{Btu}{yr}\right] \qquad (6.7.13)$$

The final heating energy savings W in $MMBtu$ due to the reduced operation of the furnaces was calculated as follows.

<u>Heating Energy Reduction</u>

$$W = \frac{\Delta Q_{cond,Loss}}{\eta_{Furnace}} \qquad \left[\frac{MMBtu}{yr}\right] \qquad (6.7.14)$$

Where
$\eta_{Furnace}$ ... $Furnace\ Efficiency\ [-]$

The cost savings were calculated according to Formula 6.7.4 using the unit energy prices. The determination of the simple payback period followed the calculation procedure as shown in Formula 6.7.5.

Replacement of window panels with SIPs

In Fire Station 8 several of the existing double-pane windows are blocked with wood panels. By replacing the windows and panels with standardized insulated panels (SIP), heating and cooling energy could be saved. The anticipated savings were calculated by quantifying the conduction heat gain and solar heat gain during summer months and the conduction and infiltration heat loss during winter months for the existing system and the SIPs, following the approach presented in ASHRAE Handbook of Fundamentals, 1981, Chapter 26. The main calculation steps are described below. For further information the complete calculation is listed in Appendices U-AA.

<u>Conduction Heat Gain</u>

$$Q = \frac{A*CLTD_{corrected}}{R} \quad \left[\frac{Btu}{yr}\right] \qquad (6.7.15)$$

where

$CLTD_{corrected} = Cooling\ Load\ Temperature\ Difference\ corrected\ for\ Window\ Direction$

The conduction heat gain savings were summed up according to Formula 6.7.7.

<u>Solar Heat Gain</u>

$$Q = A * SHGF * CLF * SC * Cooling\ hours \quad \left[\frac{Btu}{yr}\right]$$ see (6.7.8)

The solar heat gain savings were summed up according to Formula 6.7.7.

<u>Total Heat Gain Reduction</u>

$$\Delta Q_{Total,Gain} = \Delta Q_{cond,Gain} + \Delta Q_{solar,Gain} \quad \left[\frac{Btu}{yr}\right]$$ see (6.7.10)

The conduction heat losses were calculated as described in Formula 6.7.12, page 62.

Due to the tight installation of SIPs the infiltration losses are almost negligible after installing SIPs compared to the existing windows.

Infiltration losses

$$\dot{m} = \dot{V} * A * \rho_{Air} \qquad \left[\frac{lb}{hr} * door\right] \qquad (6.7.16)$$

where

$\dot{V}$ ... $Air\ flow\ rate$ $\left[\frac{ft^3}{hr}\right]$

A ... $Window\ Area$ $[ft^2]$

ρ_{Air} ... $Air\ Density$ $\left[\frac{lb}{ft^3}\right]$

Heat Loss, Infiltration

$$Q_{Loss} = \dot{m} * \Delta h * Annual\ Hours \qquad \left[\frac{Btu}{yr}\right]$$

see (6.7.2)

Energy Savings Infiltration

$$\Delta Q_{Infiltration} = Q_{Loss,exting} - Q_{Loss,SIP} \qquad \left[\frac{Btu}{yr}\right] \qquad (6.7.17)$$

Total Cooling Energy Savings

$$\Delta Q_{Total,C} = \Delta Q_{Total,Gain} + \Delta Q_{Infil,Gain} \qquad \left[\frac{Btu}{yr}\right] \qquad (6.7.18)$$

Cooling Energy Reduction

$$W = \Delta Q_{Total,C} * Conversion * Perf_C \qquad \left[\frac{kWh}{yr}\right]$$

see (6.7.11)

Total Heating Energy Savings

$$\Delta Q_{Total,H} = \Delta Q_{Total,Loss} + \Delta Q_{Infil,Loss} \qquad \left[\frac{Btu}{yr}\right] \qquad (6.7.19)$$

The calculation of heating energy savings is described in Formula 6.7.14, page 63. The total cost savings were calculated in the same way as in Formula 6.7.4 for each electricity and natural gas. The payback period calculation followed Formula 6.7.5, page 60.

Replacement of exterior wooden doors

The main entrance on the west side of the building as well as the back doors facing north and south are 3,0 wide solid core wood doors. By replacing the old doors with new insulated metal doors, energy can be saved in form of reduced solar heat gain, reduced conduction and infiltration losses, as presented in the spreadsheet calculation in the Appendices BB-HH. The general calculation steps are listed below. The spreadsheet calculation uses the cooling load temperature difference (CLTD) method for calculating the heat transfer load of the doors.

<u>Conduction Heat Gain</u>

See Formula 6.7.15, page 64.

<u>Heat Gain Reduction</u>

See Formula 6.7.7, page 61.

<u>Cooling Energy Reduction</u>

See Formula 6.7.11, page 62.

<u>Conduction Heat Loss</u>

See Formula 6.7.12, page 62.

<u>Heat Loss Reduction</u>

See Formula 6.7.13, page 62.

<u>Heating Energy Reduction</u>

See Formula 6.7.14, page 63.

<u>Infiltration Reduction</u>

See Formula 6.7.1 and 6.7.2, page 59.

<u>Total Cooling Energy Savings</u>

See Formula 6.7.18, page 65.

<u>Total Heating Energy Savings</u>

See Formula 6.7.19, page 65.

<u>Annual Cost Savings</u>

See Formula 6.7.4, page 60.

<u>Payback period</u>

See Formula 6.7.5, page 60.

Reflective Roof

A reflective coating on the roof reflects most of the solar radiation and therefore reduces the solar heat gains through the roof. However, most roof decking is simple asphalt shingles. The costs and feasibility of the application of reflective coating on existing roof was calculated in form of a spreadsheet calculation following the the cooling load temperature difference (CLTD) method outlined in ASHRAE Handbook of Fundamentals, 1981, Chapter 26, for calculating the heat transfer load of the roof, as listed in the Appendices II-LL.

The roofs' primary heat gain is from thermal conduction driven by the cooling load temperature difference (CLTD) [McGuiness et al., 1986, Chapter 5].

Conduction Heat Gain

$$Q = \frac{A * CLTD_{corrected}}{R} \quad [\frac{Btu}{yr}]$$ see (6.7.15)

Electricity Savings per Year

See Formula 6.7.18, page 65.

Annual Cost Savings

See Formula 6.7.4, page 60.

Simple Payback

See Formula 6.7.5, page 60.

6.8. Economic analysis

An economic analysis was performed for each improvement measure to evaluate its feasibility. Two different approaches were considered for the analysis. First, the simple payback period of each measure was calculated on basis of the yearly energy savings and the investment costs and secondly, the payback period was calculated by means of the net present value method. The following formulas present the two approaches.

$$Simple\ payback\ period = \frac{Investment\ costs}{Annual\ energy\ savings} \qquad (6.8.1)$$

$$Net\ Present\ Value = -X_0 + \sum_{t=0}^{n} \frac{X_t}{(1+r)^t} \qquad (6.8.2)$$

with

X_0 … $Initial\ investment$

X_t … $Net\ cash\ flow$

r … $interest\ rate$

t … $period\ of\ analysis$

While the simple payback period is easy to calculate, it does not consider interest rates or inflation. The net present value method, however, includes estimated interest rates and inflation into the calculation. The individual cash flows of the analyzed period are discounted and subtracted from the initial investment, as shown in Formula (2) above [Karathanassis, 1980]. The NPV therefore gives a more detailed and reliable information about investment options.

For the analysis an interest rate r of 5% was used. The net cash flows are the yearly energy savings. The calculation is displayed in the Appendices MM-OO.

7. RESULTS

7.1. Improvement measures

The results of the calculations of energy efficiency improvements of the fire stations are presented in Table 9. It displays the savings in electricity and natural gas consumption, the savings in $ as well as the estimated implementation costs. The results of the economic analysis as simple payback period (SPB) and the net present value (NPV) are also included in the table.

Table 9: Calculation results, Energy Assessment Report, Fire Station 8

Measure #	Description	Electric Energy (kWh)	Natural Gas (MMBtu)	Cost Savings ($/yr)	Imp. Cost ($)	SPB (yrs)	NPV_5 ($)
1	Install Weather-Stripping on Garage Doors	2.761	0	$298	$164	0,6	$1.126
2	Install Interior Storm Windows	495	2	$73	$230	3,1	$86
3	Replace Exterior Wooden Doors	388	4	$93	$792	8,5	-$389
4	Replace Windows with Insulated Panels	2.383	13	$433	$4.050	9,4	-$2.175
Total		**6.027**	**19**	**$897**	**$5.236**	**5,84**	**-$1.452**

Those four measures with simple payback periods of less than 10 years are included in the table. These include the installation of weather-stripping on garage doors with a payback period of 0,6 years, the installation of storm windows (payback period of 3,1 years), the replacement of exterior wooden doors with a payback of 8,5 years and the installation of SIPs, which has a simple payback period of 9,4 years.

The total savings amount to 6.027 kWh of electricity, which is 8% of the total consumption of 2011, and 19 MMBtu of natural gas, accounting for 24% of the total consumption. The savings sum up to $897 per year, which is 10,1% of the total energy costs. The total estimated investment costs amount to $5.236, which results in a simple payback period of 5,84 years. The net present value after five years of the total investment is -$1.452.

7.2. Simulation results

Fire Station 8, Baseline Simulation

The results of the baseline simulation with eQUEST 3.64 for Fire Station 8 are displayed in Figure 43. The figure shows the simulated electricity and natural gas consumption for the year 2011.

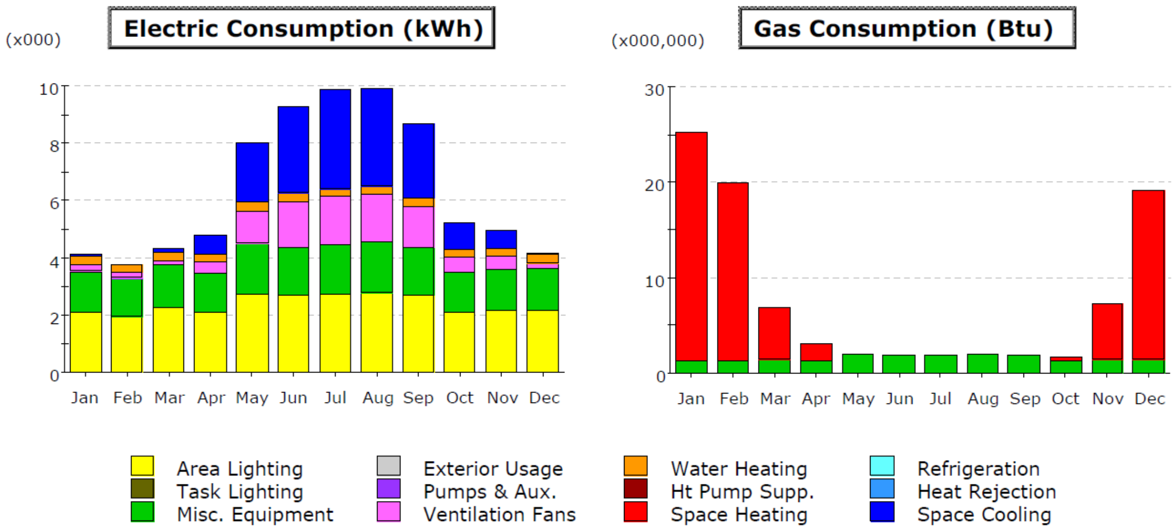


Figure 43: Simulation results, Baseline, Fire Station 8

Figure 44 compares the actual electricity consumption of Fire Station 8 in 2011 with the results of the baseline simulation. The simulation calculated lower electricity consumptions for the months of January to April. From May to December the simulation overestimated the actual electricity consumption of Fire Station 8.

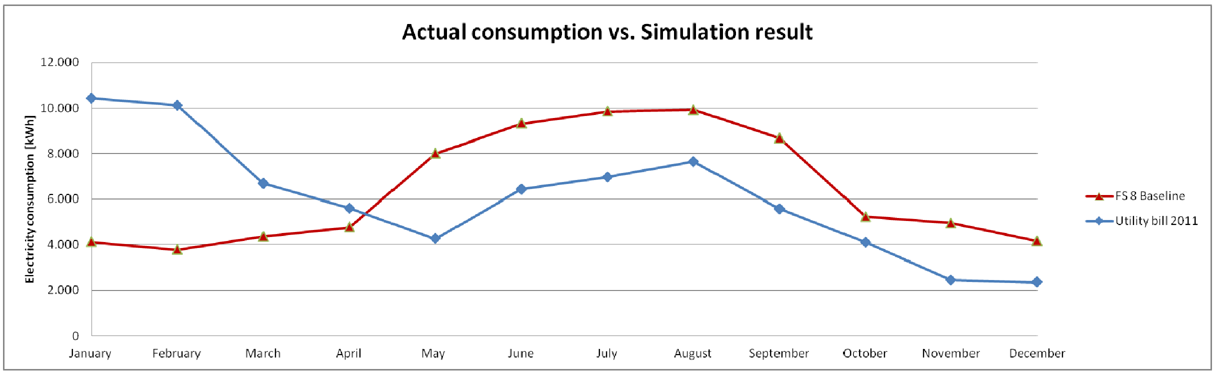


Figure 44: Comparison consumption vs. simulation, Electricity, Fire Station 8

In Figure 45 the natural gas consumption of the year 2011 of Fire Station 8 is compared with the simulation results. The actual natural gas consumption is significantly lower than the simulation result in December. For all other months the simulation results are corresponding with the consumption data.

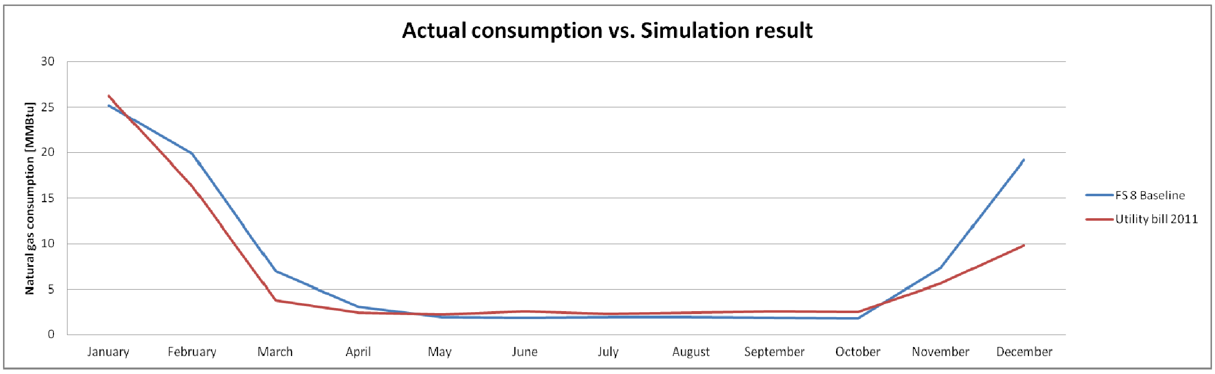


Figure 45: Comparison consumption vs. simulation, Natural gas, Fire Station 8

Fire Station 11, Baseline Simulation

The simulation results for the baseline simulation of Fire Station 11 are displayed in Figure 46 below. It shows the simulated electricity consumption of the year 2011.

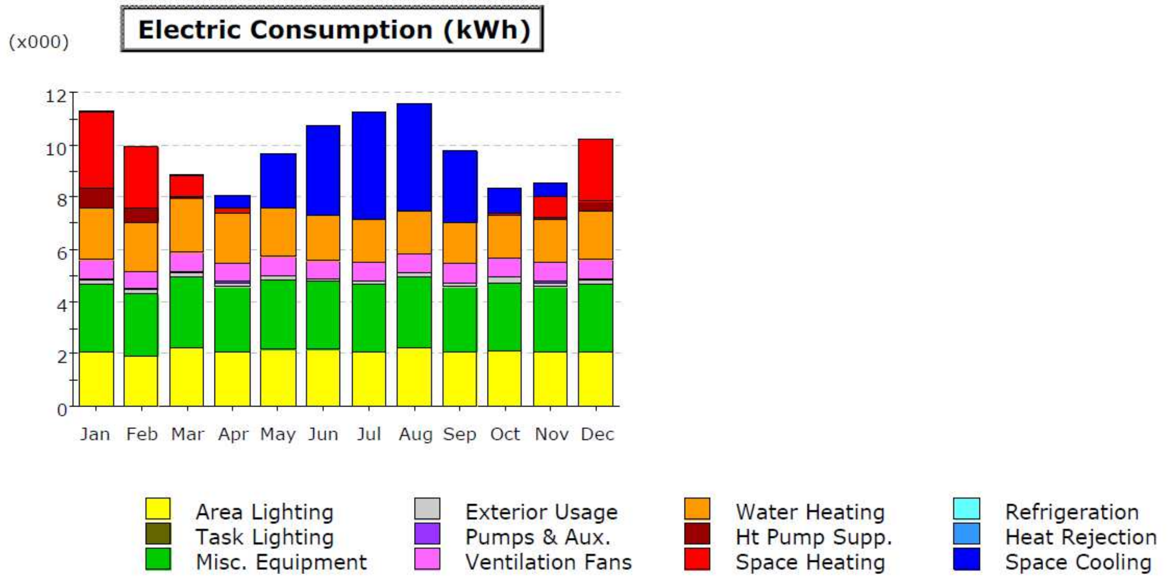


Figure 46: Simulation results, Baseline, Fire Station 11

Furthermore, the actual electricity consumption of that period is compared with the simulation results in Figure 47. In the months from March to May and in November the simulation varies significantly from the actual consumption, while simulation and real consumption are matching during the rest of the year.

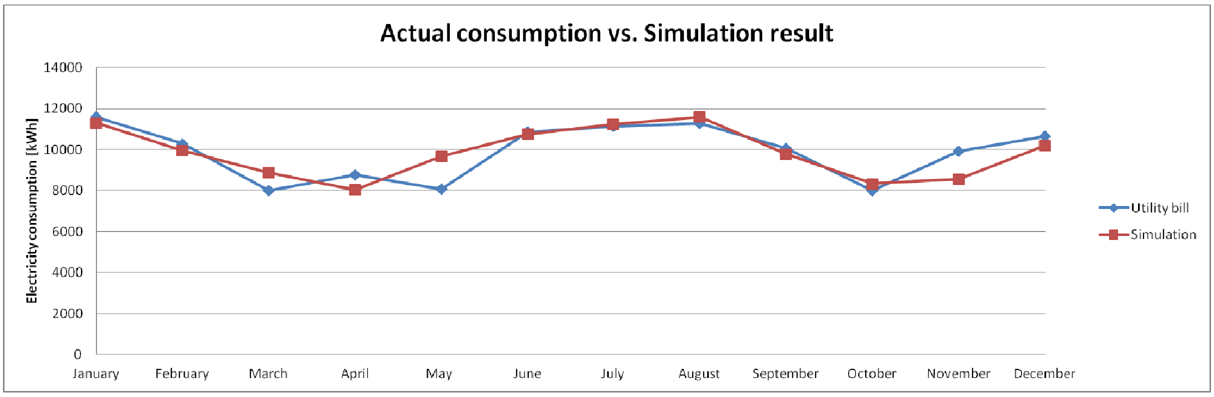


Figure 47: Comparison consumption vs. simulation, Electricity, Fire Station 11

Finally, Figure 48 and Figure 49 show the most expressive infrared pictures, taken during the on-site visit in Fire Station 11 on 11 October 2012. The first photo shows a missing insulation batt located in the ceiling of the garage, where an electric installation runs through (in pink, on the left side above the cross). The second picture displays an aluminum-frame window on the west-facing side of the building. No heat conduction or infiltration from outside is visible.

Figure 48: IR picture of garage ceiling, Fire Station 11, 11.10.2012

Figure 49: IR picture of insulated window, Fire Station 11, 11.10.2012

General findings were collected and put together in the “Green Building Guidance – A Homeowner’s reference from Austrian Engineers in Savannah”, which will be published on the webpage of the City of Savannah (www.savannahga.gov) under Community – Environment & Health – Thrive Sustainability Initivative.

8. CONCLUSION

It has been found that in hot and humid climates the energy consumption for cooling plays a more important role than the energy consumption for heating. The intense solar radiation causes massive solar heat gains in buildings. The high humidity during summer months makes the operation of HVAC systems with dehumidification inevitable. Additionally, close attention has to be paid to a tight building envelope and the accurate installation of vapor barriers during the construction of a building.

The results show that with simple and easy-to-install improvement measures 10,1% of the total energy costs can be saved. While a simple payback time of more than 5 years is considered as not feasible, the negative net present value in year five proofs that the replacement of the exterior doors and the window boards does not generate high enough savings to justify these measures. With the current energy prices in the state of Georgia, which are approximately half of those in Austria, energy-efficiency improvements in existing buildings are mostly not practicable.

However, this is not true for new constructions, where a lot of the energy-efficiency measures can be adopted with little additional costs. Therefore recommendations for future buildings in Savannah include the following:

- Pay special attention to the right building orientation. Small façades at the east and west side and large façades at the north and south side combined with overhangs at the south façade provide an optimum of solar gain in winter and protection in summer.
- Install sufficient and accurately mounted roof insulation as well as right windows. Roof insulation is important both in the heating season and in the cooling season as solar heat gain can be reduced significantly during cooling season. The HVAC system operates less due to reduced heat gain, which generates substantial energy savings.
- Install reflective roof coating.

Roof decking with reflective coating is available in a variety of colors so no visual disadvantages are caused. The reflective roof achieves savings of up to 32% of solar heat gain. As there do not accrue additional costs for the installation of the reflective roof coating in case of a new construction, as it would occur for retrofits, additional costs will be minor.

- Pay attention to a tight building envelope. Reducing infiltration rates due to sealing around windows and doors reduces the heating and cooling loads. Operation savings of the mechanical equipment can be achieved.

The simulation results of Fire Station 8 admit that there is either a failure in the consumption data or a major change in use at the end of the simulated year. After some adjustments of efficiency of heating and cooling equipment the yearly energy consumption could be simulated well (deviation from the actual consumption data of 6% in total but of 102% in November). However an exact simulation could not be achieved.

It is assumed that the software is not capable of building structures of this complexity. A baseline picture of the existing building can be produced but no conclusions on the effects of any improvement measures can be drawn from these results. The easy-to-input data wizard is a drawback when it comes to complex buildings. When it comes to fire stations or similar types of buildings, which are not built and conditioned in a standardized way due to the large garage areas, eQUEST does not provide highly diagnostic simulation results and is therefore not recommended for this particular purpose.

Fire Station 11 was constructed in 2011. Regarding the building envelope no major negative aspects have been found. The effects of the installation of a reflective roof coating have been analyzed. With a simple payback period of more than 28 years, see Appendix LL, this measure is not feasible.

Finally, due to missing data such as data sheets of the equipment or construction plans, the results are exemplary and provide information only on the surface. For more reliable results detailed plans, energy bills and measurement data would be necessary.

As general data about the buildings does not exist, an energy management system would help to give an overview of the energy consumption and energy intensity of Savannah's building structure. The implementation of such a system is labor and data intensive.

9. SUMMARY

Around 41 percent of the energy consumption in the United States is used in buildings. Energy consumption plays an important role due to increasing energy prices as well as the economical importance of that issue. The City of Savannah committed itself to reduce its overall energy consumption by 15 percent by the year 2020 compared to 2007. To identify ways to reduce the energy consumption, energy assessments for buildings were performed in cooperation with the Georgia Institute of Technology and the University of Applied Sciences Upper Austria.

Georgia is located in the hot and humid climate zone, which is characterized by high temperatures and humidity in summer and relatively dry and temperate winters. The energy consumption of buildings is mainly driven by high cooling loads in summer, while heating loads in winter play a minor role.

To find general approaches that are applicable to a vast majority of buildings, buildings with high energy consumptions were identified and subject to in-depth energy assessments. Two fire stations were selected as exemplary buildings. The four-step analysis included the analysis of energy consumption data, on-site visits, building simulation and the quantification of selected retrofit opportunities. The retrofit opportunities were calculated following the CLTD-method. The analyzed opportunities in Fire Station 8 included the replacement of windows with insulating panels and the replacement of the exterior doors with insulated metal doors. Furthermore the installation of storm windows on the existing single-pane windows as well as the installation of weather-stripping around the garage doors was determined.

It was shown that the implementation of these measures would save 6.027 kWh/year of energy, which is 8 percent of the total consumption. The implementation costs amount to $5.236, which result in a payback period of 5,84 years. From the economic point of view, the measures are too expensive to be implemented, as the overall net present value of the measures after five years is negative.

As retrofit measures are seldom feasible with respect to the low energy prices in the state of Georgia compared to the Austrian price level, attention should be paid to the implementation of energy-efficient measures in new constructions. Therefore, general recommendations for the construction of new buildings were made in form of a “Green Building Guidance” for homeowners and small businesses for Savannah.

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11. LIST OF FIGURES

12. LIST OF TABLES

13. List of formulas

14. Appendix

Benchmarking of municipal buildings

In Figure 50 and in Figure 51 on the next page the results of the benchmarking with UtilityTrac Plus are displayed.

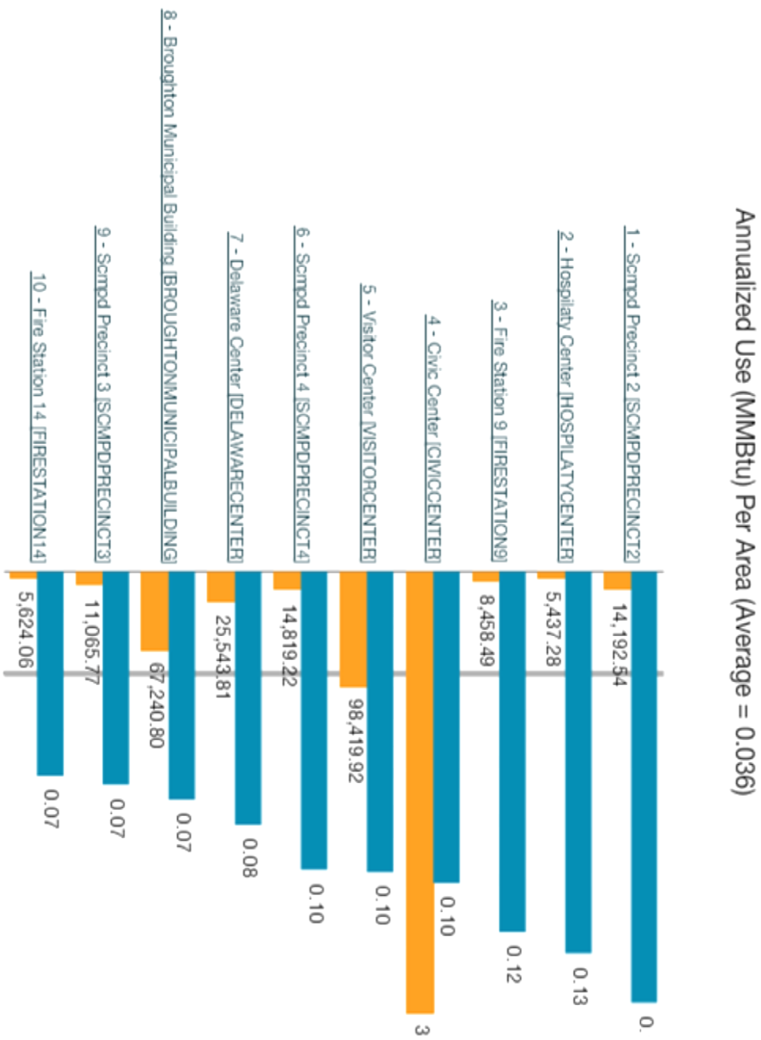

Figure 50: Buildings with the highest energy consumption per area, City of Savannah, UtilityTrac Plus,17.07.2012

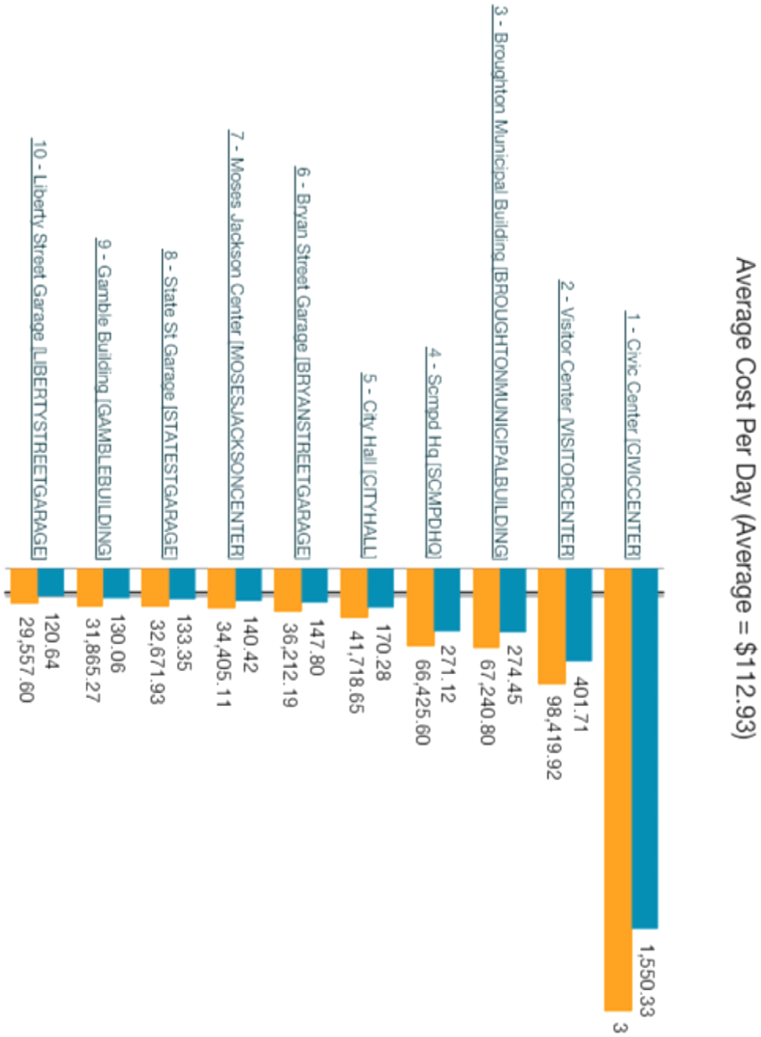

Figure 51: Buildings with the highest average energy costs , City of Savannah, UtilityTrac Plus,17.07. 2012

Electricity consumption, Fire Station 8

December 2009 to August 2012

Period	Use [kWh]	Cost [$]	Enery Costs [ct/kWh]
Dez.09	9.700,00	773,24	8,00
Jän.10	11.402,00	854,20	7,50
Feb.10	6.688,00	627,63	9,40
Mär.10	7.073,00	663,40	9,40
Apr.10	4.485,00	527,56	11,80
Mai.10	5.768,00	621,82	10,80
Jun.10	13.221,00	991,46	7,50
Jul.10	14.716,00	371,78	2,50
Aug.10	6.735,00	637,46	9,50
Sep.10	5.745,00	557,14	9,70
Okt.10	3.610,00	444,20	12,30
Nov.10	7.531,00	648,20	8,60
Dez.10	10.436,00	830,44	8,00
Jän.11	10.119,00	866,14	8,60
Feb.11	6.688,00	688,06	10,30
Mär.11	5.601,00	263,40	4,70
Apr.11	4.260,00	556,70	13,10
Mai.11	6.435,00	749,43	11,60
Jun.11	6.969,00	842,36	12,10
Jul.11	7.653,00	883,38	11,50
Aug.11	5.572,00	738,06	13,20
Sep.11	4.103,00	625,16	15,20
Okt.11	2.454,00	415,98	17,00
Nov.11	2.352,00	399,40	17,00
Dez.11	3.230,00	542,87	16,80
Jän.12	7.184,00	797,58	11,10
Feb.12	3.946,00	621,59	15,75
Mär.12	2.800,00	483,33	17,26
Apr.12	4.118,00	645,55	15,68
Mai.12			11,93
Jun.12	6.386,00	1523,24	11,93
Jul.12	7.023,00	815,16	11,61
Aug.12	5.757,00	726,75	12,62

Natural Gas Consumption, Fire Station 8

December 2010 to September 2012

Natural gas					
Fire Station 8					
Month	**MMBtu**	**Unit costs [$/MMBtu]**	**Commodity Charge**	**Distribution Charge**	**Total Costs [$]**
December 2010	18,3	6,223	113,88	44,42	158,30
January 2011	26,2	6,172	161,71	44,42	206,13
February 2011	16,3	6,272	102,23	44,42	146,65
March 2011	3,8	5,749	21,85	44,42	66,27
April 2011	2,4	6,196	14,87	44,42	59,29
May 2011	2,2	6,333	13,93	44,42	58,35
June 2011	2,6	6,282	16,33	44,42	60,75
July 2011	2,3	6,313	14,52	44,42	58,94
August 2011	2,4	6,326	15,18	44,42	59,60
September 2011	2,6	5,813	15,11	46,92	62,03
October 2011	2,5	6,956	17,39	47,29	64,68
November 2011	5,6	6,721	37,64	47,29	84,93
December 2011	9,8	6,561	64,30	47,28	111,58
January 2012	13,6	6,281	85,42	47,28	132,70
February 2012	8,5	5,875	49,94	47,28	97,22
March 2012	3,9	5,643	22,01	47,28	69,29
April 2012	2,4	5,388	12,93	47,28	60,21
May 2012	2,4	5,233	12,56	47,28	59,84
June 2012	2,2	5,626	12,38	47,28	59,66
July 2012	2,4	5,971	14,33	47,28	61,61
August 2012	2,7	6,207	16,76	47,28	64,04
September 2012	2,4	5,831	13,99	45,61	59,60

Electricity consumption, Fire Station 11

July 2011 to September 2012

Month	Days	Total kWh	Total costs	¢/kWh	Cost/day
Jul-11	30	11.120,00	$2.473,02	22,24	82,43
Aug-11	31	11.280,00	$1.425,55	12,64	45,99
Sep-11	31	10.040,00	$1.311,85	13,07	42,32
Oct-11	30	8.000,00	$1.141,12	14,26	38,04
Nov-11	31	9.920,00	$1.245,45	12,55	40,18
Dec-11	30	10.640,00	$1.324,28	12,45	44,14
Jan-12	31	11.600,00	$1.403,23	12,10	45,27
Feb-12	31	10.280,00	$1.334,34	12,98	43,04
Mar-12	29	8.000,00	$1.210,15	15,13	41,73
Apr-12	31	8.760,00	$1.269,46	14,49	40,95
May-12	30	8.080,00	$1.242,89	15,38	41,43
Jun-12	31	10.840,00	$1.742,13	16,07	56,20
Jul-12	30	21.680,00	$1.015,07	4,68	33,84
Aug-12	31	11.640,00	$1.421,33	12,21	45,85
Sep-12	31	10.880,00	$1.422,17	13,07	45,88
Total	458	162.760,00	$20.982,04	12,89	45,81
Total 12 months	398	129.960,00	$17.493,95	13,46	43,95

Simulation, Fire Station 8

Data displayed in the table below lists the input data for the baseline simulation of Fire Station 8.

Screen	**Field name**	**Selection**
1.1	Building Type	Unknown, Custom or Mixed Use
1.1	Location	All eQUEST Locations
1.1	State	Georgia
1.1	City	Savannah
1.1	Electric utility	Custom
1.1	Gas utility	Custom
1.1	Analysis year	2011
1.2	Description of Seasons	Typical Use Throughout Year
1.2	Observed Holidays	None
1.2	Number of seasons	3
1.2	Season #1	Cooling May 1 thru September 30
1.2	Season #2	Heating January 1 thru February 28 December 1 thru December 31
1.2	Season #3	Temperate March 1 thru April 30 October 1 thru November 30
1.4	Electric Utility Charges	Uniform Charges $0,108/kWh
1.6	Fuel Utility Charges	Customer Charge $46,00/Month Uniform Charges $0,61/Therm
1.7	Building location	2824 Bee Road Savannah, GA, 31404
2	Building shell	
2.1	**Shell name**	**Fire Station 8**
2.1	Building type	Unknown, Custom or Mixed Use
2.1	Site Coordinates	-
2.1	Building Area	4.300 ft2
2.1	Floors above Grade	1
2.2	Footprint shape	Custom
2.2	Zoning pattern	Custom
2.2	Plan North	East
2.2	Floor-to-Floor Height	12 ft
2.2	Floor-to-Ceiling Height	9 ft
2.2	Roof, Attic Properties	Pitched Roof, 15°
2.3	Roof Surface Construction	Wood Standard Frame
2.3	Exterior Finish/Color	Roofing, shingle; Brown, dark
2.3	Exterior Insulation	No exterior board insulation
2.3	Additional Insulation	No batt or radiant barrier
2.3	Above grade walls	12 in. CMU
2.3	Exterior Finish/Color	Brick; Red, masonry
2.3	Exterior Insulation	No board insulation
2.3	Additional Insulation	Hollow
2.3	Interior Insulation	R-4 wd furred insulation
2.3	Ground floor	Earth Contact
2.3	Construction	6 in. Concrete
2.3	Ext/Cav. Insulation	No perimeter insulation
2.3	Interior Finish	Vinyl Tile
2.3	Shell Tightness Perimeter Zone	7 ACH (estimated)
2.3	Shell Tightness Core Zones	2 ACH (estimated)
2.4	Top Floor Ceiling, Int. Finish	Lay-In Acoustic Tiles
2.4	Framing	Wood, Standard Framing

2.4	Ceiling Batt Insulation	R-11 batt
2.4	Rigid Insulation	No board insulation
2.4.	Ceilings, Int. Finish:	Lay-In Acoustic Tile
2.4	Batt Insulation	No ceiling insulation
2.4	Vertical Walls Type	Mass
2.5	Exterior Door Type 1	Opaque; 1 South, 1 West, 1 North
2.5	Exterior Door Type 2	Opaque; 2 West
2.5	Exterior Door Type 3	Opaque; 1 East
2.5	Dimensions and Construction (Type 1)	7ft x 3ft; Wood, Solid core Flush, 1-3/8 in.
2.5	Dimensions and Construction (Type 2)	9ft x 11ft, Steel Hollow core w/o Br
2.5	Dimensions and Construction (Type 3)	6ft x 7ft, Wood, Solid core Flush, 1-3/4 in.
2.6	Window Area Specification Method	Percent of Net Wall Area (floor to ceiling)
2.6	Glass Category 1	Double Clr/Tint (2006); Clear/ThinAir/Clear 3mm (6000: U=0,55 SHGC=0,76 VT=0,81) Frame Type: Wood/Vinyl, Oper, Mtl Spacer Frame Width (in) 1,3
2.6	Glass Category 2	Single Clear 1/8in (1000) Frame Type: Wood/Vinyl, Fixed Frame Width (in) 1,3
2.6	Window Dimensions	3,30ft x 3,75ft, Sill 0,5ft (2,5% West, 0,6% East, 19% South, 20% North) 5,9ft x 9ft, Sill 0ft (5,5% West)
2.7	Exterior Window Shades	All windows 0,5ft Shade depths: South 3,00ft, North 3,00ft, West 6,00ft
2.7	Window Blinds/Drapes	None
2.8	Roof Skylights	None
2.12	Building Operation Schedule	Use: Typical Use Open 24 hours, all year
2.13	Area Type	Police Station and Fire Station: 32,0% (225 sf/per, 5,00 cfm/per) Office (General): 3,0%, (75 sf/per, 15,00 cfm/per) Residential (General Living Space): 22,0% (150 sf/per, 15,00 cfm/per) Residential (Bedroom): 26,0% (375 sf/per, 15,00 cfm/per) Corridor: 4,0% (100 sf/per, 5,00 cfm/per) Storage (Conditioned): 5,0% (500 sf/per, 7,5 cfm/per) Restrooms: 5,0% (300 sf/per, 5,00 cfm/per) Mechanical/Electrical Room: 3,0% (2000 sf/per, 50,00 cfm/per)
2.13	Occupancy Profiles by Season	Alternating between 60,3% and 90%
2.14	Zone Group Definitions	Ground Floor Perimeter: HVAC System 1 Zone Group 2 (Truck Bay): unconditioned space
2.15	Interior Enduses	Interior Lighting, Office Equipment, Cooking Equipment, Miscellaneous Equipment, Self-Contained Refrigeration, Motors
2.15	Exterior Enduses	Domestic Hot Water (Model DHW Equipment with Seasonal Profiles)
2.16	Interior Lighting[2]	Police and Fire Station: 3,25 W/SqFt Office: 1 W/SqFt Residential (General): 2,5 W/SqFt Residential (Bedroom): 1,21 W/SqFt Corridor: 0,5 W/SqFt Storage: 1,00 W/SqFt Restrooms: 4,38 W/SqFt Mechanical/Electrical Room: 1,00 W/SqFt Multipliers on above intensities: 0,5
2.16	Interior Lighting Hourly Profiles	Alternating between 62% and 90% (all year)
2.17	Office Equipment	Office (General): 4,00 W/SqFt
2.17	Office Equipment Profile	Alternating between 64,3% and 90% (all year)
2.18	Cooking Loads[3]	Residential (General Living Space): 5,0 Btuh/SF; Sensible Ht: 1,00 frac
2.18	Cooking Equipment Profile	Peak at 73,9% at noon, Baseline 50,3% (all year)
2.19	Self-Contained Refrigeration	Police and Fire Station: 0,15 W/SqFt

[2] Wattage calculated with real amount of lighting fixtures (Watzak-Helmer)

[3] Estimated 80 Therms/year = 8.005.356 Btu/year

2.19	SCR Profile	64% to 90%
2.20	Miscellaneous Loads	Police and Fire Station: 0,05 W/SqFt Office: 0,10 W/SqFt Residential (General Living Space): 0,5 W/SqFt Residential (Bedroom): 0,05 W/SqFt
2.20	Misc. Loads Profile	Baseline: 66,9%, maximum 90,0% (all year)
2.22	Motor and Air Compressor Loads	Police and Fire Station: 1,25 W/SqFt
2.22	MAC Profile	Baseline: 64,6%, Maximum: 90% (all year)
2.25	Domestic Hot Water Profile	Baseline: 62%, Maximum: 90% (all year)
3	HVAC System Definition	
3.1	System Type Name	HVAC System 1
3.1	Cooling Source	DX Coils
3.1	Heating Source	Furnace
3.1	System Type	Split System Single Zone DX with Furnace
3.1	System per Area	System per Zone
3.1	Return Air Path	Ducted
3.2	Seasonal Thermostat Setpoints: Cooling	Occupied: 70 (Cool), 60 (Heat) Unoccupied: 72 (Cool), 55 (Heat)
3.2	Seasonal Thermostat Setpoints: Heating	Occupied: 70 (Cool), 60 (Heat) Unoccupied: 72 (Cool), 55 (Heat)
3.2	Seasonal Thermostat Setpoints: Temperate	Occupied: 70 (Cool), 60 (Heat) Unoccupied: 72 (Cool), 55 (Heat)
3.2	Cooling Design Temperature	Indoor: 75; Supply: 55
3.2	Heating Design Temperature	Indoor: 72; Supply: 90
3.2	Minimum Design Flow	0,50 cfm/ft2
3.3	Cooling: Overall Size	Specify: 12,5 tons
3.3	Typical Unit Size	135-240 kBtuh or 11,25-20 tons
3.3	Condenser Type	Air-Cooled
3.3	Efficiency	EER 8,5
3.3	Heating: Size	Auto-size
3.3	Typical Unit Size	<225 kBtuh
3.3	Efficiency	AFUE 0,9
3.4	Supply Fans Power	1 in. WG, High efficiency
3.4	Fan Flow	Auto-size Flow
3.5	Fan Schedules	On 24 h, every day
3.5	Cycle Fan at Night	Cycle Fans (min OA at night)
3.5	Night Cycle Fans On via	Control Zones
3.5	Fan 'On' Mode	Intermittent
3.6	Baseboards	None
3.6	Economizer	Drybulb Temperature
3.6	High Limit	65
3.6	Compressor	Cannot Run with Economizer
4	DHW Equipment	
4.1	Heater Fuel	Electricity
4.1	Heater Type	Storage
4.1	Hot Water Use	8,00 gal/person/day
4.1	Input Rating	4,5
4.1	Efficiency Spec.	Energy Factor
4.1	Energy Factor	0,88
4.1	Storage Tank	40 gal
4.1	Insulation R-Value	7,0
4.1	Supply Water Temp	140,0
4.1	Inlet	Equals Ground Temperature
4.1	Pumping Recirculation	-

Simulation Input, Fire Station 11

Data displayed in the table below lists the input data for the baseline simulation of Fire Station 11.

Screen	Field name	Selection	
1.1	Project Name	Fire Station #11	
1.1	Building Type	Unknown, Custom or Mixed Use	
1.1	Location	All eQUEST Locations	
1.1	State	Georgia	
1.1	City	Savannah	
1.1	Electric utility	Custom	
1.1	Gas utility	None	
1.1	Analysis year	2011	
1.2	Description of Seasons	Typical Use Throughout Year	
1.2	Observed Holidays	None	
1.2	Number of seasons	3	
1.2	Season #1	Cooling May 1 thru September 30	
1.2	Season #2	Heating January 1 thru February 28 December 1 thru December 31	
1.2	Season #3	Temperate March 1 thru April 30 October 1 thru November 30	
1.4	Electric Utility Charges	Uniform Charges $0,135/kWh	
1.7	Building location	11844 Apache Avenue Savannah, GA, 31419	
2	Building shell		
2.1	**Shell name**	**Living area**	**Bay**
2.1	Building type	Unknown, Custom or Mixed Use	Unknown, Custom or Mixed Use
2.1	Site Coordinates	-45,0/-41,4/0,0 (X/Y/Z)	0/0/0
2.1	Building Area	4.380 ft2	3.915 ft2
2.1	Floors above Grade	1	1
2.2	Footprint shape	+ Shape, X1: 58ft, X2: 10ft, X3: 38ft, Y1: 80ft, Y2: 10ft, Y3: 67ft	Rectangle, 45x87ft
2.2	Zoning pattern	Custom	Custom
2.2	Plan North	Southwest	Southeast
2.2	Floor-to-Floor Height	12 ft	16 ft
2.2	Floor-to-Ceiling Height	9 ft	15 ft
2.2	Roof, Attic Properties	15° Pitched Roof, 2,0ft Overhang	20° Pitched Roof, 2,0ft Overhang
2.3	Roof Surface Construction	Metal Frame >24 in. o.c.	Metal Frame >24 in. o.c.
2.3	Exterior Finish/Color	Roofing, shingle; Brown, medium	Roofing, shingle; Brown, medium
2.3	Exterior Insulation	No exterior board insulation	No exterior board insulation
2.3	Additional Insulation	No batt or radiant barrier	No batt or radiant barrier
2.3	Above grade walls	12 in. CMU	12 in. CMU
2.3	Exterior Finish/Color	Brick; Beige, masonry	Brick; Red, masonry
2.3	Exterior Insulation	No board insulation	No board insulation
2.3	Additional Insulation	Grout 24 in. o.c. & Empty Cells	Hollow
2.3	Interior Insulation	No furred insulation	R-13 wd furred insulation
2.3	Ground floor	Earth Contact	Earth Contact
2.3	Construction	6 in. Concrete	6 in. Concrete
2.3	Ext/Cav. Insulation	No perimeter insulation	No perimeter insulation
2.3	Interior Finish	Vinyl Tile	Vinyl Tile
2.3	Shell Tightness Perimeter Zone	3 ACH (estimated)	0,038 CFM/ft2 (ext wall area)

2.3	Shell Tightness Core Zones	2 ACH (estimated)	0,001 CFM/ft2 (floor area)
2.4	Top Floor Ceiling Interior Finish	Drywall Finish	Lay-In Acoustic Tile
2.4	Framing	Metal Stud, 24 in. o.c.	Metal Stud, 24 in. o.c.
2.4	Batt Insulation	R-19 batt	R-7 batt
2.4	Rigid Insulation	No board insulation	No board insulation
2.4	Ceilings Int. Finish	Lay-In Acoustic Tile	Lay-In Acoustic Tile
2.4	Batt Insulation	No ceiling insulation	No ceiling insulation
2.4	Vertical Walls Type	Mass	Mass
2.5	Exterior Door Type	Glass; 2 Southeast, 2 Northwest	Opaque; 2 Southeast
2.5	Exterior Door Type	-	Opaque; 1 Southeast
2.5	Exterior Door Type	-	Opaque; 2 Northwest
2.5	Dimensions and Construction	7ft x 3ft; Double AFG, Comfort E Clear/Air/Clear 6mm (6173: U=0,34; SHGC=0,62; VT=0,73), Frame Wd (in) 3,0	1: 7,0x3,0 ft; Steel, Polyurethane core with break 2: 7,0x8,0 Steel Hollow core without break 3: 9,0x19,0 Steel Hollow core without break
2.6	Window Area Specification Method	Percent of Net Wall Area (floor to ceiling)	Percent of Net Wall Area (floor to ceiling)
2.6	Glass Category 1	Double AFG; Comfort E Clear/ThinAir/Clear 3mm (6170: U=0,45; SHGC=0,66; VT=0,75), Frame Wd (in) 3,0Frame Width (in) 1,3	No windows
2.6	Window Dimensions	4,00ft x 3,75ft, Sill 3,0ft (8,5% Southeast, 7% Northwest, 11% Southwest)	-
2.7	Exterior Window Shades	All windows Dist. From Win: 4,00ft Shade depths: Southeast/Northwest/Southwest á 2,00ft	None
2.7	Window Blinds/Drapes	None	None
2.8	Roof Skylights	None	None
2.12	Building Operation Schedule	Use: Typical Use Open 24 hours (all year)	Use: Typical Use 8am-8pm (every day, all year)
2.13	Area Type	Residential (General Living Space) (40%, 624 sf/per, 0 cfm/per) Office (General) (15%, 200 sf/per, 20 cfm/per) Residential (Bedroom) (10%, 624 sf/per, 0 cfm/per) All Others (5%, 50 sf/per, 15 cfm/per) Corridor (10%, 1000 sf/per, 50 cfm/per) Restrooms (10%, 300 sf/per, 50 cfm/per) Mechanical/Electrical Room (5%, 2000 sf/per, 100 cfm/per)	Police Station and Fire Station (80%, 225 sf/per, 15 cfm/per) Comm/Ind Work (General, Low Bay) (10%, 300 sf/per, 15 cfm/per) Storage (Conditioned) (10%, 500 sf/per, 75 cfm/per)
2.13	Occupancy Profiles by Season	Min: 60,3%, Max: 90% alternating	6am until 12pm: 90% alternating, rest of the time: 0%
2.14	Zone Group Definitions	HVAC System 1 for core zone HVAC System 2 for perimeter zone	HVAC system 1 for all zones
2.15	Interior Enduses	Interior Lighting, Office Equipment, Cooking Equipment, Miscellaneous Equipment, Self-contained Refrigeration,	Interior Lighting, Miscellaneous equipment, Motors
2.15	Exterior Enduses	Exterior Lighting, Domestic Hot Water	Exterior Lighting
2.16	Interior Lighting	Residential/Residential/All Others/Corridor/Restrooms/Mechanical/ Electrical Room: 0,5 W/SqFt Office/Storage: 1,0 W/SqFt Multipliers on above intensities: 1,0	Police Station and Fire Station: 1,0 W/SqFt Comm/Ind Work (General, Low Bay): 1,50 W/SqFt Storage (Conditioned): 1,00 W/SqFt

			Multipliers on above intensities: 0,9
2.16	Interior Lighting Hourly Profiles	6.30am until 8.30pm: 80%; rest of time: 5% (all year)	Min: 5%, Max: 90%
2.17	Office Equipment	Office (General): 2,00 W/SqFt	-
2.17	Office Equipment Profile	25% constant	-
2.18	Cooking Loads	Residential (General Living Space): 2,25 W/SqFt	-
2.18	Cooking Equipment Profile	12.30pm: peak 72,3%, min 15%	-
2.20	Miscellaneous Loads	Residential: 0,3 W/SqFt Office: 0,75 W/SqFt Residential (Bedroom): 0,3 W/SqFt All Other/Restrooms: 0,1 W/SqFt Storage/Mechanical/Electrical Room: 0 W/SqFt	Police/Fire Station: 0,3 W/SqFt Comm/Ind Work (General, Low Bay): 1,0 W/SqFt Storage (Conditioned): 0 W/SqFt
2.20	Misc. Loads Profile	6.30am until 8.30pm: 75%; rest of time: 20%	6.30am until 8.30pm: 75%; rest of time: 15%
2.19	Self-Contained Refrigeration	Storage (Conditioned): 4,0 W/SqFt	-
2.19	SCR Profile	10% constant	-
2.22	Motor and Air Compressor Loads	-	Police/Fire Station: 4 W/SqFt
2.22	MAC Profile	-	5% all year
2.23	Exterior Lighting Loads and Profiles	0,05 W/SqFt	0,05 W/SqFt
2.25	Domestic Hot Water Profile	Min: 25%, Max: 75%	-
3	HVAC System Definition		
3.1	System Type Name	HVAC System 1	HVAC System 2
3.1	Cooling Source	DX Coils	DX Coils
3.1	Heating Source	DX Coils (Heat Pump)	DX Coils (Heat Pump)
3.1	Heat Pump Source	Air	Air
3.1	System Type	Split System Single Zone Heat Pump	Split System Single Zone Heat Pump
3.1	System per Area	System per Zone (Living Area)	System per Zone
3.1	Return Air Path	Ducted	Plenum
3.2	Seasonal Thermostat Setpoints: Cooling	Occupied: 79 (Cool), 72 (Heat) Unoccupied: 81 (Cool), 66 (Heat)	Occupied: 79 (Cool), 72 (Heat) Unoccupied: 81 (Cool), 66 (Heat)
3.2	Seasonal Thermostat Setpoints: Heating	Occupied: 79 (Cool), 72 (Heat) Unoccupied: 81 (Cool), 66 (Heat)	Occupied: 79 (Cool), 72 (Heat) Unoccupied: 81 (Cool), 66 (Heat)
3.2	Seasonal Thermostat Setpoints: Temperate	Occupied: 79 (Cool), 72 (Heat) Unoccupied: 81 (Cool), 66 (Heat)	Occupied: 79 (Cool), 72 (Heat) Unoccupied: 81 (Cool), 66 (Heat)
3.2	Cooling Design Temperature	Indoor: 78; Supply: 60	Indoor: 78; Supply: 60
3.2	Heating Design Temperature	Indoor: 72; Supply: 90	Indoor: 72; Supply: 90
3.2	Minimum Design Flow	0,50 cfm/ft2	0.50 cfm/ft2
3.3	Cooling: Overall Size	Auto-size	Auto-size
3.3	Typical Unit Size	90-135 kBtuh or 7,5-11,25 tons	90-135 kBtuh or 7,5-11,25 tons
3.3	Efficiency	EER 9,000	EER 8,900
3.3	Heating: Size	Auto-size	Auto-size
3.3	Efficiency	COP 3,000	COP 3,000
3.4	Supply Fans Power	0,5 in. WG, High efficiency	0,5 in. WG, High efficiency
3.4	Fan Flow	Auto-size Flow	Auto-size Flow
3.5	Fan Schedules	On 24 h, every day	On 24 h, every day
3.5	Cycle Fans at Night	Cycle Fans (min OA at night)	No Fan Night Cycle
3.5	Night Cycle Fans On via	Control Zones only	-
3.5	Fan ‘On’ Mode	Intermittent	Intermittent

3.6	Baseboards	None	None
3.6	Economizer	Drybulb Temperature	Drybulb Temperature
3.6	High Limit	65	65
4	DHW Equipment		
4.1	Heater Fuel	-	Electricity
4.1	Heater Type	-	Storage
4.1	Hot Water Use	-	10,00 gal/person/day
4.1	Input Rating	-	16,2 kW
4.1	Efficiency Spec.	-	Energy Factor
4.1	Energy Factor	-	0,8
4.1	Storage Tank	-	125 gal
4.1	Insulation R-Value	-	12 h-ft2-F/Btu
4.1	Supply Water Temp	-	135 °F
4.1	Inlet	-	Equals Ground Temperature
4.1	Pumping Recirculation	-	0%

Quantification of improvement measures

The following calculations present the approach of quantification of improvement opportunities. As these calculations are part of the final energy assessment reports for the City of Savannah, USCS units are used. Michael Brown from Enterprise Innovation Institute, Georgia Tech, guided the calculations and estimated the hourly rates for installation works used in the calculations [Brown, 2012]. All data tables in the following chapter, except M.1, P.1 and calculation results, are taken from [McGuiness et al., 1986, Chapter 5].

Installation of weather-stripping around garage doors

The fire truck bay is equipped with two 12,5 foot by 11,2 foot roll-up doors. Because the doors are difficult to seal on the sides and top, cold air enters the space through gaps. This infiltration flow reduces the temperature in the space causing space heating to operate more. The net result of poorly sealed doors is an increase in the cost to keep the truck bays heated in winter.

The solution to the problem of poorly sealed roll-up doors is installation of weather-stripping around the perimeter of the door. Several types of weather-stripping are available. One type is made of extruded aluminum with a vinyl sealing flap. The aluminum strip is attached to the doorframe and the flexible vinyl seal covers the gap between the door and frame. Another more expensive type is an aluminum and vinyl where the aluminum clips onto the metal door track. The final type is a brush made of polypropylene fibers which rub against the door when mounted on the jamb.
Although all of the weather-stripping types will reduce infiltration, the aluminum-vinyl was selected for this application. It is lower in cost than the others and provides a good air seal. The aluminum-vinyl seal for the top is slightly different in order to provide a positive seal.
[AGDS, 2012]

Anticipated Savings

To determine the savings from installation of weather-stripping on garage doors, one must measure or estimate the air leakage rate through the door. Test data for a garage door with no weather-stripping, vinyl seals and brush seals is presented in Table M.1, [Sealeze, 2012] and [McGuiness et al., 1986].

Table M.1 Garage Door Infiltration

Note: infiltration units should be cfm/ft of door perimeter
American notation, [.] is used as comma

Simulated Wind Speed	No Weatherseal	Vinyl seal on Top & Sides	Weatherseal Brush on Top & Sides
15 mph	6.24 cfm/ft²	0.30 cfm/ft²	**0.10 cfm/ft²**
25 mph	see note	0.64 cfm/ft²	**0.21 cfm/ft²**
50 mph	see note	see note	**0.63 cfm/ft²**
Note: Infiltration rate exceeded capacity of measuring equipment.			

To estimate the infiltration, the table data must be corrected for wind speed. The average winter wind speed in Savannah is about 7,5 mph [climate-ZONE, 2012]. Since the test data is based on 15 mph, the infiltration must be reduced by half. Note that even with weather-stripping, there is still some residual infiltration around the door. Although brush seals provide a better seal than vinyl, it was selected because of the lower cost.

Estimated Infiltration Rates

No weather-stripping:	6,24 cfm/ft/2=	3,12 cfm/ft
Vinyl weather-stripping	0,30 cfm/ft/2=	0,15 cfm/ft

Each door has a perimeter of 34,9 lf.

Heating energy consumption due to infiltration for each temperature bin is presented in Table O.1 [McGuiness et al., 1986, Chapter 5]. An example calculation for the 50/54°F (52°F mid-point) is presented below.

Infiltration Heat Loss - No weather-stripping
Infiltration rate = Unit flow x Door Perimeter x Air Density
= 3,12 cfm/ft x 60 min/hr x 34,9 ft x 0,07669 lb/ft3 x2 doors
= 1.002,07 lb/hr-door

Heat loss = Flow rate x Enthalpy Difference x Annual Hours x Conversion
= 1.002,07 lb/hr x (20,37 – 19,2) Btu/lb x 643 hr/yr
= 753.867,3 Btu/yr

Infiltration Heat Loss - Vinyl weather-stripping
Infiltration rate = Unit flow x Door Perimeter x Air Density
= 0,15 cfm/ft x 60 min/hr x 34,9 ft x 0,07669 lb/ft3 x2 doors
= 48,1766 lb/hr

Heat loss = Flow rate x Enthalpy Difference x Annual Hours x Conversion
= 48,1766 lb/hr x (20,37 – 19,2) Btu/lb x 643 hr/yr
= 36.243,8 Btu/yr

Heater Energy Savings
= Heater Loss / 3.412 Btu/kWh
= (753.867,3 – 36.243,8) Btu/yr / 3.412 Btu/kWh
= 210,33 kWh/yr

Savings for all temperature ranges is **2.761 kWh/yr,** see Table O.1**.**

Annual Energy Cost Savings
= Energy Savings x Energy Cost
= 2.761 kWh/yr x $0,108/kWh
= $298,2 / year

Implementation Cost [AGDS, 2012] and [Brown, 2012]
Double contact, sectional door top seal ($1,45/ft x 20 ft.) $29

Aluminum-vinyl perimeter seal-10 ft (2 x $17,50)	$35
Weather-stripping Installation (2 hr. @ $50/hr)	$100
Total Cost	$164

Simple Payback Period

Payback = Implementation Cost / Annual Cost Savings
= $164 / $298,2 per year
= 0,55 years

Table O.1
Heating Energy Calculations

infilt w/o seals	3,12	cfm/ft
infilt w/seals	0,15	cfm/ft
opening-lf	69,8	ft/2 doors
	34,9	ft/door

Space Temp	60°F	50%RH
Enthalpy	20,37	Btu/lb

Bin Mid-pts	Temp. Range DB (F)	Annual Hrs	Enthalpy (Btu/lb)	Density lb/ft3	Heat Loss w/o seal Btu/yr	Heat Loss w/ seal Btu/yr	Heating Savings kWh/yr
57	55/59	739	21,4		0,00	0,0	0
52	50/54	643	19,2	0,07669	753.870	36.244	210
47	45/49	539	16,6	0,07764	2.061.469	99.109	575
42	40/44	412	14,3	0,07849	2.564.847	123.310	715
37	35/39	252	12,6	0,07937	2.030.669	97.628	567
32	30/34	138	10,5	0,08026	1.428.422	68.674	399
27	25/29	60	8,9	0,08117	729.914	35.092	204
22	20/24	19	7,5	0,08203	262.099	12.601	73
17	15/19	4	5,7	0,08292	63.579	3.057	18
Total							2.761

Installation of storm windows

Three single glaze window panes border the entry door. The measurements of the windows are 5,83 ft by 6,83 ft, 5,83 ft by 2 ft and 3 ft by 2 ft. The three panes comprise a total area of 57,5 square feet.

The thermal properties of the existing and proposed designs are shown in Table P.1 [Brown, 2012]. The storm windows will increase the thermal insulation value of the windows by almost 60% and reduce heat gain and loss by conduction and solar heat gain into the building.

Table P.1
Window Properties

Material	**glass** **hr-ft2-°F/Btu**	**storm window** **hr-ft2-°F/Btu**
inside air film	0,68	0,68
Glass	0,91	0,91
air film	0	1
storm window	0	0,9
outside air film	0,17	0,17
Total	1,76	3,66

The energy savings calculations assume that cooling operates at temperatures above 70℉, at temperatures from 60 to 70℉ neither heating nor cooling is required and heating operates at temperatures below 60℉ .

<u>Anticipated Savings</u>
The energy savings from storm window addition were estimated using average ambient conditions for winter heat loss reduction and simulating the effects of conduction and solar gain during the summer months as proposed in ASHRAE Handbook of Fundamentals, 1981 and described in *McGuiness et al., 1986*. An example calculation for savings from storm windows in the month of June is presented below.

Given:

Window Area, sf	57,5
Window Facing	West
Annul Hours Cooling	4.045 hr/yr
Cooling System Performance	1,13 kW/ton
Furnace Efficiency	80%

Conduction Heat Gain, Existing Window [McGuiness et al., 1986, page 247]:

Q = A x CLTD / R
= 57,5 sf x 5,208 ℉ / 1,76 hr-ft2-℉/Btu

= 170,2 Btu/hr

Conduction Heat Gain, Storm Window:
Q = A x CLTD / R
= 57,5 sf x 5,208 °F / 3,66 hr-ft2-°F/Btu
= 81,8 Btu/hr

The solar heat gain reduction calculation is presented in Table T.1, following the approach of ASHRAE Handbook of Fundamentals, 1981. The heat gain savings is based on cooling occurring between the months of April and October. The solar heat gain factor (SHGF) gives the maximum solar gain in Btu/hf-sf for a given month. To correct for reduced solar gain, the SHGF must be corrected by multiplying it by the CLF (cooling load factor), which is presented in Table S.1, [McGuiness et al., 1986, Chapter 5]. Heat gain is reduced with a storm window by selecting material with a high shading coefficient (SC). A shading coefficient of 0,56 is assumed for the storm windows. This can be achieved by the addition of a low emissivity film (low-E) or by selecting a colored Plexiglas. The 0,56 shading coefficient is for a bronze colored Plexiglas material. Shading coefficients used in the calculations are presented in Table S.2 [McGuiness et al., 1986, Chapter 5].

Solar Heat Gain, Existing Window-June:
Q = A x SHGF x CLF x SC x Cooling Hrs/mo
= 57,5 sf x 194 Btu/hr-sf x 0,2575 x 1,0 x 653 hr/yr
= 1.876.011 Btu/mo

Solar Heat Gain, Storm Window, June:
Q = A x SHGF x CLF x SC x Cooling Hrs/mo
= 57,5 sf x 194 Btu/hr-sf x 0,2575 x 0,56 x 653 hr/mo
= 1.050.566 Btu/mo

Solar Heat Gain Reduction, June:
Q = Current Gain – Gain w/Storm Window Added
= 1.876.003 Btu/mo – 1.050.567 Btu/mo
= 825.445 Btu/mo

The solar heat gain reduction for all cooling months is **4.896.732 Btu/yr**.

Heat Gain Reduction:
Btu = Conduction Savings + Solar Gain Reduction
= (170,2 – 81,8) Btu/hr x 4.045 hr/yr + (4.896.732 Btu/yr)
= 357.578 Btu/yr + 4.896.732 Btu/yr
= 5.254.310 Btu/yr

Cooling Energy Reduction:
kWh = Heat Gain Reduction x 1 ton-hr/12.000 Btu x Cooling Perf
= 5.254.310 Btu/yr x 1 ton-hr/Btu x 1,13 kW/ton
= 494,8 kWh/yr

The energy loss during the heating season is found by multiplying the interior minus exterior temperature difference times the window area and annual hours then dividing by the thermal resistance. Heating is assumed to operate at temperatures below 60℉. An example calculation for the 59℉ bin is shown below. The energy savings for all temperatures is presented in Table T.2.

Conduction Heat Loss, Existing Window:
Q = Area x Temperature Difference x Annual Hrs./(Thermal Resistance R)
= 57,51 sf x (73,0 – 59,0) ℉ x 206 hr/yr / (1,76 h r-ft^2-℉/Btu)
= 94.237 Btu/yr

Conduction Heat Loss, Storm Window:
Q = Area x Temperature Difference x Annual Hrs./(Thermal Resistance R)
= 57,51 sf x (73,0 – 59,0) ℉ x 206 hr/yr / (3,66 h r-ft^2-℉/Btu)
= 45.317 Btu/yr

Heating Savings:
MMBtu = Conduction Savings/ Furnace Efficiency
= (94.237 – 45.317) Btu/yr/(1.000.000 Btu/MMBtu x 0,8)
= 0,061 MMBtu/yr

The heating savings for the windows for all temperatures are **1,514 MMBtu/yr**.

Total Electricity Savings:
kWh = Conduction Savings + Solar Gain Savings
= 33,6 kWh/yr + 461,2 kWh/yr
= 494,8 kWh/yr

Cost Savings:
$ = (Electricity Saved x Electricity Cost) + (Natural Gas Saved x Gas Cost)
= (494,8 kWh/yr x $0,108/kWh) + (1,514 MMBtu/yr x $13,205/MMBtu)
= $53,4 + $20
= $73,4/yr

<u>Implementation Cost</u>
The required estimated cost to install a ⅛ inch thick interior, acrylic storm window is $4/sf [Brown, 2012]. The storm windows can be mounted with Velcro strips or perimeter braces. The total window area on the north side is 57,5 square feet. The estimated cost of installing storm windows is $230.

Storm window cost = 57,5 sf x $4/sf
= $230

Simple Payback Period
PB = Investment/Savings
= $230 / $73,4/yr
= 3,1 years

Table S.1

Solar Factors for Glass

Time	CLTD-°F	CLF-East
1	1	0,05
2	0	0,05
3	-1	0,04
4	-2	0,04
5	-2	0,03
6	-2	0,06
7	-2	0,09
8	0	0,11
9	2	0,13
10	4	0,15
11	7	0,16
12	9	0,17
13	12	0,31
14	13	0,53
15	14	0,72
16	14	0,82
17	13	0,81
18	12	0,61
19	10	0,16
20	8	0,12
21	6	0,1
22	4	0,08
23	3	0,31
24	2	0,53
daily avg.	**5,208**	**0,2575**

Table S.2

Shading Coefficients

Type glass	SC
Clear glass ⅛-inch	1,00
Acrylic storm bronze	0,56

Table T.1
Front Window Solar Gain Savings

Bin Mid-pts	Temp. Range DB (F)	Month Apr hr	May hr	Jun hr	Jul hr	Aug hr	Sep hr	Oct hr	Annual Totals
102	100/104			2		1			
97	95/99		3	9	9	11	1		
92	90/94	1	18	34	57	56	13	1	
87	85/89	9	47	92	132	120	69	11	
82	80/84	38	99	143	157	153	116	52	
77	75/79	78	138	202	239	240	208	86	
72	70/74	117	196	171	144	146	198	138	
67	65/69	OFF	OFF	OFF	OFF	OFF	OFF	OFF	
Cooling hr/mo		243	501	653	738	727	605	288	
SHGF-Btu/hr-sf		210	200	194	196	203	206	197	
Current solar gain Btu/hr		3.109,9	2.961,8	2.872,9	2.902,5	3.006,2	3.050,6	2.917,3	20.821
Storm window solar gain		1.741,5	1.658,6	1.608,8	1.625,4	1.683,5	1.708,3	1.633,7	11.660
Saved Btu/mo		332.506	652.891	825.445	942.509	961.621	812.074	369.685	4.896.732
kWh/mo Saved		31,3	61,5	77,7	88,8	90,6	76,5	34,8	461,2

Table T.2
Winter Heat Loss Reduction

Mid-pts	Temperature DB (F)	Annual Hrs	Enthalpy (Btu/lb)	current heat loss Btu/yr	reduced heat loss Btu/yr	energy saved MMBtu/yr
65	64 to 66	391	26,5	0	0	0,000
63	62 to 64	329	25	0	0	0,000
61	60 to 62	345	24	0	0	0,000
59	58 to 60	206	22,6	94.238	45.317	0,061
57	56 to 58	264	21,6	138.024	66.372	0,090
55	54 to 56	341	20,5	200.566	96.447	0,130
53	52 to 54	197	18,8	128.744	61.910	0,084
51	50 to 52	205	18,4	147.369	70.866	0,096
49	48 to 50	178	17,4	139.592	67.126	0,091
47	46 to 48	192	16,5	163.119	78.440	0,106
45	44 to 46	166	15,5	151.879	73.035	0,099
43	42 to 44	201	14,9	197.037	94.750	0,128
41	40 to 42	118	14,2	123.385	59.333	0,080
39	38 to 40	168	13,6	186.646	89.753	0,121
37	36 to 38	162	12,6	190.567	91.639	0,124
35	34 to 36	94	11,8	116.719	56.127	0,076
33	32 to 34	69	11	90.186	43.368	0,059
31	30 to 32	44	10,3	60.386	29.038	0,039
29	28 to 30	75	9,6	107.831	51.853	0,070
27	26 to 28	28	8,8	42.087	20.238	0,027
25	24 to 26	17	8,3	26.664	12.822	0,017
23	22 to 24	3	7,8	4.901	2.357	0,003
21	20 to 22	9	7,2	15.292	7.354	0,010
19	18 to 20	2	6,4	3.529	1.697	0,002
17	16 to 18	2	5,8	3.660	1.760	0,002
Total						1,514

Window replacement

The north and south facing windows have been covered with plywood to limit exposure to natural light. The addition of a wood covering does increase the thermal resistance of the windows slightly; however, because the wood is not airtight, the infiltration of outside air is not significantly reduced. A simple way to increase the wall R-value and reduce infiltration is to replace the plywood-covered windows with structural insulated panels (SIPs). A 3,5-inch thick wall panel has an R-value of 15 and essentially no infiltration [Brown, 2012].

Table X.1 shows the wall R-value with and without added insulation. Table Z.1 shows the calculated heat gain with and without added insulation and the expected energy savings. Table Y.2 and Y.3 are the uncorrected CLTD for each hour of the day. [McGuiness et al., 1986, Chapter 5] The spreadsheet calculation uses the cooling load temperature difference (CLTD) method outlined in ASHRAE Handbook of Fundamentals, 1981, Chapter 26, for calculating the heat transfer load of the windows. The CLTD method is used to determine the window heat gain for different times of the day during the cooling season (about 6 months per year). Heat transfer savings are found by comparing the heat gain of the windows with the gain through insulated panels.

In addition to the heat transfer savings, the insulated panels will reduce the energy consumption due to infiltration of outside air. Historical temperature data for Savannah and typical infiltration rates for double hung windows is used to determine the savings from reduced infiltration. The infiltration rate for a double hung window is approximately 0,75 cfm/ft of crack length or 0,5 cfm/ft^2 of window area. The savings from reduced infiltration is shown in Table AA.1. It is based on replacing windows with 3,5-inch structural insulated panels with an insulation value of R-15. Panels can be sized to directly replace the existing windows.

<u>Anticipated Savings</u>
The following data and information is useful in calculating the annual heat gain through the north facing windows.

Average CLTD for 1-24 hour time range, N	12^{o}F
Average Corrected CLTD for Cooling Months, N	10,3^{o}F
Average Corrected CLTD for Cooling Months, S	17^{o}F
Present Window R Value, with ¼" Plywood	2,00 hr-ft^2-^{o}F/Btu
Roof R Value with 3-inch Structural Panel (SIP)	15,78 hr-ft^2-^{o}F/Btu
North Window Area	54 ft^2
Annual Cooling Hours	4.045 hr/yr
Cooling System Efficiency	1,13 kW/ton
Average Electricity Cost	$0,108/kWh

The vertical wall panels' primary heat gain is from thermal conduction driven by the cooling load temperature difference (CLTD) [ASHRAE Handbook, 1981, Chapter 26]. In addition to the conduction, transparent windows also have solar heat gain driven by the SHGF.

Present Average Heat Gain, North Windows:

Q = Area of Window x CLTD, Corrected / (Present Window R Value)
= 54 ft^2 x (5,2083^oF) / (2,00 hr-ft^2-^oF/Btu)
= 140,6 Btu/hr

Proposed Average Heat Gain with Increased Insulation, North SIP Wall:
Q = Area of Window x Temperature Difference/(Proposed Window R Value)
= 54 ft^2 x (10,3^oF) / (15,78 hr-ft^2-^oF/Btu)
= 35,247 Btu/hr

Annual Conduction Heat Gain Reduction from Covering Windows:
Btu/yr = (Present Heat Gain – Proposed Heat Gain) x Cooling Hours
= (140,6 Btu/hr – 35,247 Btu/hr) x 4.045 hr/yr
= 426.152 Btu/yr

Electricity Savings per Year:
kWh/yr = Heat Gain Reduction/Conversion x Air-conditioner Energy Consumption
= 426.152 Btu/yr/12.000 Btu/ton-hr x 1,13 kW/ton
= 40,1 kWh/yr

The savings from the north windows must be added to the savings from the south windows to get the total heat transfer savings from insulated panels. The south window area is 148,5 sf, and the heat transfer savings is 133,3 kWh/yr.

In addition to the conduction savings, replacing the existing windows with an opaque, insulated panel will eliminate heat gain from solar radiation. The solar heat gain reduction calculation is presented in Table Z.1. The heat gain savings are based on cooling occurring between the months of April and October. The solar heat gain factor (SHGF) gives the maximum solar gain in Btu/hr.sf for a given month. To correct for reduced solar gain, the SHGF must be corrected by multiplying it by the CLF (cooling load factor) which is presented in Table Y.1. Heat gain is reduced with a storm window by selecting material with a high shading coefficient (SC). A shading coefficient of 0,87 is used for double pane windows.
[McGuiness et al., 1986, Chapter 5]

Solar Heat Gain, Existing Window-North, June:
Q = A x SHGF x CLF x SC
= 54 sf x 44 Btu/hr-sf x 0,48 x 0,87
= 993,1 Btu/hr

Solar Heat Gain, Existing Window-South, June:
Q = A x SHGF x CLF x SC
= 148,5 sf x 60 Btu/hr-sf x 0,27 x 0,87
= 2.076,8 Btu/hr

Solar Heat Gain Reduction, June:
Q = (Current Gain, North + Current Gain, South) x Hours, June
= (993,1 Btu/hr + 2.076,8 Btu/hr) x 653 hr/mo
= 2.005.000 Btu/mo

The solar heat gain reduction for all cooling months is **17.145.000 Btu/yr**.

Combined Savings from both North and South Window Replacement:

kWh/yr = (South + North Solar Gain Savings) / Conversion factor x Cooling Performance
= (17.145.000 Btu/yr)/12.000 Btu/ton-hr x 1,13 kW/ton
= 1.614,5 kWh/yr

Cooling Energy Savings:

kWh/yr = Conduction Savings + Solar Gain Savings
= 173,4 kWh/yr + 1.614,5 kWh/yr
= 1.787,9 kWh/yr

Example heat loss reduction calculation for 57^{o}F bin temperature is presented below.

Conduction Heat Loss Reduction, Current Window:

Btu/hr = Area x Temp. Difference / Thermal Resistance
= 202,5 sf x (73 – 57) ^{o}F / 2,0 hr-ft^{2}-^{o}F/Btu
= 1.620,0 Btu/hr

Conduction Heat Loss Reduction, Insulated Panel:

Btu/hr = Area x Temp. Difference / Thermal Resistance
= 202,5 sf x (73 – 57) ^{o}F / 15,78 hr-ft^{2}-^{o}F/Btu
= 205,3 Btu/hr

Annual Heating Energy Savings:

Q = Hourly Heat Loss Reduction x Annual Hours / Furnace Efficiency x 1.000.000 Btu/MMBtu
= (1.620,0 Btu/hr – 205,3 Btu/hr) x 739 hr/yr / (0,8 x 1.000.000)
= 1,31 MMBtu/yr

The conduction heat loss savings for all temperatures are presented in Table Z.2. The annual conduction heat loss reduction is 7,82 million Btu/hr.
In addition to the savings from reduced heat transfer losses, the insulated panels will reduce energy losses due to infiltration of outside air. The savings from reduced infiltration losses are presented in Table AA.1. The savings from reduced infiltration are 585,3 kWh of cooling energy and 5,84 million Btu of heating energy.

Total Electricity Savings:
= Savings from Heat Gain Reduction + Savings from Infiltration
= 173,4 kWh/yr + 1.614,5 kWh/yr + 585,3 kWh/yr
= 2.373,2 kWh/yr

Total Natural Gas Savings”
= Savings from Heat Loss Reduction + Savings from Infiltration
= 7,8 MMBtu/yr + 5,8 MMBtu/yr
= 13,6 MMBtu/yr

Annual Cost Savings:

$$/yr = (Annual Electricity Savings x Electricity Cost) + (Annual Natural Gas

Savings x Average Gas Cost)
=(2.373,2 kWh/yr x $0,108/kWh) + (13,6 MMBtu/yr x $13,205)
= $256,31/yr + $179,59
= $435,9 /yr

Implementation Cost [Brown, 2012]
The cost of structural insulated panel is approximately $15/sf. Assuming the existing windows can be removed and the replacement panels installed for $5/sf, the anticipated cost of the project is $20/sf.

Window Area	
North- 4 windows x 13,5 sf/window	54,0 sf
South-11 windows x 13,5 sf/window	148,5 sf
Total	202,5 sf

The total investment to install the insulation is $4.050 for an area of 202,5 sf. This yields a simple payback of 9,3 years for the measure.

Simple Payback:
= Investment/Annual Savings
= $4.050/$435,9/yr
= 9,3 years

Table X.1
Wall Insulation R-Value determination

Existing Wall

Wall component	R-value
Inside air film	0,61
⅛" flat glass window	0,91
½" air space	0,00
¼" plywood sheet	0,31
Outside air film	0,17
Total R	2,00

Proposed SIP Wall

Wall component	R-value
Inside air film	0,61
3" insulating panel	15,00
Outside air film	0,17
Total R	15,78

Table X.2
Corrected CLTD for N &S Insulated Panels

Month	LM corr.-N	cltd-corr-N	LM corr.-S	Cltd-corr-S
sep	-3	9	7	24,2
apr/aug	-2	10	1	18,2
may/jul	1	11	-3	14,2
Jun	1	11	-4	13,2
Yearly Avg		10,3		17,0

Table Y.1
Window CLTD and Cooling Load Factor (CLF)

Time	CLTD-F	CLF-N	CLF-S
1	1	0,17	0,08
2	0	0,14	0,07
3	-1	0,11	0,05
4	-2	0,09	0,04
5	-2	0,08	0,04
6	-2	0,33	0,06
7	-2	0,42	0,09
8	0	0,48	0,14
9	2	0,56	0,22
10	4	0,63	0,34
11	7	0,71	0,48
12	9	0,76	0,59
13	12	0,80	0,65
14	13	0,82	0,65
15	14	0,82	0,59
16	14	0,79	0,50
17	13	0,75	0,43
18	12	0,84	0,36
19	10	0,61	0,28
20	8	0,48	0,22
21	6	0,38	0,18
22	4	0,31	0,15
23	3	0,25	0,12
24	2	0,20	0,10
daily avg	**5,2083**	**0,48**	**0,27**

Table Y.2
Uncorrected CLTD for Lightweight Frame Wall-North

Time	1	2	3	4	5	6	7	8	9	10	11	12	Average
CLTD	3	2	1	0	-1	2	7	8	9	12	15	18	6,33
Time	13	14	15	16	17	18	19	20	21	22	23	24	
CLTD	21	23	24	24	25	26	22	15	11	9	7	5	17,67
												daily avg.	12,00

Table Y.3
Uncorrected CLTD for Lightweight Frame Wall-South

Time	1	2	3	4	5	6	7	8	9	10	11	12	Average
CLTD	4	2	1	0	-1	0	1	5	12	22	31	39	9,67
Time	13	14	15	16	17	18	19	20	21	22	23	24	
CLTD	45	46	43	37	31	25	20	15	12	10	8	5	24,75
												daily avg.	17,21

Table Z.1
Solar Heat Gain Through Windows

Bin Mid-pts	Temp. Range DB (F)	Month Apr hr	May hr	Jun hr	Jul hr	Aug hr	Sep hr	Oct hr	Annual Totals
102	100/104			2		1			
97	95/99		3	9	9	11	1		
92	90/94	1	18	34	57	56	13	1	
87	85/89	9	47	92	132	120	69	11	
82	80/84	38	99	143	157	153	116	52	
77	75/79	78	138	202	239	240	208	86	
72	70/74	117	196	171	144	146	198	138	
67	65/69	OFF	OFF	OFF	OFF	OFF	OFF	OFF	
Cooling hr/mo		243	501	653	738	727	605	288	
SHGF-Btu/h-sf	North window	36	38	44	40	37	33	28	
Current solar gain Btu/hr		812,5	857,7	993,1	902,8	835,1	744,8	632,0	5.778
SHGF-Btu/h-sf	South window	115	74	60	72	111	171	215	
Current solar gain Btu/hr		4.011,5	2.581,3	2.092,9	2.511,6	3.871,9	5.964,9	7.499,8	28.534
Saved MBtu/mo	North +South	1,172	1,723	2,015	2,519	3,422	4,059	2,342	17,252
kWh/mo Saved		110,4	162,2	189,8	237,3	322,2	382,3	220,5	1.624,7

Table Z.2
Conduction Heat Loss Savings

	Temp	RH%	Enthalpy
Space Cond.	72	50	26,4

Bin Mid-pts	Temp. Range DB (F)	Annual hrs (hr/yr)	Window Loss Btu/hr	Wall Loss (Btu/hr)	Heat Saved Btu/yr	Energy Saved (kWh/yr MMBtu/yr)
67	65/69	989	OFF			0,00
62	60/64	926	OFF			0,00
57	55/59	739	1.518,8	192,5	980.136	1,23
52	50/54	643	2.025,0	256,7	1.137.016	1,42
47	45/49	539	2.531,3	320,8	1.191.459	1,49
42	40/44	412	3.037,5	385,0	1.092.838	1,37
37	35/39	252	3.543,8	449,1	779.864	0,97
32	30/34	138	4.050,0	513,3	488.065	0,61
27	25/29	60	4.556,3	577,5	238.727	0,30
22	20/24	19	5.062,5	641,6	83.996	0,10
17	15/19	4	5.568,8	705,8	19.452	0,02
MMBtu Saved						7,51

Table AA.1
Infiltration Losses Through Plywood-Covered Windows

	Window	SIP*	
R-value	2,00	15,78	hr-ft2-F/Btu
Infiltration	0,20	0,01	cfm/ft2

	Temp	RH%	Enthalpy
Space Cond.	73	50	26,4

Bin Mid-pts	Temp. Range DB (F)	Annual hrs (hr/yr)	Enthalpy Btu/lb	Infiltration Gain Window (Btu/yr)	Infiltration Gain SIP (Btu/yr)	Heat Saved Btu/yr	Energy Saved (kWh/yr MMBtu/yr)
102	100/104	3	41,3	211.410	10.571	200.840	18,9
97	95/99	33	41,4	85.804	4.290	81.513	7,7
92	90/94	180	40,4	440.775	22.039	418.736	39,4
87	85/89	483	38,5	1.031.575	51.579	979.996	92,3
82	80/84	782	36,6	1.420.899	71.045	1.349.854	127,1
77	75/79	1275	34,9	1.948.545	97.427	1.851.118	174,3
72	70/74	1289	32,4	1.403.615	70.181	1.333.435	125,6
67	65/69	989	OFF				0,0
62	60/64	926	OFF				0,0
57	55/59	739	21,4	690.048	34.502	655.546	0,82
52	50/54	643	19,2	873.030	43.651	829.378	1,04
47	45/49	539	16,6	1.005.918	50.296	955.622	1,19
42	40/44	412	14,3	958.814	47.941	910.874	1,14
37	35/39	252	12,6	675.583	33.779	641.804	0,80
32	30/34	138	10,5	430.593	21.530	409.063	0,51
27	25/29	60	8,9	208.169	10.408	197.761	0,25
22	20/24	19	7,5	71.932	3.597	68.336	0,09
17	15/19	4	5,7	16.760	10.060	6.700	0,01
kWh Saved							570
MMBtu Saved							5,84

Door replacement

The main entrance on the west side of the building as well as the back doors facing north and south are 3,0 ft wide solid core wood doors. Aged doors have lower thermal insulation but higher infiltration of unconditioned air compared to new doors. By replacing the doors with fiberglass insulated metal doors with magnetic weather stripping will increase thermal resistance and reduce infiltration losses significantly. Once the existing doors are removed, the new doorframes can be moved into place, secured and sealed with caulking around the frame. 3,5-inch thick door with fiberglass insulation has an R-value of ≥12. The infiltration rate can be reduced to 1,05 cfh/ft.

Table EE.1 shows the R-value of the existing and new doors. Table EE.2 shows the Cooling Load Temperature Differences for each hour of the day. Table FF.1 is the corrected CLTD for cooling months. [McGuiness et al., 1986, Chapter 5] The spreadsheet calculation uses the cooling load temperature difference (CLTD) method outlined in ASHRAE Handbook of Fundamentals, 1981, Chapter 26, for calculating the heat transfer load of the doors. The CLTD method is used to determine the door heat gain for different times of the day during the cooling season (about 6 months per year). Heat transfer savings are found by comparing the heat gain of the wood doors with the heat gain of insulated metal doors as presented in Table FF.2 [McGuiness et al., 1986, Chapter 5].

The total annual energy savings is the sum of the heat conduction savings, reduced heat gain, and the reduced air infiltration of outside air. Historical temperature data for Savannah and typical infiltration rates for doors is used to determine the savings from reduced infiltration. The infiltration rate for a wood door is approximately 20,0 cfh/ft of perimeter length. The savings from reduced infiltration is shown in Table HH.1 [McGuiness et al., 1986, Chapter 5] and is based on the replacement of wood doors with metal doors with an insulation value of R-12 and magnetic seals.

<u>Anticipated Savings</u>

The following data and information is useful in calculating the annual heat gain through the west-facing door.

Average CLTD for 1-24 hour time range, W	22,46^{o}F
Average Corrected CLTD for Cooling Mos., W	22,21^{o}F
Present Door R Value	3,88 hr-ft^{2}-^{o}F/Btu
Insulated Metal Door R Value	13,35 hr-ft^{2}-^{o}F/Btu
Infiltration Rate Wood Door	20,0 cfh/ft
Infiltration Rate Metal Door	1,05 cfh/ft
Door Area	20,01 ft^{2}
Annual Cooling Hours	4.045 hr/yr
Cooling System Efficiency	1,13 kW/ton
Average Electricity Cost	$0,108/kWh

The doors' primary heat gain is from solar heat gain driven by the cooling load temperature difference (CLTD).

Present Average Heat Gain, West Door, June:

Q = Area of Door x CLTD, Corrected / (Present Door R Value)
= 20,01 ft^2 x (26,46°F) / (3,88 hr-ft^2-°F/Btu)
= 136,45 Btu/hr

Proposed Average Heat Gain with Increased Insulation, West Door:

Q = Area of Door x Temperature Difference / (Proposed Door R Value)
= 20,01 ft^2 x (26,46°F) / (13,35 hr-ft^2-°F/Btu)
= 39,66 Btu/hr

Annual Conduction Heat Gain Reduction from Replacing Doors:

Btu/yr = (Present Heat Gain – Proposed Heat Gain) x Cooling Hours
= (136,45 Btu/hr – 39,66 Btu/hr) x 720 hr/mo
= 69.689 Btu

Electricity Savings per Year:

kWh/yr = Heat Gain Reduction/Conversion x Air-conditioner Energy Consumption
= 69.689 Btu / 12.000 Btu/ton-hr x 1,13 kW/ton
= 13,56 kWh

The savings from the west door must be added to the savings from the south and north doors for all cooling months to get the total solar heat gain savings. The door area is 20,01 sf each, and the heat gain savings for the cooling season is 91,35 kWh/yr.

In addition to the solar heat gain savings; replacing the existing doors with an insulated metal door with new, magnetic weather-stripping will reduce heat conduction losses.

Example heat loss reduction calculation for 57°F bin temperature is presented below.

Conduction Heat Loss Reduction, Current Door:

Btu/hr = Area x Temp. Difference / Thermal Resistance
= 20,01 sf x (73 – 57) °F / 3,88 hr-ft^2-°F/Btu
= 77,36 Btu/hr

Conduction Heat Loss Reduction, Insulated Door:

Btu/hr = Area x Temp. Difference / Thermal Resistance
= 20,01 sf x (73 – 57) °F / 13,35 hr-ft^2-°F/Btu
= 22,48 Btu/hr

Annual Heating Energy Savings:

Q = Hourly Heat Loss Reduction x Annual Hours x No. of doors x Conversion / Furnace Efficiency
= (77,36 Btu/hr – 22,48 Btu/hr) x 739 hr/yr x 3 doors x 1/1.000.000 Btu/MMBtu / (0,8)
= 0,12 MMBtu/yr

The heat conduction savings for all temperatures are presented in Table GG.1. The annual electricity savings are 26,82 kWh/yr and 1,06 MMBtu/yr of natural gas.

The metal doors with magnetic seals will also reduce energy losses due to infiltration of outside air. The savings from reduced infiltration losses are presented in Table HH.1. An example infiltration calculation for the 102 ℉ temperature bin is presented below.

Current door:
Infiltration rate = 20,0 cfh/ft x 19,34 ft/door x 3 doors x 0,0707 lb/ft^3
= 82,04 lb/hr

Foam core door:
Infiltration rate = 1,05 cfh/ft x 19,34 ft/door x 3 doors x 0,0707 lb/ft3
= 4,307 lb/hr

Energy Savings:
Btu saved = Infiltration Reduction x Enthalpy Difference x Annual Hours
= (82,04 – 4,307) lb/hr x (41,3 – 26,4) Btu/lb x 3 hr/yr
= 3.475 Btu/yr

The savings from reduced infiltration are 270,1 kWh/yr of cooling energy and 2,79 MMBtu/yr of heating energy.

Total Electricity Savings:
= Savings Heat Gain Reduction + Savings Conduction Loss Reduction + Savings Infiltration
= 34,14 kWh/yr + 15,65 kWh/yr + 41,56 kWh/yr + 270,1 kWh/yr + 26,82 kWh/yr
= 388,27 kWh/yr

Total Natural Gas Savings:
= Savings from Infiltration + Savings from Conduction Loss Reduction
= 2,79 MMBtu/yr + 1,06 MMBtu/yr
= 3,85 MMBtu/yr

Annual Cost Savings:
$$/yr = (Annual Electricity Savings x Electricity Cost) + (Annual Natural Gas Savings x Natural Gas Rate)
=(388,27 kWh/yr x $0,108/kWh) + (3,85 MMBtu/yr x $13,205/MMBtu)
= $92,77

<u>Implementation Cost</u> [The Home Depot, 2012]
The cost of an insulated metal door is approximately $214/door. The anticipated cost of the project is $642. This yields a simple payback of 6,9 years for the measure.
Simple Payback:
= Investment/Annual Savings
= $642 / $92,77/yr
= 6,9 years

Table EE.1
Combined R-Value doors

Material	Current door	Foam Core
Inside film	0,68	0,68
Door	3,03	12,5
Outside film	0,17	0,17
Total	**3,88**	**13,35**

Table EE.2
Cooling Load Temperature Difference (CLTD) for Solar Gain Calculations

CLTD, walls [°F]			
Hour	**CLTD North**	**CLTD South**	**CLTD West**
1	3	4	6
2	2	2	5
3	1	1	3
4	0	0	2
5	-1	-1	1
6	2	0	1
7	7	1	2
8	8	5	5
9	9	12	8
10	12	22	11
11	15	31	15
12	18	39	19
13	21	45	27
14	23	46	41
15	24	43	56
16	24	37	67
17	25	31	72
18	26	25	67
19	11	20	48
20	15	15	29
21	11	12	20
22	9	10	15
23	7	8	11
24	5	5	8
Average	**11,54**	**17,21**	**22,46**

Table FF.1
Corrected CLTD for Doors

CLTDcorr	North	South	West
Sept	6,54	28,21	15,46
Apr/Aug	8,54	28,21	21,46
May/Jul	12,54	27,21	25,46
Jun	13,54	26,21	26,46

Table FF.2
Solar Heat Gain Reduction

Old Door	North	South	West	
April	32.157	106.198	80.786	Btu/mo
May	47.216	102.433	95.845	Btu/mo
June	50.981	98.668	99.609	Btu/mo
July	47.216	102.433	95.845	Btu/mo
Aug	32.157	106.198	80.786	Btu/mo
Sept	24.628	106.198	58.197	Btu/mo
Sum	**234.357**	**622.128**	**511.067**	**Btu/yr**
New Door				
April	9.346	30.865	23.479	Btu/mo
May	13.723	29.771	27.856	Btu/mo
June	14.817	28.677	28.950	Btu/mo
July	13.723	29.771	27.856	Btu/mo
Aug	9.346	30.865	23.479	Btu/mo
Sept	7.158	30.865	16.914	Btu/mo
Sum	**68.113**	**180.813**	**148.535**	**Btu/yr**
Heat Gain Reduction	**166.244**	**441.315**	**362.532**	**Btu/yr**
Cooling energy Saved	**13,85**	**36,78**	**30,21**	**ton.hr/yr**
Electricity savings	**15,65**	**41,56**	**34,14**	**kWh/yr**

Table GG.1
Heat Conduction Savings per door

	Temp	RH [%]
Space Condition	72	50

Mid points	Temp range	Annual hours	Loss Old Door	Loss New Door	Energy savings [kWh/yr.door] [MMBtu/yr.door]
102	100/104	3	-464	-135	0,03
97	95/99	33	-4.255	-1.237	0,28
92	90/94	180	-18.566	-5.396	1,24
87	85/89	483	-37.364	-10.859	2,50
82	80/84	782	-40.329	-11.721	2,69
77	75/79	1275	-32.877	-9.555	2,20
72	70/74	1289	0	0	
67	65/69	989	0	0	
62	60/64	926	47.756	13.880	0,04
57	55/59	739	57.168	16.615	0,05
52	50/54	643	66.322	19.276	0,06
47	45/49	539	69.493	20.197	0,06
42	40/44	412	63.743	18.526	0,06
37	35/39	252	45.487	13.220	0,04
32	30/34	138	28.468	8.274	0,03
27	25/29	60	13.924	4.047	0,01
22	20/24	19	4.899	1.424	0,00
17	15/19	4	1.135	330	0,00

Table HH.1
Infiltration Savings per door

	Old Door	New Door	
R-Value	3,88	13,35	hr.ft2.℉/Btu
Infiltration	20,0	1,05	cfh/ft

	Temp	RH [%]	Enthalpy [Btu/lb]
Space Condition	72	50	26,40

Mid points	**Temp range**	**Annual hours**	**Enthalpy**	**Air density**	**Infiltration Old Door**	**Infiltration New Door**	**Energy savings (kWh/yr.door) (MMBtu/yr.door)**
102	100/104	3	41,3	0,070700	1.222	64	0,11
97	95/99	33	41,4	0,071330	13.657	717	1,22
92	90/94	180	40,4	0,071980	70.162	3.683	6,26
87	85/89	483	38,5	0,072640	164.208	8.621	14,65
82	80/84	782	36,6	0,073310	226.181	11.875	20,18
77	75/79	1275	34,9	0,073990	310.162	16.284	27,67
72	70/74	1289	32,4	0,074690	223.436	11.730	19,94
67	65/69	989	OFF	0,075390			
62	60/64	926	OFF	0,076120			
57	55/59	739	21,4	0,076850	109.836	5.766	0,13
52	50/54	643	19,2	0,077600	138.961	7.295	0,16
47	45/49	539	16,6	0,078370	160.122	8.406	0,19
42	40/44	412	14,3	0,079150	152.623	8.013	0,18
37	35/39	252	12,6	0,079950	107.544	5.646	0,13
32	30/34	138	10,5	0,080760	68.542	3.598	0,08
27	25/29	60	8,9	0,081590	33.134	1.740	0,04
22	20/24	19	7,5	0,082430	11.450	601	0,01
17	15/19	4	5,7	0,083300	2.668	140	0,00

Reflective Roof

Dark brown asphalt roof shingles are installed on the whole roof area. The roof absorbs solar radiation and heat is transmitted into the interior of the building. The heat gain that is particularly in summer costly, as it has to be removed by means of air conditioning.

A simple way to reduce heat gain through the roof is to install a reflective roof coating on the asphalt shingles to increase light reflection on the roof and reduce the absorption. These coatings are easy to apply by painting or spraying, support the lifetime of the roof and are available in different colors.

Table JJ.1 shows the wall R-value of the existing roof. Table KK.1 shows the corrected CLTD with and without reflective roof. Table LL.1 is the corrected CLTD for each hour of the day.
[McGuiness et al., 1986, Chapter 5]

The spreadsheet calculation uses the cooling load temperature difference (CLTD) method outlined in ASHRAE Fundamentals, Chapter 26, for calculating the heat transfer load of the roof. The CLTD method is used to determine the roof heat gain for different times of the day during the cooling season (about 6 months per year). Heat transfer savings are found by comparing the heat gain of the dark-colored roof with the gain through the light-colored roof.

Anticipated Savings
The following data and information is useful in calculating the annual heat gain through the south-facing roof.

Average CLTD for 1-24 hour time range, S	29,04^{o}F
Average Corrected CLTD for Cooling Months, S	28,30°F
Present Roof R Value	14,88 hr-ft^2-F/Btu
Roof Area above Sleeping Area, S	2.919 ft^2
Annual Cooling Hours	4.045 hr/yr
Cooling System Efficiency	1,13 kW/ton
Average Electricity Cost	$0,125/kWh

The roofs' primary heat gain is from thermal conduction driven by the cooling load temperature difference (CLTD) [McGuiness et al., 1986, Chapter 5].

Present Average Heat Gain, Dark-Colored Roof:

Q = Area of Roof x CLTD, Corrected / (Present Roof R Value)
= 2.919 ft^2 x (44,3^{o}F) / (14,88 hr-ft^2-^{o}F/Btu)
= 4.345,6 Btu/hr

Proposed Average Heat Gain with Reflective Coating:

Q = Area of Roof x Temperature Difference / (Present Roof R Value)
= 2.919 ft^2 x (30,15^{o}F) / (14,88 hr-ft^2-^{o}F/Btu)
= 2.957,7 Btu/hr

Annual Conduction Heat Gain Reduction from Reflective Roof Coating:

Btu/yr = (Present Heat Gain – Proposed Heat Gain) x Cooling Hours
= (4.345,6 Btu/hr – 2.957,7 Btu/hr) x 4.045 hr/yr
= 6.079.028 Btu/yr

Electricity Savings per Year:

kWh/yr = Heat Gain Reduction/Conversion x Air-conditioner Energy Consumption
= 6.079.028 Btu/yr/12.000 Btu/ton-hr x 1,13 kW/ton
= 557.24 kWh/yr

Annual Cost Savings:

$$/yr = (Annual Electricity Savings x Electricity Cost) x No. of doors
= (557,24 kWh/yr x $0,108/kWh)
= $60,2

<u>Implementation Cost</u>

The cost of material and installation of reflective roof coating is estimated by the U.S. Department of Energy to be $1,50/sf [DOE, 2010]. Assuming that only the sleeping area on the southern part of the building, 2.919sf, is coated, the anticipated investment cost of the project is $2.189,5. This yields a simple payback of 36,4 years for the measure. Therefore, this measure was not included in the assessment report or in the recommendations.

Simple Payback:
= Investment/Annual Savings
= $2.189,5/$60,2/yr
= 36,4 years

Table JJ.1
R-Value doors

R-value Roof	Constr. 1	Constr. 2	
Exterior Resistance	0,25	0,25	hr.ft2.°F/Btu
Asphalt Shingles	0,44	0,44	hr.ft2.°F/Btu
Plywood 0,625 in.	0,77	0,77	hr.ft2.°F/Btu
Wood joists 2x6	0	6,88	hr.ft2.°F/Btu
Air space	1	1	hr.ft2.°F/Btu
Mineral fiber insulation	10,92	0	hr.ft2.°F/Btu
Wood joists	0	6,88	hr.ft2.°F/Btu
Ceiling panels 3/8in.	0,47	0,47	hr.ft2.°F/Btu
Interior Resistance	0,76	0,76	hr.ft2.°F/Btu
R-Value	14,61	17,45	hr.ft2.°F/Btu
Percentage	91%	9%	with 16" o.c.
R-value Roof	**14,88**		**hr.ft2.°F/Btu**
U-Factor total	**0,067**		**Btu/sq ft * °F**

Table KK.1
Average CLTD for flat, south-facing Roof

Time	CLTD
1	35
2	34
3	33
4	32
5	31
6	29
7	27
8	26
9	24
10	23
11	22
12	21
13	22
14	22
15	24
16	25
17	27
18	30
19	32
20	34
21	35
22	36
23	37
24	36
Daily Average	29,042

Table LL.1
Corrected CLTD for Flat Roof with/without reflective coating

Month	*LM Corr. Hor.*	*CLTD+LM*	*CLTD Corr. Light roof*	*Dark roof*
March/Sept	-5	24,0417	28,0208	40,0417
Apr/Aug	-1	28,0417	30,0708	44,0417
May/July	1	30,0417	31,0208	46,0417
June	2	31,0417	31,5208	47,0417
Yearly/Avg		**28,2917**	**30,1458**	**44,2917**

This improvement measure was also calculated for Fire Station 11 with a simple payback period of 28 years. As the same calculation procedure was followed but the measure is not feasible, the calculation is not listed in this paper.

Net present value calculation

In the following tables the net present value calculation for the improvement measures is presented. As a discount rate 5% was selected. This was done for several reasons:

- In general the opportunity costs (WACC) are selected as calculation rate. However as the City of Savannah is not a private company that receives secured loans, it is assumed that general interest rates are lower than average market rates
- The interest rates published by the U.S. Federal Reserve have been and still are very low with 0,17% p.a. as of 3 January 2013 (www.federalreserve.gov).
- The average inflation over the past 10 years (2002 to 2012) in the United States has been 2,66% as from the U.S. Inflation Calculator.

Weather-stripping on garage doors			
Yearly cashflow	**298,00**		
Interest rate	**5,00%**		
Year	**Investment**	**Cashflows**	**Sum**
0	164,00		-164,00
1		283,81	119,81
2		270,29	390,10
3		257,42	647,53
4		245,17	892,69
5		233,49	**1.126,18**
6		222,37	1.348,56
7		211,78	1.560,34
8		201,70	1.762,04
9		192,09	1.954,13
10		182,95	**2.137,08**

Installation of Storm Windows			
Yearly cashflow	**73,00**		
Interest rate	**5,00%**		
Year	**Investment**	**Cashflows**	**Sum**
0	230,00		-230,00
1		69,52	-160,48
2		66,21	-94,26
3		63,06	-31,20
4		60,06	28,85
5		57,20	**86,05**
6		54,47	140,53
7		51,88	192,41
8		49,41	241,81
9		47,06	288,87
10		44,82	**333,69**

Installation of SIPs			
Yearly cashflow	**433,00**		
Interest rate	**5,00%**		
Year	**Investment**	**Cashflows**	**Sum**
0	4.050,00		-4.050,00
1		412,38	-3.637,62
2		392,74	-3.244,88
3		374,04	-2.870,83
4		356,23	-2.514,60
5		339,27	**-2.175,34**
6		323,11	-1.852,23
7		307,73	-1.544,50
8		293,07	-1.251,43
9		279,12	-972,31
10		265,82	**-706,49**

Replacement of wood doors			
Yearly cashflow	**93,00**		
Interest rate	**5,00%**		
Year	**Investment**	**Cashflows**	**Sum**
0	792,00		-792,00
1		88,57	-703,43
2		84,35	-619,07
3		80,34	-538,74
4		76,51	-462,23
5		72,87	**-389,36**
6		69,40	-319,96
7		66,09	-253,87
8		62,95	-190,92
9		59,95	-130,97
10		57,09	**-73,88**