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ECO-ENERGY ENGINEERING

Transformation of a 1940's Panelized Construction Duplex into an Energy-Efficient and Green Office and Community Space

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

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

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Andreas Karl

Walding, August 28th 2014

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Abstract

Using almost a hundred quadrillion Btu each year, the United States are one of the main contributors to the world's energy consumption, whereof a large amount is used to provide electrical energy for lighting and thermal energy for residential and non-residential buildings. However, many buildings have been built prior 1950 and thus, have a weak thermal shell and low overall efficiency.

Renovating and repurposing such old buildings for office purposes, which demand a total of 75 % of their overall energy consumption for HVAC and lighting, is an approach, the City of Savannah tries to accomplish. After partly demolishing and rebuilding a sustainable community in a local area called "Savannah Gardens", one remaining historic building is about to be readapted as an office and public community space. This building, nevertheless, is part of a historic preservation program. Hence, repurposing this landmark combined historic preservation, accessibility and energy efficiency related aspects, making a renovation an overall complex and challenging approach.

As a co-operation between the City of Savannah, the Georgia Institute of Technology and the University of Applied Sciences Upper Austria has been established several years ago, students are given the opportunity work on such ambitious projects. Hence, this thesis discusses different measures for transforming such an old, historic landmark into an energy-efficient building.

Retrofitting this building within an "EarthCraft", an energy label in the South-East, certified community, this building should also be certified. Thus, minimum requirements for the thermal shell and mechanical system are sophisticated. Analyzing the existing, uninsulated building, sufficient insulation can be easily added to the framed construction, providing a high performance building envelope. However, restrictions in historic preservation minimalized the possibilities for on-site renewable energy generation. Considering all relevant requirements, a ground source heat pump has been proposed as a mechanical system and additional passive cooling strategies have been implied.

Specific recommendations for the construction of the new building shell were given to a contracting company, which implemented only a fractional amount of energy-saving and environment-protecting measures. However, the overall proposed renovation would reduce the energy demand for HVAC by 93.3 % while the quoted building design still saves 87 %. Investing a total of $ 94,587.06, $ 4628.89, based on the current electricity rate, can be saved annually and investment would pay back, using NPV calculations, in 19 years. This outlines that retrofitting and old building from an energy stand point is feasible and also easily to achieve.

A detailed comprehensive building analysis in TRNSYS furthermore outlined that quick energy calculation, used for calculating HERS ratings is exact and the implementation of passive cooling strategies is possible. Passive cooling strategies, like night ventilation, can be easily adopted in the hot and humid climate of the South-East United States. Nevertheless detailed measurement of relative humidity is necessary as high humidity does not only decrease comfort but also increases the danger of molt within the thermal shell. Those measures do not only provide savings in energy demand and cost, but also increase thermal comfort with a building. Even though design loads of 36 kBtu/hr have been calculated, ASHRAE and EarthCraft require Manual J conforming design and thus, the system has to be oversized at least 50 %. This enables huge investment cost potentials.

An environmental analysis additionally showed that common practice spray foam application, as it was also proposed by the contractor for this building, has a huge impact and negative effect to the environment. Spray foam does not only include greenhouse gases, like CFC's, but generally contributes harm the environment as way more primary energy input is necessary.

As solar-thermal cooling has been considered as potential technology to provide necessary cooling loads during summer month, but could not be implemented due to historic preservation restrictions, further investigation on this topic for hot and humid climate should be considered.

Kurzfassung

Mit einem Verbrauch von rund 100 Milliarden Btu pro Jahr (293 071 TWh), wovon ein Großteil in Form von elektrischer Energie für Beleuchtung und thermischer Energie in Haushalt und Gewerbe benötigt wird, gehören die USA zu einem der Hauptkonsumenten für Energie weltweit. Viele Gebäude wurden allerdings vor 1950 errichtet und haben daher eine thermisch minderwertige Gebäudehüllen und schwache Gesamtenergieeffizienz.

Die Renovierung und Neuanpassung solcher alten Gebäude zu Bürogebäuden, welche in Summe 75 % ihrer Verbrauchsenergie für Beleuchtung und HLK Zwecke benötigen, ist ein Ansatz, welchen die Stadt Savannah umzusetzen versucht. Nachdem die alte und marode Nachbarschaft „Savannah Gardens“ bereits teilweise abgerissen und neu errichtet wurde, soll ein altes Bestandsgebäude zu einem Büro- und Gemeinschaftsgebäude umstrukturiert werden. Dieses Gebäude ist allerdings Teil des regionalen Denkmalschutzes und eine Sanierung umfasst neben dieser Thematik auch Aspekte der Barrierefreiheit und Energie-effizient. Durch das gegenseitige Beeinflussen dieser drei Betrachtungspunkte gestaltet sich eine Renovierung jedoch als komplexes Anliegen.

Da der Grundstein für Zusammenarbeit zwischen der Stadt Savannah, dem Georgia Institute of Technology und der Fachhochschule Wels schon vor Jahren gelegt wurde, können Studenten der FH Wels an solchen Projekten mitwirken. Diese Thesis diskutiert Maßnahmen, wie solch alte, historische Gebäude, und dieses Gebäude im speziellen, in energieeffiziente Gebäude transformiert werden können.

Die „Savannah Gardens“ sind eine „EarthCraft“ (ein Energielabel aus dem Süd-Osten der Vereinigten Staaten) zertifizierte Nachbarschaft und soll daher auch auf denselben Energiestandard gebracht werden. Eine detaillierte der bestenden thermischen Gebäudehülle ergab, dass ausreichend Wärmedämmung ohne Veränderung der Wandaufbauten hinzugefügt werden kann. Auflagen des Denkmalschutzes vermindern jedoch die Möglichkeiten für Energiegewinnung vor Ort. Um kosteneffizient Heizen und Kühlen zu können, wurde eine Wärmepumpe mit Tiefenbohrung in Kombination mit einem Hochleistungslüftungsgerät vorgeschlagen. Die Lüftungsanlage ermöglicht zudem die Möglichkeit einer Nachtlüftung, welche zusätzlich analysiert wurde.

Konstruktionsvorschläge für Wandaufbauten, welche im Zuge der Arbeit ausgearbeitet wurden, sowie Vorschläge für die Umsetzung aller projekt- und energietechnisch relevanter Maßnahmen wurden an die Contracting Firma weiter gegeben, welche jedoch nur einen Bruchteil der Maßnahmen in deren Angebot einarbeitete. In Summe würde das in dieser Arbeit besprochene Konzept 93,3 % und das veranschlagte Konzept 87 % Energie einsparen. Bei einem Investitionsvolumen von $ 94 587,06, können $ 4 628, 89 jährlich gespart werden, wodurch sich eine Amortisationszeit von 19 Jahren (Kapitalwertmethode) ergibt. Dieses Ergebnis bekräftigt, dass Renovierung alter Gebäude sowohl energetisch, als auch finanziell realisierbar und umsetzbar sind.

Eine detaillierte thermische Analyse im Simulationstool „TRNSYS“ ergab, dass einfachere Berechnungstools, welche zum Beispiel verwendet werden um das in den USA übliche HERS Rating zu ermitteln, genaue Ergebnisse liefern, sofern keine passiven Kühlungskonzepte implementiert werden. Passives Kühlen, zum Beispiel über Nachtventilation, ist im Süd-Osten der Vereinigten Staaten, trotz der hohen Luftfeuchte möglich. Jedoch muss die Luftfeuchte hierzu genau gemessen werden, da hohe Feuchtigkeit in den Innenräumen zu gemindertem Komfort und auch zu einer erhöhten Schimmelgefahr führt. Grundsätzlich sind Nachtlüftungskonzepte aber energietechnisch und wirtschaftlich sinnvoll und erhöhen zudem den thermischen Komfort. Trotz der Berechnung einer Auslegeleistung für die Wärmepumpe von 36 kBtu/hr (10.55 kW) wird von der Contracting Firma das Equipment um 50 % überdimensioniert. Grund hierfür sind von ASHRAE und EarthCraft erforderte „Manual J“ Berechnungen, welche zu solchen Ergebnissen führen. Dadurch besteht schon alleine bei der Dimensionierung der Anlagenkomponenten großes Einsparpotential.

Eine umwelttechnische Analyse zeigte zudem, dass praxisübliche Verwendung von Sprühschaum, wie auch vom Contractor vorgeschlagen, einen großen und negativen Einfluss auf die Umwelt haben.

Da solare Kühlung als potentielle Technologie für ein Kühlkonzept angesehen wurde, jedoch auf Grund der Denkmalschutzrestriktionen nicht umgesetzt werden konnte, sollte diese Technologie für das feuchte und heiße Klima im Süd-Osten der USA noch näher untersucht werden.

Conversion Table and Nomenclature

Table 1: Units and Conversion Table [O MIT, 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

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

Time

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

Fuel Economy

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

Distance

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

Area

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

Pressure

1MPa = 10bar = 9.87atm = 145psi
1atm = 1.0132 bar = 760 mmHg
= 14.696 psi = 10.33 ton/m^2

Volume

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

Flow Rates

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

Energy Unit Conversion

1 J = 1 Nm = 1 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
1 toe = 41.868 GJ = 39.683 mmBtu = 11.63 MWh = 7.33bbl
1 tce = 29.308 GJ = 27.778 mmBtu = 8.141 MWh
1 Quad = 10^{15} Btu = 1.055 EJ = 293 TWh = 25.2 Mtoe = .974 TCF
1 EJ = 10^9 GJ = 10^{18} J = .95 Quad
1 TWyr = 31.5 EJ = 29.86 Quad

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

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

Energy of Familiar Phenomena/Society

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

Density

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

Power Unit Conversion

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

Historic US Retail Prices (US2000$/GJ)

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

This table, provided by the Energy Club of MIT, contains all units within this paper. However, *[.]* in this case stands for comma, while *[,]* represents the separation of thousands. Deriving from this conversion table, furthermore, for quicker conversion, following equations can have been used:

$$R_{US}\left[\frac{h\,ft^2F}{Btu}\right] = R_{SI}\left[\frac{m^2K}{W}\right] * 5.67826337$$

Equation (0-1) : Conversion for thermal resistance

$$U_{US}\left[\frac{Btu}{h\,ft^2F}\right] = R_{SI}\left[\frac{W}{m^2K}\right] / 5.67826337$$

Equation (0-2) : Conversion for U-value

$$\dot{V}_{US}\,[cfm] = \dot{V}_{SI}\left[\frac{m^3}{s}\right] * 2118.88$$

Equation (0-3) : Conversion for volumetric flow

$$E_{US}\,[mmBtu] = E_{SI}\,[kWh]/293.08$$

Equation (0-4) : Conversion factor for energy

In addition to the conversion factors listed above, 1 inch *[“]* represents 25.4 mm and 12 inch equal 1 foot *[‘]*.

References distinguish in their designation between their sources. Thus, references starting with a capital “O” characterize online resources. References starting with a capital “P” indicate publications and capital “S” stands for spoken and e-mail sources.

Table of Contents

ACKNOWLEDGEMENT I

ABSTRACT II

KURZFASSUNG IV

CONVERSION TABLE AND NOMENCLATURE VI

TABLE OF CONTENTS VIII

1 PREFACE 1

1.1 ENERGY DEMAND FOR THE COMMERCIAL SECTOR OF THE UNITED STATES 1
1.2 CLIMATE 3
1.3 SAVANNAH GARDENS 4

2 SCOPE 9

3 LITERATURE REVIEW 11

3.1 HISTORIC PRESERVATION 11
3.1.1 GOALS AND STANDARDS 11
3.1.2 IMPLEMENTATION AND COMMON PRACTICE 11
3.2 ACCESSIBILITY 12
3.2.1 ENTRANCE AND ACCESSIBLE ROUTES 12
3.2.2 RESTROOMS AND BATHROOMS 15
3.2.3 AREAS FOR COMMON USE 17
3.3 EARTHCRAFT 18
3.3.1 MAIN OBJECTIVES 19
3.3.2 ASSESSMENT CRITERIA 20
3.3.3 HERS RATING 21

4 REDESIGNING A HISTORIC LANDMARK INTO A GREEN BUILDING 23

4.1 METHODOLOGY 23
4.2 HISTORIC LANDMARK: ACTUAL STATE 25
4.2.1 ON-SITE VISIT AND BUILDING DESCRIPTION 25
4.2.2 CONSTRUCTION PRINCIPLES 30
4.2.3 EXISTING LAYOUT 35

4.3 HISTORIC LANDMARK: PROPOSED IMPROVEMENT ... 37
4.3.1 IMPLEMENTATION OF HISTORIC PRESERVATION STANDARDS ... 37
4.3.2 IMPLEMENTATION OF EARTHCRAFT RENOVATION STANDARDS ... 38
4.3.3 PROPOSED LAYOUT ... 41
4.3.4 OFFICE CONFIGURATION ... 43
4.3.5 EXHIBITION ROOM ... 45
4.3.6 CONSTRUCTION PRINCIPLES ... 47
4.3.7 MECHANICAL AND THERMAL SYSTEM ... 55
4.3.8 COOLING STRATEGY ... 60
4.3.9 ENERGY MODELING AND THERMAL SIMULATION ... 63
4.4 COST ANALYSIS ... 65
4.5 ENVIRONMENTAL ANALYSIS OF BUILDING MATERIALS ... 68

5 RESULTS AND DISCUSSION ... 69

5.1 FINAL QUOTE AND IMPLEMENTED IMPROVEMENTS ... 69
5.2 HERS INDEX AND ENERGY CONSUMPTION ... 73
5.3 DETAILED THERMAL SIMULATION ... 76
5.4 COST BENEFIT ... 83
5.4.1 PASSIVE COOLING AND AIR VENTILATION ... 83
5.4.2 THERMAL BOUNDARY ... 85
5.4.3 HVAC SYSTEM ... 86
5.5 ENVIRONMENTAL ANALYSIS OF BUILDING MATERIALS ... 87

6 CONCLUSION ... 91

7 REGISTER ... 95

7.1 LIST OF REFERENCES ... 95
7.1.1 PUBLICATIONS ... 95
7.1.2 ONLINE SOURCES ... 97
7.1.3 SPOKEN AND E-MAIL SOURCES ... 102
7.1.4 SOFTWARE ... 103
7.2 TABLE OF FIGURES ... 104
7.3 TABLE OF TABLES ... 106
7.4 TABLE OF EQUATIONS ... 107

8 APPENDIX ... 108

1 Preface

The following chapter gives a short introduction on basic topic concerning this project.

1.1 Energy Demand for the Commercial Sector of the United States

The total energy demand of the United States of America consumption amounts to 97.53 quadrillion Btu, whereof 21.67 % belong to the residential, 18.38 % are used in the commercial, 32.26 % are consumed in the industrial and the remaining 27.69 % are burnt in the transportation sector, As Figure 1 displays. Additionally only 9.53 % of the consumed energy is generated by renewable energy sources. This demand makes the United States the second biggest energy consumer and tenth biggest consumer per capita worldwide [O WorldBank Energy, 2014].

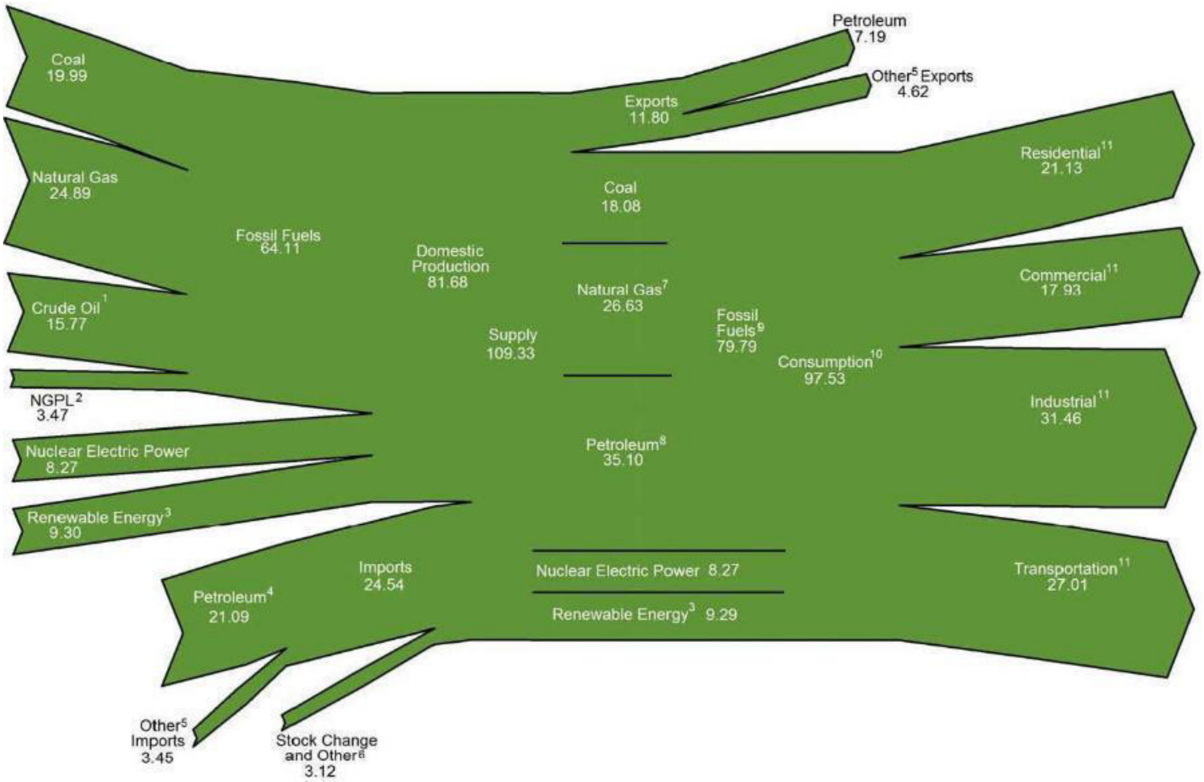


Figure 1: Energy flow chart for the United States in quadrillion Btu [O EIA Flow, 2014]

The commercial sector, encompassing education, offices, services, warehouses and retail, and requires almost 50 % of its energy for HVAC and lighting [O EIA AEO A5, 2014]. Even there is a huge block of 33.6 % unspecified uses [O EIA AEO A5, 2014], those two main contributors to energy consumption within the commercial sector have to be targeted for energy saving potentials. Figure 2, derived from tabular data in the "Annual Energy Outlook 2014" [O EIA AEO A5, 2014], indicates a detailed split up of commercial energy usage.

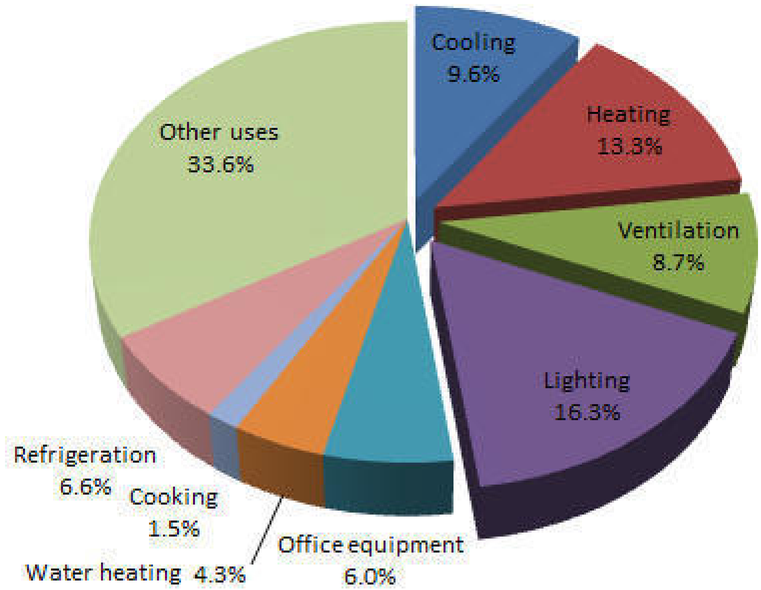


Figure 2: Energy use within the commercial sector [O EIA AEO A5, 2014]

Figure 2 indicates energy usage for the whole commercial sector, whereof only 17.4 % represent offices, whereof again 76 % have been built before 1979 [O EIA AER 2.9, 2012]. Considering only office spaces, the energy distribution within the building significantly differs from the energy use in the commercial sector. A rough total of 75 % of all consumed energy is required for HVAC and lighting appliances [O EIA CBECS, 2008]. The detailed segmentation is shown in Figure 3, derived from tabular data in the "CBECS 2008".

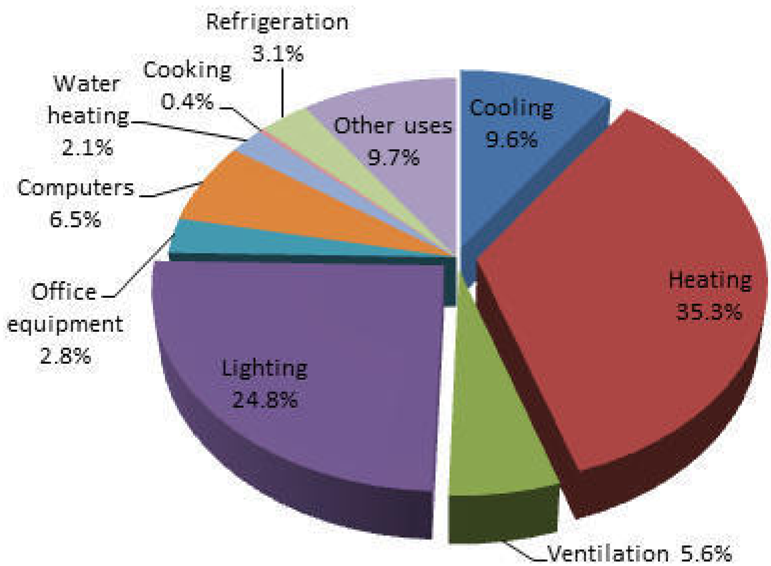


Figure 3: Energy usage in offices [O EIA AEO A5, 2014]

Furthermore it has to be distinguished that due to different climate zones with the United States, energy usage for heating and cooling depends on the offices location. In the South Atlantic States, including Florida, Georgia, North- and South Carolina, exceed average cooling degree days by 53 % and undercut average heating degree days by 40 % and thus, cooling and heating degrees are roughly the same [O EIA AEO A5, 2014]. Thus, energy consumption decreases for heating purposes, while energy consumption for cooling increases. Nevertheless, the HVAC system is responsible for roughly 50% of the total energy consumption.

1.2 Climate

As already researched in previous publications [P Bachner, 2012, pg. 6 cont.], the South Atlantic States encompass a total of four different climate zones, whereof the target area, Savannah, GA, is located in climate zone 2. This climate zone does not only encompass the Savannah region in South-East Georgia, but also covers the South of South Carolina, Southern Alabama, Southern Mississippi, Louisiana, Eastern Texas and Florida (without the greater Miami area and the Keys). The city Savannah, located on the East coast to the border to South Carolina, has moderate winters and hot and humid summers, which are typical for this climate zone. This leads to constructional challenges as those conditions are perfect for termites and furthermore the moisture content of the air extends the risk condensate and molt.

Nevertheless, for further considerations TMY 3 based data, typical weather data for observed area from 1991 to 2005, for Savannah Hilton Head Intl. Airport [O NREL, 2008] has been used as a database to simulate weather conditions in the Savannah area.

1.3 Savannah Gardens

The Savannah Gardens are a small neighborhood in the East of Savannah, GA, United States. Located 32.06° N and 81.06° W, this site along Pennsylvania Avenue, displayed in Figure 4 within the white boundary, encompasses a total of 90 acres of land.

Figure 4: Location of Savannah Gardens [O Google Maps, 2014]

Figure 5 shows the first plans of Savannah Gardens, the so called 'Josiah Tattnall Homes', (view from South-East direction), which have been published in the Savannah Evening Press on September 30th, 1942.

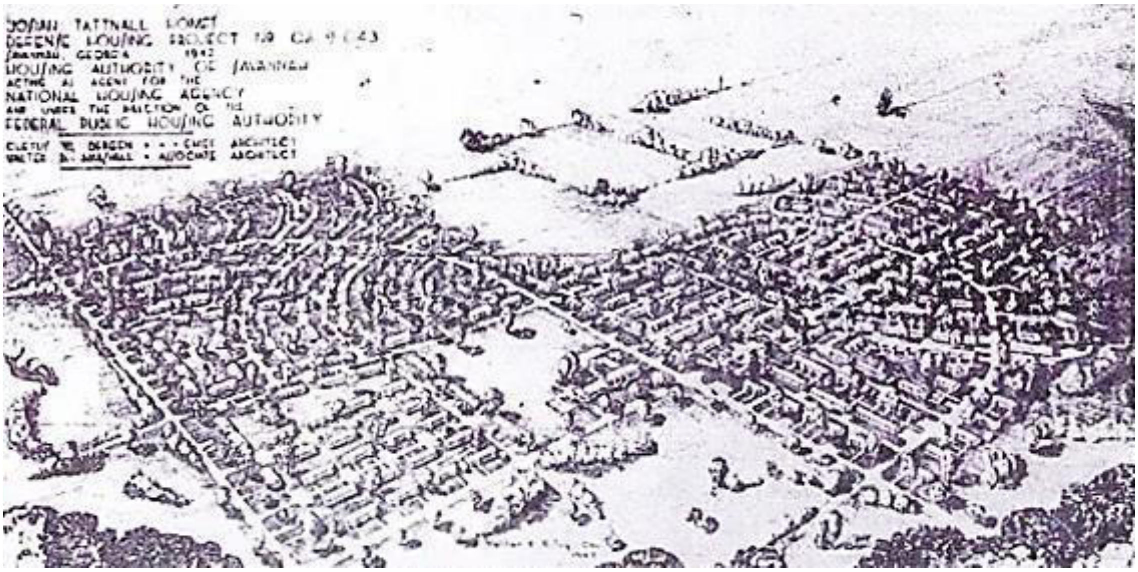


Figure 5: Proposed plans of Savannah Gardens, 1942 [P Keber, 2011, pg. 103]

The street, separating those two squared blocks and bending through the left block, is Elgin Street (former: Jones Street). The street separating the right block in two halves is Pennsylvania Avenue and the half-circle shaped road today's Crescent Drive.

All components have been prefabricated and were of good quality, as some constructions and beam widths (e.g. 2 by 4 wall framing and 2 by 6 floor framing) are still used in modern homes. However, it took only five months to build this neighborhood with over 700 homes. Figure 6 shows the development of historic Savannah Gardens just one month after construction work started where several homes have already been finished.

Figure 6: Constructing historic Savannah Gardens, October 1942 [P Keber, 2011, pg. 104]

Living in those homes was affordable for those times and with maximum $ 40.50 less than a third than the workers income. All those homes have been designed for family living with widespread, unfenced areas and common back yards. Thus, life quality for the ship workers was intended to be very high and they established strong community bonds. Even there lived afro American and white people next door; there've been almost no racism issues. Figure 7 pictures shows idyllic, widespread area alongside Pennsylvania Avenue.

Figure 7: Historic Savannah Gardens in July 1943 [P Keber, 2011, pg. 63]

While these 'demountable' houses were intended to be dismantled, once World War II was over, ship building has been stopped and the last manufactured ship - AV-1 S.S. Half Knot - left Savannah on September 14th, 1945, they instead, have been sold from property owner to property owner and became home for low-income, hardworking families. As the houses steadily fell into disrepair, crime rate increased significantly and only a small percentage was still occupied, the school board bought 47 acres of land in 1990, demolished 374 housing units and built Savannah High School [P Keber, 2011].

In further consequence the City of Savannah bought the remaining 43 acres on November 16th, 2007 from Strathmore Estates. As only 140 units were still occupied the City of Savannah started a housing project for Savannah Gardens, to make this are worth living again. In March 2009 the City of Savannah approved the proposed master plan of the CHSA (Community Housing Services Agency Development, Inc.). Figure 8 shows the proposed layout for new Savannah Gardens, provided by Engineering Office Thomas & Hutton, which is additionally attached as appendix A1.1.

Figure 8: Proposed master plan for new Savannah Gardens [Thomas&Hutton, 2009, pg. 1]

All in all Savannah Gardens should become an attractive, family and environmental friendly neighborhood, for reasonable, affordable prices – just like Savannah Gardens in the 1940's. Over 500 EarthCraft certified housing units are planned to be built (single and two-story homes as well as multifamily apartments). All those buildings meet high quality standards, use recyclable and recycled material, geothermal wells and are built solar ready. Additionally five acres of green space, local bus stops and bike lanes as well as five acres of commercial parcels are provided. Thus, time spent in a car should be reduced and quality of life increased. The first of four development and building phases began in June 2010 and the final phase is supposed to be finished late 2014/early 2015 [P Daise, 2012, pg. 4]. Figure 9 pictures how one of the last remaining duplex has been demolished, while Figure 10 indicates shows already finished buildings at the centered community hub.

Figure 9: One of the last remaining buildings is demolished [O SavannahNow, 2013]

Figure 10: Community hub of new Savannah Gardens [P Daise, 2012, pg. 11]

However, even the old buildings had been torn down and replaced by new, energy efficient (multi-)family homes, the State Historical Preservation Office SHPO requires maintaining one building as a historic landmark. Thus, there is one remaining historic building, which is about collapse, as the shell has been damaged by the demolition company [S GMarr, 2014].

This building is one example of total of 1.3 Million homes in climate zone 2, which has been built before 1950 [O EIA RECS HC2.6, 2009] whereof an average of 56 % are wooden buildings [O EIA RECS HC2.3, 2009]. This amounts in a total of 728,000 historic panelized wood buildings which are in need of being adapted and modernized, as a negligible amount of those has already been renovated and the thermal shell has been improved by adding insulation [O EIA RECS HC2.3, 2009].

2 Scope

This historic landmark should be transformed and redesigned to an energy efficient and green office and community space. This task leads to several key issues which have to be considered. First of all the building should meet, like every other housing unit in Savannah Gardens, EarthCraft standards and should be certified. Secondly the proposed design has to be mindful of historic preservation issues. Lastly this building should not only have low operation and maintenance cost, but also low cost in retrofitting and renovating the old building shell.

Once the existing historic landmark has been observed and analyzed, the building has to be redesigned, to create office as well as community spaces. Therefore design issues are as important as energy issues. This contains, on the one hand, implementation of sustainable and renewable materials as well as a sustainable heating and cooling system to provide energy-efficient and green energy for the building. Efficient distribution has to be considered too. On the other hand, design should be appealing for both, office and community place. This implies that several technologies, which should be used (e.g. use of solar-thermal energy, air conditioning, sustainable building insulation) have to interact and the functions have to be optimized, while architectonic issues should not be neglected.

Completing construction relevant parameters, a simulation of the building has to be carried out, to prevent overheating of the building in summer and to adjust parameters such as the use of air conditioning systems. Hence, energy modeling of the new building concept is necessary to fulfill government requirements and set the buildings energy demand to a minimum at maximum comfort. Additionally an energy model of the old historic landmark has to be generated, as improvements in energy demands have to be highlighted.

Last but not least, practicability has to be evaluated. On the one hand cost analysis has to be done. This is necessary as it is important to know if and when the investment cost will benefit and affect effective cost savings. However, therefore a small scale investment calculation is necessary, where investment costs have to be confronted with energy- and, as a result, money-savings. Those costs should meet in a desired time of some years. On the other hand is has to be verified if desired changes meet legal aspects concerning landmarked buildings.

The research should result in a basic concept, how this 1940's panelized construction duplex, as well as other similar buildings in general, can be transformed into an energy-efficient and green office and community space. Thus, a foundation for rehabilitation sanctions, considering aspects of environmentally friendly buildings, outlining costs and amortization as well, should be created. This is necessary, as there are many building complexes of roughly same age in need of renovation in Georgia and the Southern United States.

3 Literature Review

This chapter deals with basic information on project relevant topics. Detailed information of how those topics and issues are integrated in the project can be found in *Chapter 4.3 'Historic Landmark: Proposed Improvement'*. Further additional helpful literature can be obtained from previously established research by Daniela Bachner, MSc [P Bachner, 2012].

3.1 Historic Preservation

Historic Preservation is relatively new topic in the United States. Goals and how measures are implemented is described in the following sub-chapters.

3.1.1 Goals and Standards

The United States' historic preservation is carried out separate in every of its states SHPO (State Historic Preservation Office). Nevertheless there is a super ordinate state plan of the National Park Service. This nationwide valid guidelines and standards basically state that historic objects should be preserved and embedded into modern structures. However, 'historical objects' are such of those which represent either classical types of construction for a certain era, have a significant role in the city's/state's history or is/was an important factor in cultural and/or social development [O NPS, 2014].

Buildings falling in those category and are not already part of the historic preservation program are basically buildings with context to World War II or buildings from the early 1960's. Purpose of integrating those into the historic preservation program is to "*expand the use of technology to provide better access to information about historic resources to a wider audience and promote a deeper understanding of Georgia's historic resources*" [O GASHPO, 2014].

3.1.2 Implementation and Common Practice

Detailed Information concerning Georgia's legal situation can be found in the Official Code of Georgia, Chapter 44 'Property', Article 10 'Historic Preservation'[O GHPA 44-10, 1982],. However, there are several points with have to be considered for redesigning the 1940's duplex. Basically this object has to be projected as it is, referring to the previously mentioned regulations, *"an outstanding example of a structure representative of its era"* [O GHPA 44-10-22, 1982], *"one of the few remaining examples of a past architectural style"* [O

GHPA 44-10-22, 1982], and *"a place or structure associated with an event or person of historic or cultural significance to the region"* [O GHPA 44-10-22, 1982].

As this building is in bad shape and has to be renovated, it is of special importance to consider, that a change in material of such a property is prohibited [O GHPA 40-10-22, 1982]. Such a 'material change in appearance' encompasses *"a reconstruction or alteration of the size, shape, or facade of a historic property, including relocation of any doors or windows or removal or alteration of any architectural features, details, or elements"* [O GHPA 44-10-22, 1982]. However, this article also states that *"Nothing in this article shall be construed to prevent the ordinary maintenance or repair of any exterior architectural feature in or on a historic property […], nor to prevent any property owner from making any use of his property not prohibited by other laws, ordinances, or regulations"* [O GHPA 44-10-29, 1982]. Hence, it is allowed to replace doors, windows, roof and siding with state-of-the-art materials and constructions, as long as the exterior appearance is not affected.

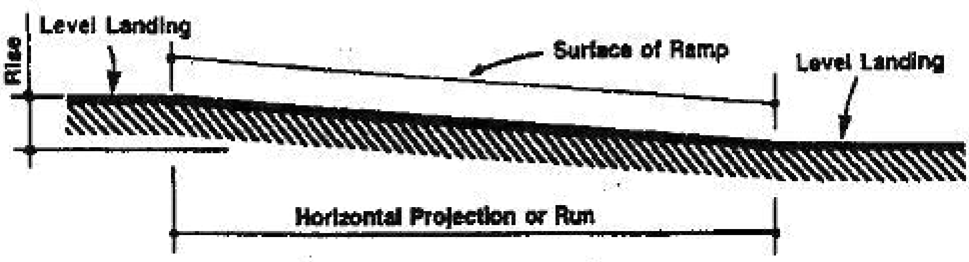
As the redesigned building should also contain public community spaces, with reference to the Georgia Accessibility Code, at least one accessible entrance and accessible interior design has to be provided except those *"ramps, entrances, or toilets would threaten or destroy the historic significance of the building or facility"* [P GAC 120-3-20-.12, 1987, pg. 26]. Furthermore there has to be at least on accessible, unisex restroom, if toilets are provided, and "d*isplays and written information, documents, etc., should be located where they can be seen by a seated person. Exhibits and signage displayed horizontally (e.g., open books), should be no higher than 44 inches (1120 mm) above the floor surface."* [P GAC 120-3-20-.12, 1987, pg. 26]

3.2 Accessibility

For granting accessibility for all people, regulations concerning standards for accessible routes and facilities have to be considered during the construction process. Following sub-chapters describe which things have to be considered when planning full accessibility.

3.2.1 Entrance and Accessible Routes

In order to fulfill accessibility requirements for entrances, bathrooms and corridors within the historic, public building, Georgia's Accessibility Code regulates the required minimum dimensions. However, as already mentioned in *chapter 3.1.2 'Implementation and Common Practice'*, an accessible entrance has to be provided to public buildings. Even this regulation has exceptions and special requirements for historic sites, erecting a ramp or a wheelchair elevator can't be avoided. Figure 11 indicates a typical ramp construction, where the clear width of the ramp should be at least 36" and the length of both landing zones at least 60" [P GAC 120-3-20-.19, 1987, pg. 46].



	Maximum Rise		Maximum Horizontal Projection	
Slope	in	mm	ft	m
1:12 to < 1:16	30	760	30	9
1:16 to < 1:20	30	760	40	12

Figure 11: Wheelchair ramp requirements [P GAC 120-3-20-.19, 1987, pg. 46]

Even the regulations regulate a slope between 1:12 and 1:16 for shorter ramps, a slope of 1:20 is recommended for any wheelchair ramp, as they are easier accessible. Additionally, ramps with a rise greater than 6" are required having handrails on both side [P GAC 120-3-20-.19, 1987, pg. 47]. Details for handrails are displayed in Figure 12.

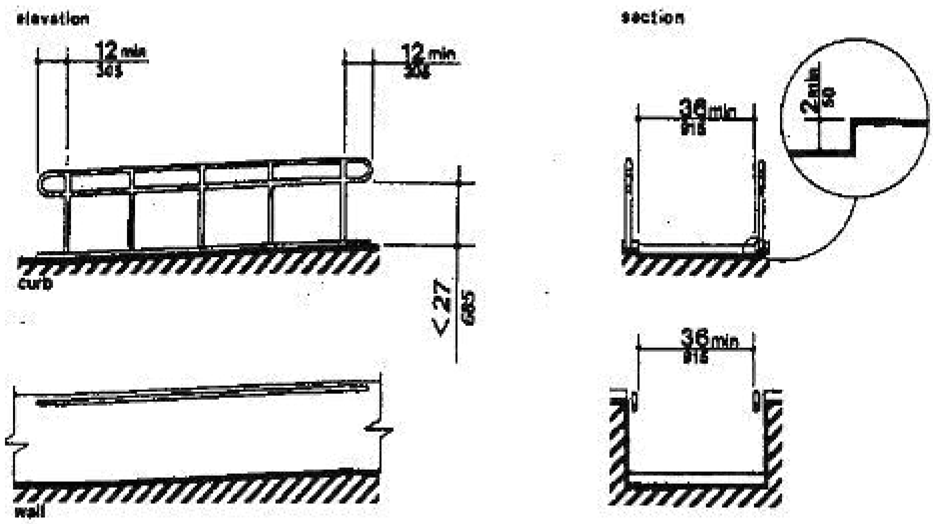


Figure 12: Handrail requirements [P GAC 120-3-20-.19, 1987, pg. 47]

A clear width of at least 36 inch generally applies to every hallway and corridor. However, if an accessible route should be passable by both, wheelchair user and pedestrian, the Georgia Accessibility Code prescribes a minimum width of 48” [P GAC 120-3-20-.13, 1987, pg. 27]. If there are doors or right angled bends alongside the corridor, those accessible routes are also required being at least 48 inch wide [P GAC 120-3-20-.13, 1987, pg. 56], as a wheelchair has to be turned and thus, required more space. Figure 13**Fehler! Verweisquelle konnte nicht gefunden werden.** and Figure 14 summarize those minimum dimensions for accessible routes.

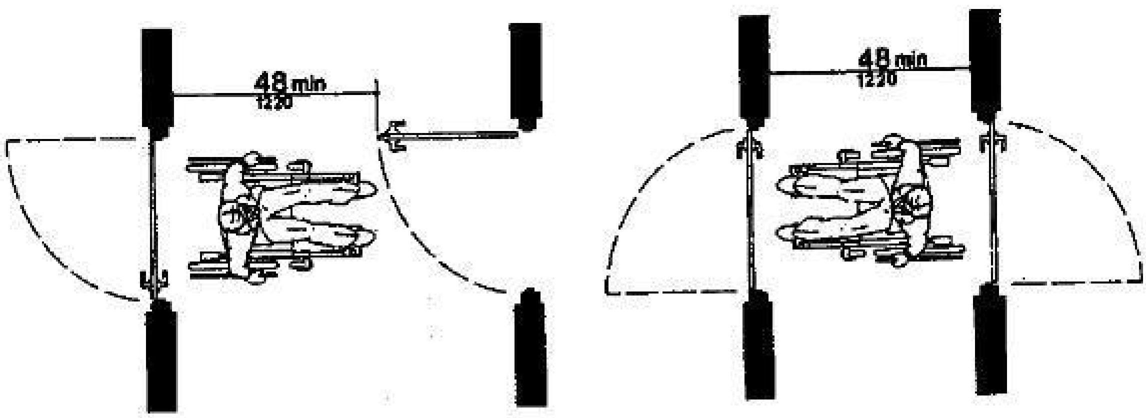


Figure 13: Hallway clear-width requirements for door openings [P GAC 120-3-20-.13, 1987, pg. 55]

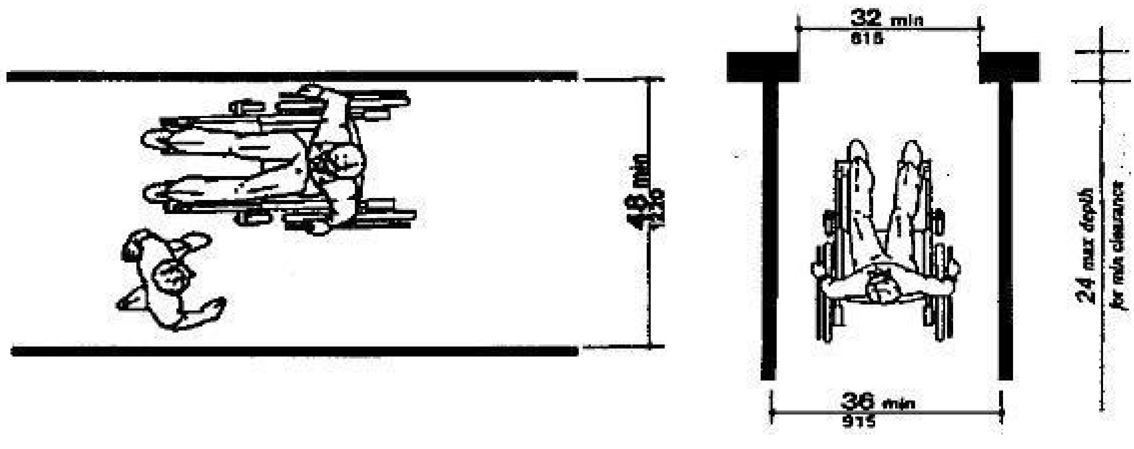


Figure 14: Hallway clear-width requirements for passing [P GAC 120-3-20-.13, 1987, pg. 26 and 27]

As it can be also seen from **Fehler! Verweisquelle konnte nicht gefunden werden.**, doors and choke points with a maximum length of 24 inch have to be at least 32” wide. Those regulations, regarding doors, apply for every door on an accessible route [P GAC 120-3-20-.24, 1987, pg. 56] and are displayed more detailed in Figure 15.

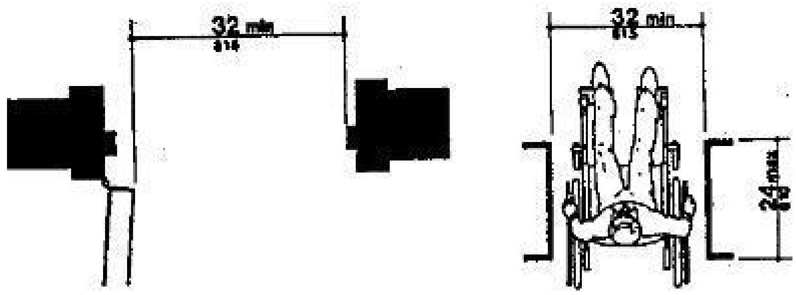


Figure 15: Minimum door clear-width regulations [P GAC 120-3-20-.24, 1987, pg. 55]

3.2.2 Restrooms and Bathrooms

To fulfill requirements concerning restrooms, at least one accessible restroom has to be considered in every planning process of public buildings. This restroom has to be along an accessible route within the planned structure. However, there are multiple minimum dimensions for the toilet and the arrangement of additional necessary equipment (like access grab bars) is displayed in Figure 16.

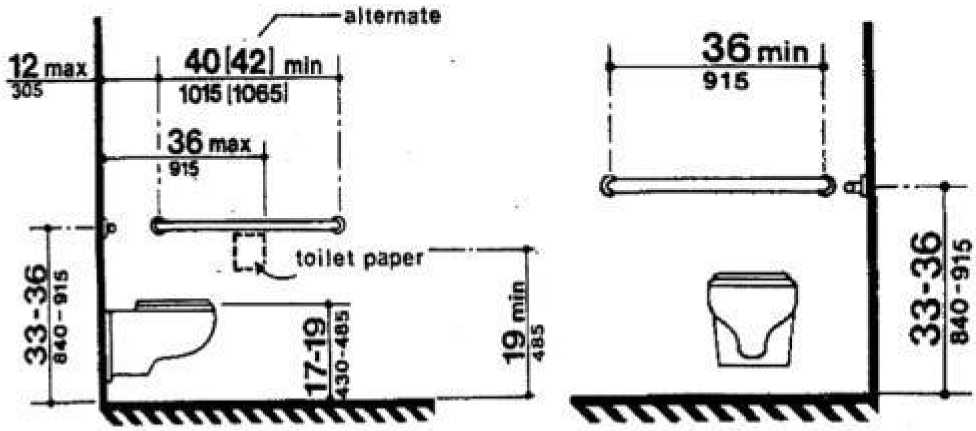


Figure 16: Layout of an accessible restroom [P GAC 120-3-20-.27, 1987, pg. 66]

Nevertheless, not only the space requirements of the toilet and grab bar are necessary to design an accessible restroom. An additional important measure is the room besides the toilet bowl. As there is a minimum space needed to allow wheelchair user using the restroom, at least 18" to 30" (grab rails to the left and right of the bowl are mandatory) for a diagonal approach are required. At the same time the Georgia Accessibility Code recommends a total of 42 inch space on one side of the toilet (measured from the center of the toilet), to enable easier side approach [P GAC 120-3-20-.27, 1987, pg. 63]. Figure 18 and indicated how those different toilet approaches are performed by a wheelchair user and how the minimum measures affect this action.

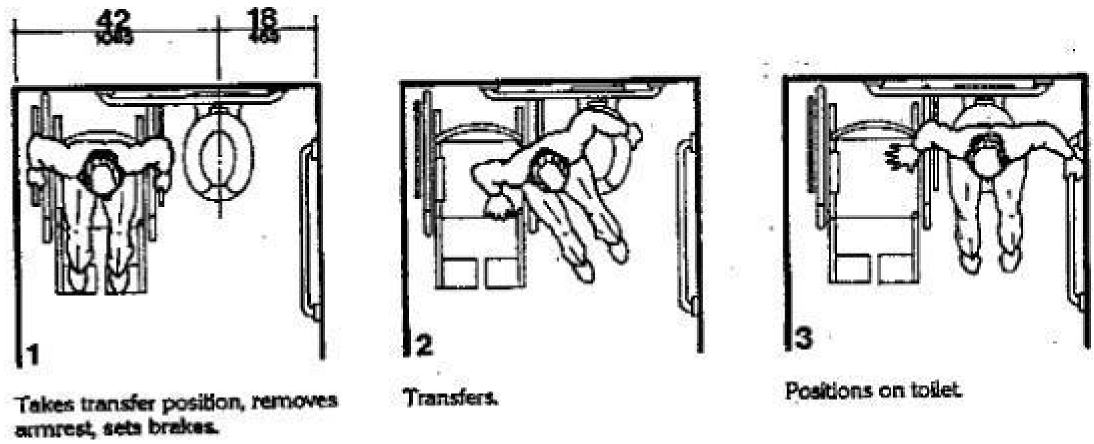


Figure 17: Side toilet approach [P GAC 120-3-20-.27, 1987, pg. 63]

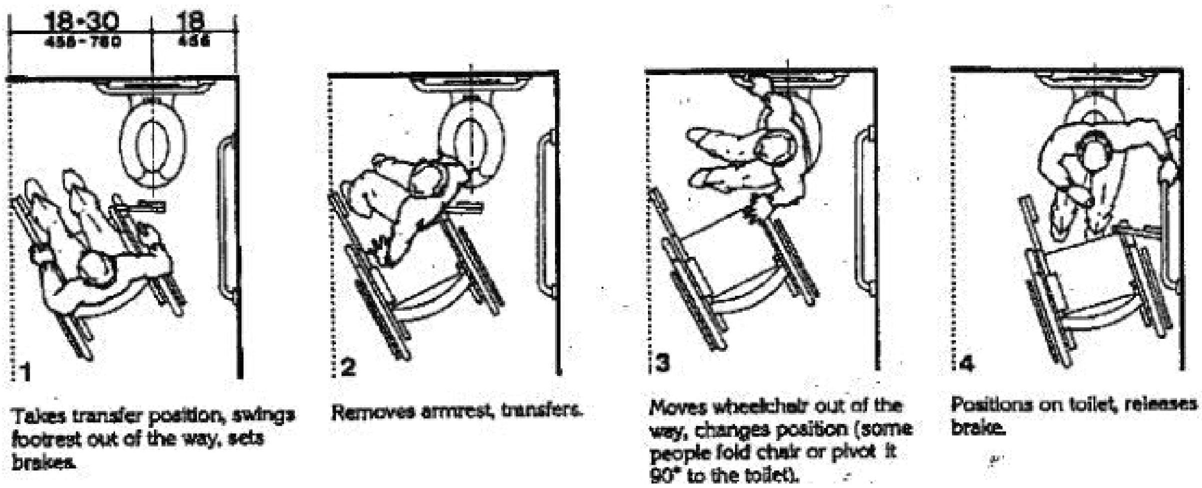


Figure 18: Diagonal toilet approach [P GAC 120-3-20-.27, 1987, pg. 63]

It can be seen, that a side approach is much easier to accomplish and requires way less exercise for the user. Thus, this approach shall be considered as most common, as the transfer from the wheelchair to the toilet can be an exhausting process, especially for elder people [P GAC 120-3-20-.27, 1987, pg. 62 cont.]. In further addition every restroom requires sinks to provide hygienic standards. Those sinks have to be mounted at lower height as usual sinks and have to have a certain level of knee clearance, as wheelchair users have to roll beneath the sink. However, there are a several 'handicapped lavatories', but, referring to the Georgia Accessibility Code *"standard sink designs are recommended to be used instead of the handicapped sink designs where possible"* [P GAC 120-3-20-.34, 1987, pg. 77]. Additionally every faucet with the accessible route *"shall be operable with one hand and shall not require tight grasping, pinching, or twisting of the wrist"* [P GAC 120-3-20-.38, 1987, pg. 81]. Thus, *"lever-operated, push-type, touch-type, or electronically controlled* *mechanisms are acceptable designs"* [P GAC 120-3-20-.35, 1987, pg. 77]. Figure 19 shows minimum measures for sinks with an accessible bathroom.

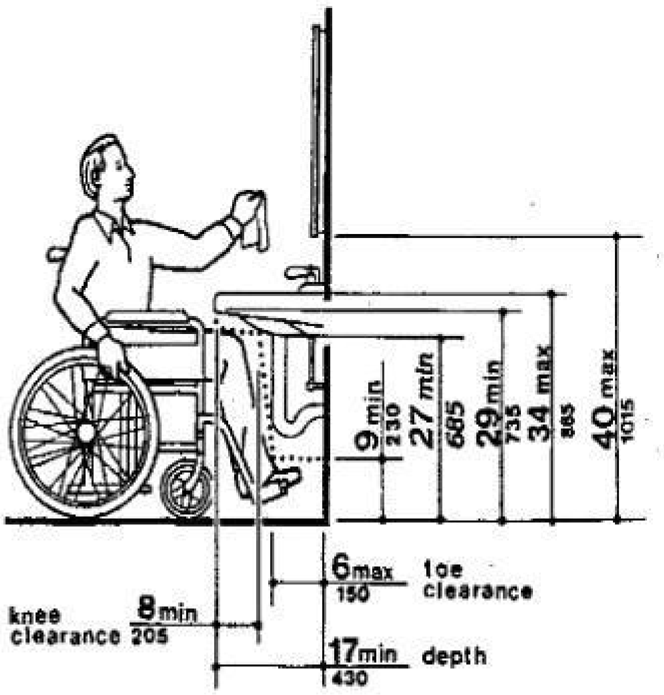


Figure 19: Clear-space underneath an accessible lavatory [P GAC 120-3-20-.35, 1987, pg. 77]

Furthermore every hot pipe underneath the sink has to be insulated or otherwise protected as well as there shall not be any sharp or abrasive surfaces. Besides minimum measures, *"at a minimum, visual signal appliances shall be provided in buildings and facilities in each of the following areas: restrooms and any other general usage areas […] and any other area for common use"* [P GAC 120-3-20-.39, 1987, pg. 82].

3.2.3 Areas for Common Use

Areas for common use shall basically have accessible design. Such areas, for example kitchens and sitting accommodations, need to have certain knee and toe clearances. Tables or work surfaces in a kitchen have to have at least a clear floor space underneath the countertop of at least 27 inches high, 30 inches wide and 19 inches deep [P GAC 120-3-20-.43, 1987, pg. 92].

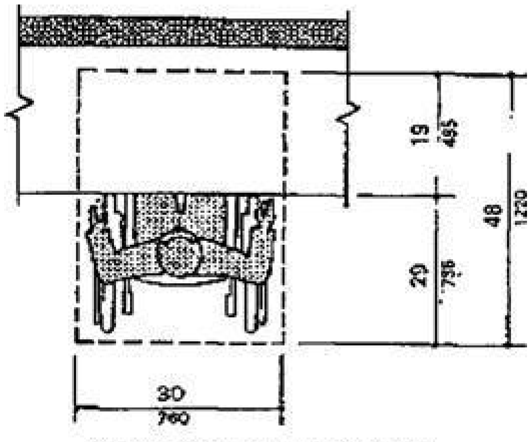


Figure 20: Clear-space underneath work surface [P GAC 120-3-20-.43, 1987, pg. 127]

Despite a minimum knee clearance of minimum 27 inches height, any countertop or table is not allowed to be higher than 34 inches above ground. However, general cabinets with a maximal depth of 24" are not required to have any specified toe or knee clearance. As illustrated in Figure 21, wheelchair users can reach every point on such a surface in maximum height of 34 inches. Additionally any electrical sockets or switches have to be mounted maximum 46 inches above ground level [P GAC 120-3-20-.43, 1987, pg. 93].

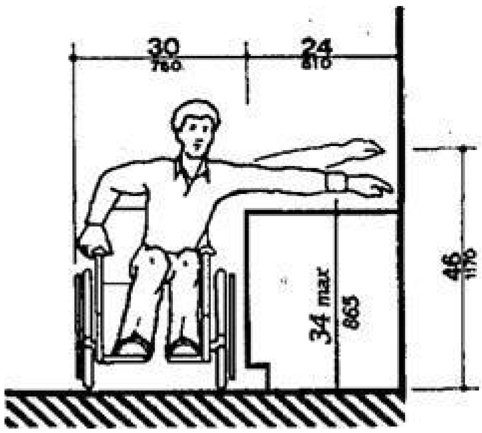


Figure 21: Maximum side reach over obstruction [P GAC 120-3-20-.43, 1987, pg. 93]

3.3 EarthCraft

EarthCraft is an energy standard for green buildings, established in 1999 and developed by a collaboration of Southface Institute Atlanta and the Grater Atlanta Home Builders Association. This green building certification program serves the South-East of the United States of America, Virginia, South and North Carolina as well as Georgia, Alabama and

Tennessee. As those states have similar building standards and climate includes high heat, humidity and temperature swings [O EarthCraft, 2014].

Figure 22: EarthCraft logo [O Earthcraft, 2014]

3.3.1 Main Objectives

EarthCraft's main objectives are, on the one hand, to reduce greenhouse gases, increase sustainability and use available resources more efficient and, on the second hand, to raise awareness of energy efficient building utilization and energy related topics. However, the EarthCraft standard focuses on the following topics [O EarthCraft, 2014]:

- Indoor air quality
- Energy efficiency
- Water efficiency
- Resource-efficient design
- Resource-efficient building materials
- Waste management
- Site planning

According to the Southface Institute, an *"a home or building is required to undergo independent third-party verification by a qualified technical advisor to confirm that it meets program requirements"* [O Southface, 2014] to achieve EarthCraft certification. Compared to LEED, which is a national and international certification, an EarthCraft certification is easier to accomplish and causes only a fraction of the cost. As there is a lack of awareness for energy efficient design, only roughly over 25,000 home have been EarthCraft certified. However, EarthCraft considers fewer aspects than LEED and is recommended for being used for smaller homes and projects. As this green standard is still similar to LEED, EarthCraft is the most used certification standard in the South-East [O Southface, 2014].

3.3.2 Assessment Criteria

EarthCraft has, like LEED and other green building certificates, point based criteria. There are several list items in different categories where points can be achieved. However, some list items are mandatory for achieving certification and do not provide points if those are fulfilled. Other list items are optional and grant a certain amount of points as a 'reward'. Those additional points have to be filled and summarized in the 'EarthCraft Worksheet'. Once the building is finished, the worksheet will be strictly controlled by and assigned EarthCraft inspector. Depending on how much points can be achieved, the building will be either certified or achieve Gold or Platinum status [O EarthCraft, 2014].

There are a total of eleven different criteria where points can be assigned. Those criteria [O Earthcraft GL, 2014] are, in order they are placed on the EarthCraft worksheet:

- Site Planning (SP),
- Construction Waste Management (CW),
- Resource Efficiency (RE),
- Durability and Moisture Management (DU),
- Indoor Air Quality (IAQ),
- High Efficiency Building Envelope (BE),
- Energy Efficient Systems (ES),
- Water Efficiency (WE),
- Education and Operation (EO) and
- Innovation (IN).

Depending on the program, the building is participating different minimum, mandatory and optional list items are set with each criterion. Thus, also the achievable and required points vary from program to program. However, the available EarthCraft programs are 'Housing', 'Multi-Family, 'Renovation', 'Community' and 'Light Commercial' [O EarthCraft, 2014].

Analyzing the 'Renovation' program, a total maximum of roughly 650 points can theoretically achieved, whereof most points can be assigned to the categories 'High Efficient

Building Envelope' and 'Energy Efficient Systems'. Nevertheless, a total of only 100 to 160 points, depending if conditioned space and/or foundation is added, is required for certifying a building. As many list items do not apply for every project, are inconsistent or not reasonable (e.g. replacing multiple furnaces, HVAC systems, heat pumps and additional cooling systems for just one building), the maximum amount of achievable points is limited to a lower value [O EarthCraft GL, 2014]. Considering newly built buildings, 180 to 220 points can be accomplished elaborately and with technical cleverness [S GMarr, 2014], while 200 points are required for platinum certification [O EarthCraft WS H, 2014]. All in all, most points can be approached by reducing the energy demand of old buildings, increase air tightness and basically by replacing the existing mechanical system. By applying those three measures a total of up 45 points can be easily achieved [O EarthCraft GL, 2014].

3.3.3 HERS Rating

For evaluating the energy demand and energy consumption of a building, the HERS (Home Energy Rating System) index has been introduced by RESNET (Residential Energy Services Network). This index is also used for LEED certifications and benchmarks the analyzed home to a 'standard home', which represents the national energy standard for standardized climate. This reference building (based on the 2006 International Energy Conservation Code) has a HERS rating of 100 [O RESNET, 2014].

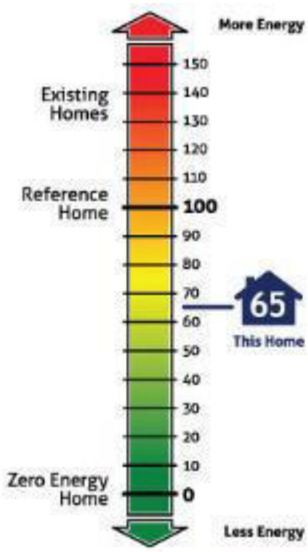


Figure 23: HERS index [O RESNET, 2014]

Figure 23 shows an exemplary HERS index for a building. The labeled numbers on the right side of the colored arrow indicate the HERS rating for the analyzed building. A HERS Rating of 150 represents existing homes, while a rating of 0 is representative for 'Zero Energy Homes'. However, the analyzed building in this case has a HERS rating of 65, which means, it only consumes 65 % of the energy, a standard, reference home consumed. Thus, it requires 35 % less energy, but this does not necessarily mean that this building is designed efficient [O RESNET, 2014].

The HERS index does consider both, thermal building shell and mechanical equipment as well as auxiliary electrical energy for fans, water heaters, kitchen appliances, washer/dryer units and lightning. Even though the HERS rating is designed for domestic homes (input of kitchen appliances, number of bedrooms do calculate internal gains) it can be also used for commercial buildings. However, as offices have different design and the number of offices can't be entered, occupation has to be guessed by entering the number of bedrooms. Moreover any additional gain caused by printers, computers and other office equipment can't be added [P REMRATE, 2008, pg. 69]. Thus, the HERS rating for any office might not be as exact as for a domestic home.

As the HERS Rating is also referring to a 'Standard Home' in a reference climate, calculated values number for heating and cooling demand might differ from what's visible in the HERS rating. Anyway, heating and cooling loads are calculated for indoor set points of 68 °F for heating purposes and 78 °F for cooling [P REMRATE, 2008, pg. 19]. There are several software's used for calculating the HERS index of a building, but the most commonly, and in further consequence used software for this project, is REM|*Rate* ™ [SW REMRATE, 2014], engineered by the Architectural Energy Corporation based in Boulder Colorado.

4 Redesigning a Historic Landmark into a Green Building

This chapter deals with the main steps which have been researched and conducted for transforming the old, 1940's duplex in Savannah Gardens into an energy efficient and green office and community space.

4.1 Methodology

For redesigning the historic landmark, following methodology has been developed to provide meaningful analysis and structural suggestions for the renovation.

- On-site visit and structural survey
    - Inspection of the existing building
    - Take measurements
    - Acquire structural details

- Modeling as-completed state of the historic landmark
    - Draw as-completed plans
    - 3D model of the historic landmark
    - Energy model of the existing building

- Implementation of required standards and anticipated layouts
    - Implementation of EarthCraft requirements
    - Implementation of historic preservation requirements
    - Implementation of accessibility requirements
    - Adapt building layout for desired usage

- Contractor meeting
    - Hand in desired layout
    - Hand in desired design configuration
    - Hand in desired and necessary EarthCraft list items

- Simulation of desired building
  - Analyze HVAC systems and technologies
  - Energy model of the proposed landmark
  - Thermal simulation of the proposed landmark

- First initial contactor quote
  - Review quote
  - Modify and improve list items
  - Identify cost saving potentials and request new, updated quote

However, it was intended to receive a second, modified quote during this project. Unfortunately the contractor quote update took too long and there was no updated proposal sent to the Housing Department by the end of August. Furthermore, it was planned to compare cost of different heat pump technologies. Nevertheless, there were also quoted missing by the end of August. Thus, a final cost analysis of the project and HVAC alternatives was not possible.

4.2 Historic Landmark: Actual State

This chapter describes the actual state of the treated building. It gives information concerning location, wall structures, zoning and condition of the exterior shell and interior equipment and structures.

4.2.1 On-Site Visit and Building Description

There have been two site visits in order to measure the building and analyze wall compositions and constructions. Additionally the quality of the existing constructions (frames and beams, wood floor, etc.) has been observed. All following photographs have been taken on those two dates and are property of the reports author's. However, Table 2 summarizes the key data of both visits.

Table 2: On-site visit

	First visit	Second Visit
Date of visit	March 13th, 2014 12:40 am – 5:50 pm	March 26th, 2014 10:45 am – 1:30 pm
Weather conditions	Sunny, 65 °F NNE wind	Sunny, 73 °F no wind
Participants	Andreas Karl, student Sonja Mitsch, student Bill Rovolis (City of Savannah)	Andreas Karl, student Bill Rovolis (City of Savannah) Martin Fretty (City of Savannah) Cara O'Rourke (City of Savannah) Doug Patten (City of Savannah) Chris Thompson and three additional members of Johnson and Laux Construction, Savannah
Main activities	Taking basic measures, analyzing wall constructions, inspecting recent energy distribution and HVAC concept	Taking detailed measures, taking missing measures, taking detailed and missing measures of constructions, presenting first basic ideas

There was an additional third on-site visit on April 15th, 2014, participating Bill Rovolis, Chris Thompson, an architect from Lott Barber and an EarthCraft technical advisor. However, due to notifications on short notice, this on-site visit could not be attended. Furthermore no major findings by the EarthCraft advisor and the architect have been submitted.

The building itself is located, as described in chapter *1.3 'Savannah Gardens'* and indicated in Figure 24, in Savannah Gardens, Savannah, Georgia at 520-522 E Crescent Drive (32.060364, -81.058413) on the East side of the planned and already partly completed green space.

Figure 24: Location of the historic landmark [O Google Maps, 2014]

Built in the 1940's and partly demolished in 2013, this building, 82'-8" in length and 24'-8" wide, is in desolate exterior and interior shape, but framing and flooring is still for the most part in good condition and eligible for being reused. Nevertheless, as the building is leaky and it rained inside, some beams have to be exchanged, as they are a partly rotten. Additionally, several indoor and entrance doors, as well as windows and furniture are unusable or have already been removed.

The photographs, displayed in the following figures, show the desolate exterior state of the building. The exterior siding is already crumbling, there are holes in the walls, windows and doors are covered with wooden boards and the back entrances have collapsed. Furthermore the asphalt shingles have gotten loose and are covered with fleece and bituminous sheets.

Figure 25: Photograph of the historic landmark, North-West elevation (March 13th, 2014)

Figure 26: Photograph of the historic landmark, North elevation (March 13th, 2014)

Figure 27: Photograph of the historic landmark, South-East Elevation (March 26th, 2014)

Figure 28: Photograph of the roofed North entrance of the historic landmark (March 13th, 2014)

Referring to previously established research for the City of Savannah, accomplished by Daniela Bachner, MSc [P Bachner, 2013], the building can be classified as a building using 'western framing' using small individual components, merged together to one construction. In further addition the historic landmark used to have simple single- and double-hung windows, which are basically used in American wood constructions. Those windows have wooden frame, mullion and muntin and use single paned glass. Describing the structure of the building, it is constructed the following way:

- **Vented, unclosed open crawl space:** hollow bricks, partly above, partly below grade, forming the foundation of the historic landmark (shown in Figure 29)

- **Framed floor and wall construction:** wooden beams, either 2” by 4” or 2” by 6” forming the building shell for the ground floor. Both, framed floor and framed wall do not use any insulation (shown in Figure 30 and Figure 31)
- **Pitched, vented attic using wood trusses:** several wood trusses in the top of the wall frames forming the vented attic and are foundation for roofing (shown in Figure 32)

Figure 29: Photograph of the existing open crawl space construction (March 13th, 2014)

Figure 30: Photograph of the existing wall construction (March 13th, 2014)

Figure 31: Photograph of the existing floor frame construction (March 26th, 2014)

Figure 32: Photograph of the existing wood trusses and roof construction (March 26th, 2014)

Technical details concerning structural composition, like detailed measures and thermal relevant characteristics are described in *chapter 4.2.2 ’Construction Principles’*.

The interior of the building is a shadow of its former self. Even the walls still look good, the interior cladding, gypsum board, contains asbestos substances and is required to be removed. The wooden floor is, close to the entrances, wavy, as it has been exposed to rain due to the leaky roof. However, the floors in the corridors and bedrooms are still in good condition and able for reuse. Historic kitchens, sinks and all other equipment, except one couch, have already been removed. Basically the building's interior rather looks like a disposal site than a place for living.

Following pictures, taken on both on-site visits, show the interior state of the building.

Figure 33: Photograph of the smokestack in the historic landmark (March 26th, 2014)

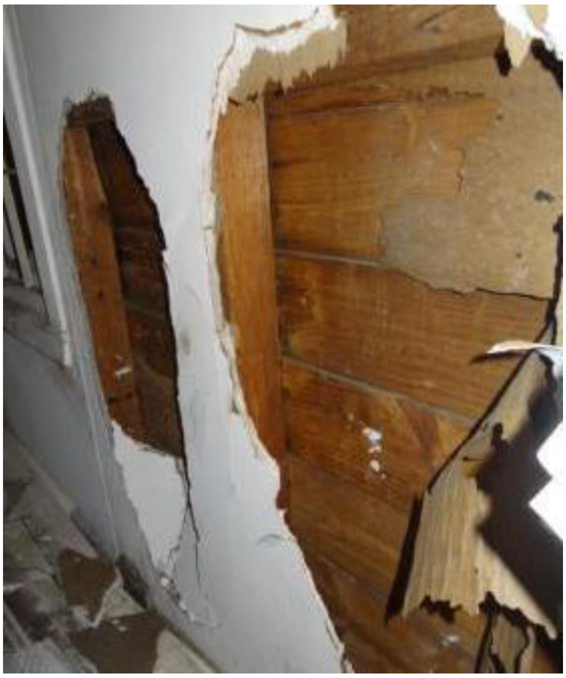


Figure 34: Photograph of the crumbling interior wall cladding in the historic landmark (March 26th, 2014)

Figure 35: Photograph of the crumbling ceiling gypsum boards and open attic in the historic landmark (March 13th, 2014)

Figure 36: Photograph of one of the remaining windows and trash covered floor (March 13th, 2014)

Unfortunately, neither literature research nor the on-site visit could solve queries concerning the historic mechanical systems. Each apartment of the duplex has its own chimney which can be connected to a fire place in the kitchen/living room area, but has not been used in years. Thus, it is assumed that at least the historic homes used those fire places for heating purposes. Additionally, some existing windows in the kitchen/living room area contained remains of window mounted air conditioners have been found. However, as indicated on the product label, those have been installed in the early 80's. Further questions regarding provision of hot water, heating in the 80's and possible cooling in the 1940's have not been clarified. Anyway, considering expert knowledge, further thermal energy most probably has been provided by low efficient electrical heating elements [S MFretty, 2014].

4.2.2 Construction Principles

All following constructions have been drawn by the author and are based on visual inspections and research for basic structures within renovation guidelines by EarthCraft [O EarthCraft GL, 2014].

R- and U-values, depicted in the figures, have been calculated confirming to ASHRAE standards. All therefore necessary equations have been taken from previously conducted research [P Bachner, 2013, pg. 20 cont.] and are not listed in this report. However, all mandatory characteristics of the used building components, like thermal conductivity (k-value or λ-value), have been taken from 'Baukonstruktionslehre 4' by Christof Riccabona [P Riccabona, 2003, Table 1] and the Austrian Standards Institute [P ONV31, 2001, pg. 12 cont.] and are listed in Table 3.

Table 3: Building material characteristics for the historic landmark [P Riccabona, 2003] [P ONV31, 2001]

Material	Conductivity k	Density ρ	Capacity c
	[W/mK]	*[kg/m^3]*	*[kJ/kgK]*
Air	0.025	1	1.008
Asphalt shingles	0.700	2100	0.950
Exterior rendering	1.000	2000	1.100
Gypsum board	0.210	900	1.05
Hard wood flooring[1]	0.200	800	2.500
Hollow concrete brick	0.490	1000	1.150
Pine wood[1]	0.200	800	2.500
Wood siding[1]	0.200	800	2.500

[1] As not every wood component is listed in the catalogue, general physical properties for hard wood are used.

Considering those properties and the heat transfer coefficient of the adjacent air layers, the R- and U-values for every component can be calculated. However, Table 4 summarizes those benchmark numbers for the historic landmark.

Table 4: R- and U-values for the historic landmark

Component	U-value		R-value	
	[W/m²K]	[Btu /h ft² °F]	[m²K/W]	[h ft² °F/Btu]
Exterior wall	3.12	0.549	0.321	1.819
Roof	3.68	0.649	0.272	1.543
Ceiling	3.84	0.676	0.260	1.478
Floor	2.48	0.438	0.403	2.289
Open crawl space AG[1]	1.67	0.294	0.599	3.401
Open crawl space BG[1]	1.79	0.315	0.559	3.172
Window	4.73	0.833	0.147	1.200

[1] AG indicates the open crawl space exposed to ambient air (above grade), while BG indicates the construction below grade, surrounded by ground.

Roof construction

The 1" thick wood board and the 1/8" think asphalt shingles, forming the roof, are directly mounted on the 24" spaced 2" by 4" timber wood trusses (pine wood). However, as the attic is vented, the roof does not form the upper thermal boundary of the historic landmark. The existing buildings thermal shell is bounded by the ceiling. Nevertheless, Figure 37 displays the described construction of the roof. The effective thickness is reduced by a ½" as 2" by 4" beams usually are 1 ½" thick and 3 ½" deep [S GMarr, 2014].

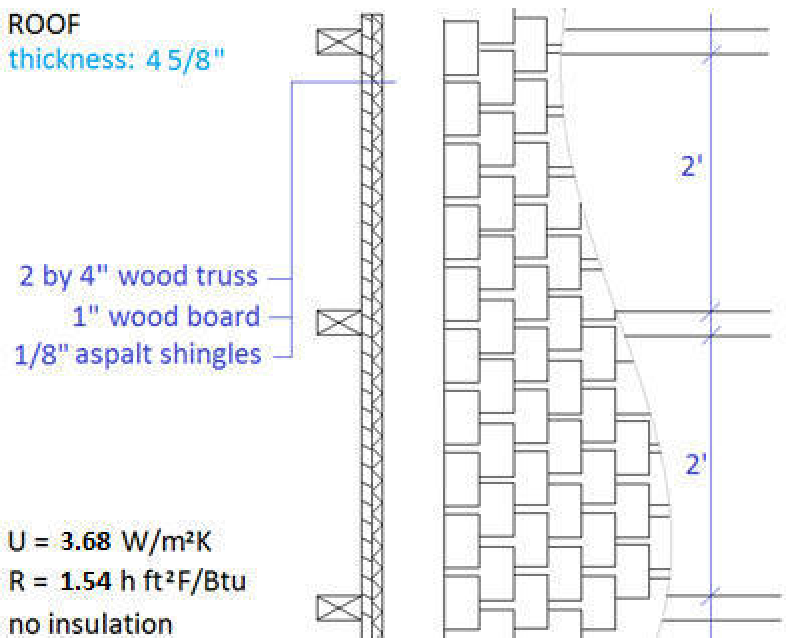


Figure 37: Roof construction of the historic landmark

Ceiling construction:

The ceiling consists of ½" thick gypsum board as cladding, whose is mounted on 1" by 4" wood stripes, which are in turn mounted on the 2" by 4" wood trusses. As mentioned before, the attic is vented. Thus, the gypsum board is forming the thermal boundary. Figure 38 depicts the described ceiling construction.

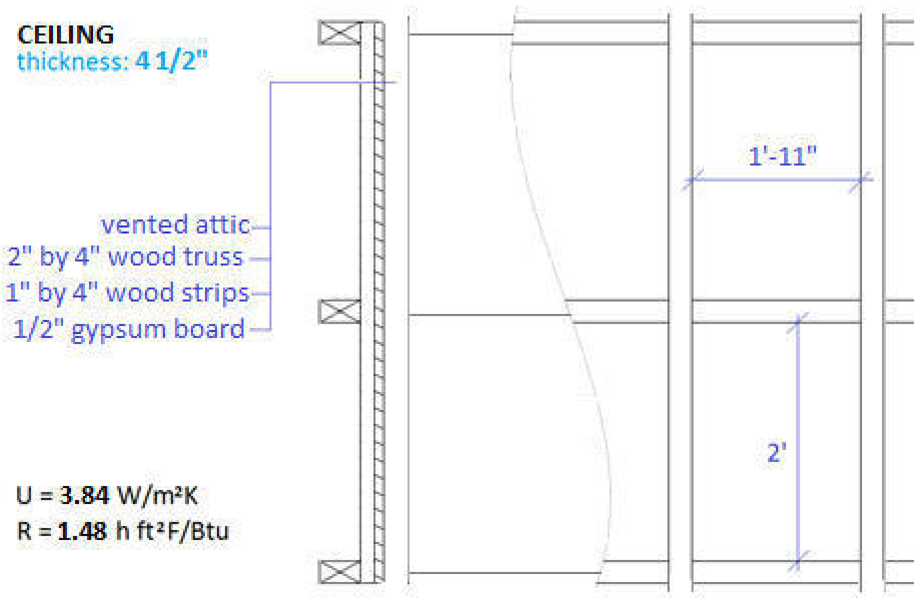


Figure 38: Ceiling construction of the historic landmark

Exterior wall construction:

The exterior wall's 2" by 4" timber frame has a 24" horizontal and 36" vertical spacing. The interior cladding, ½" thick gypsum board, contains asbestos and is directly nailed to the frame. The exterior siding, ½" thick painted wooden board, is arranged overlapping and also directly nailed to the 2" by 4" beams. This horizontally vented construction has no insulation between the wooden bars and thus, the interior cladding is the effective thermal system boundary. This construction is shown in Figure 39.

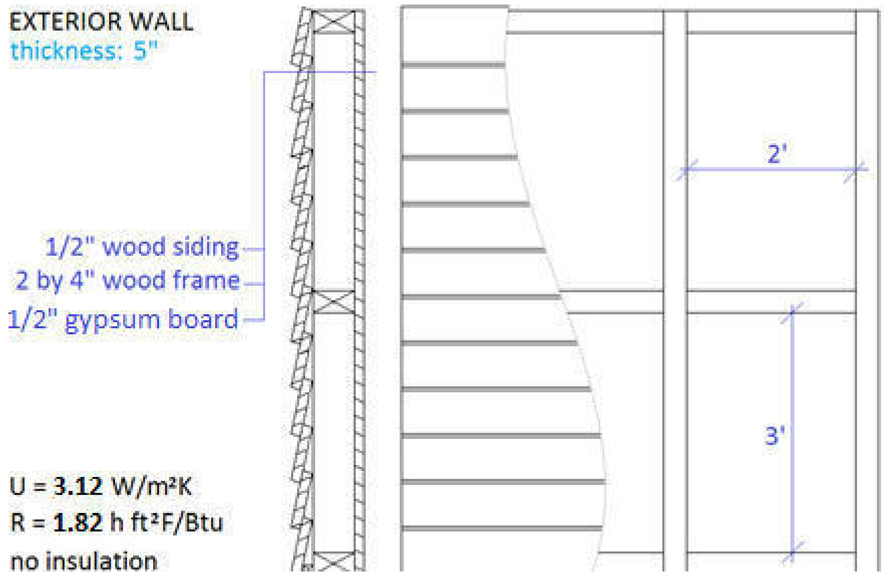


Figure 39: Exterior wall construction of the historic landmark

Open crawl space and floor construction:

The open crawl space, a total of 1’ and 5” in height, has its base located 5” below grade and consists of an 8” thick hollow concrete brick, covered with ½” of weatherproof exterior rendering. The construction is not closed and the open crawl space furthermore does not have any thermal insulation. Those openings are necessary for venting the crawl space, as there is no moisture protection. The floor construction, directly above, consists of 2” by 6” timer framing, 24” spaced, covered by ½” of hard wood floor on the inside.

Thus, the effective lower thermal boundary is only formed by the hard wood floor, which has direct contact to the vented open crawl space. The constructions for both, open crawl space and wood-frame floor construction are shown in Figure 40.

However, despite detailed on-site inspection, literature research and interviews the exact depth of the concrete foundation could not been determined. Research only led to the conclusion that there must be a rectangular shaped concrete foundation below the concrete bricks [O EarthCraft GL, 2014].

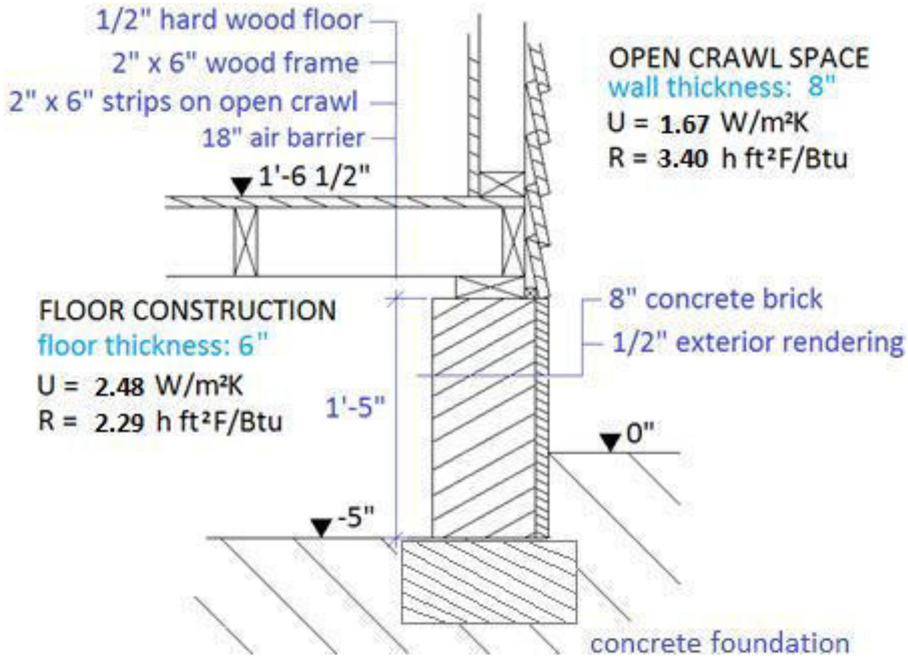


Figure 40: Floor and open crawl space construction of the historic landmark

The windows, used in the building, have all single paned glass, hard wood framing and have a total of two vertical timber mullions and two horizontal timber muntins. The U-values for this window have been taken from the REM|*Rate* library [SW REMRATE, 2014]. This 'SingWoodMaxU-0.833' window has a U-value of 0.833 Btu/h ft^2 °F (which is, using the conversion table, equal to 4.73 W/m^2K) and a SHGC (solar heat gain coefficient) of 0.800.

4.2.3 Existing Layout

The building itself basically consists of two mirrored apartments, each having four bedrooms, a small bathroom and large combined kitchen, dining and living room area. There is an additional corridor to enable access to all rooms in the middle of the building. Two of the bathrooms are on the West side and the other two and the bathroom on the East side of the building. The chimney is hidden behind interior walls in the middle of the living area.

Considering all measured dimensions, room layout and details for construction principles, which have been recorded during both on-site visits and additional construction information [P Miller, 2004, pg. 190 cont.] [O EarthCraft GL, 2014] [S BRovolis, 2014] [S MFretty, 2014], the building can be reconstructed in CAD.

All following architectural plans, layouts and views have been generated in ArchiCAD 16 [SW ArchiCAD, 2013]. Figure 41 displays the site plan of the historic landmark while Figure 42 to Figure 44 depict selected, generated 3D views. However, all additional plans – floor plans, elevations, sections and details, are attached as appendix A1.2.

Figure 41: Rendered site plan of the historic building (1" = 25')

Figure 42: ArchiCAD rendering of the North-South view for the existing building (front)

Figure 43: ArchiCAD rendering of the North-South view for the existing building (back)

Figure 44: ArchiCAD rendering of the street view for the existing building

4.3 Historic Landmark: Proposed Improvement

This chapter outlines which implementations and structural changes are necessary to improve the thermal shell and transform the historic duplex into an energy efficient office and community space.

4.3.1 Implementation of Historic Preservation Standards

Referring to *Chapter 3.1.2 'Implementation and Common Practice'*, there is basically only one restriction on redesigning a historic landmark. However, this single restriction, as any changes are prohibited to '*affect the buildings appearance or destroy the historic aspect'* limits the quantity of possible improvements.

As the remaining furniture of the building is completely destroyed or it has already been removed, the proposed interior design is designed to use as much existing walls as possible, to maintain the historic floor layout and minimize costs which would arise for new interior walls. To remain further historic character an exhibition room is planned, which should expose 1940's wall, floor and roof structures. In addition to that, a small gallery is planned which should exhibit photographs of historic Savannah Garden and represent the ship builders and their families lives during World War II. This exhibit should raise people's awareness of the neighborhoods history. Furthermore this exhibition room is also to be meant as a community room. Thus, people should come together, meet and rediscover and reestablish the harmonic social coexistence of 1940's Savannah Gardens. To meet accessibility requirements, corridor width has to be enhanced and an accessible restroom has to be added. However, as those implementations do not affect the historic character of the building, no historic sinks and toilets are remaining at this site and those changes are mandatory by law, no problems from the historical preservation side should arise.

Even the building is in desolate shape and about to fall apart, the proposed and redesigned building should lookalike a 1940's duplex. Thus, as required, nothing affecting the exterior appearance, such as window sizes and positions, eaves and entrances, exterior siding and roofing as well as the position of the chimneys is about to be changed. Thus, planned renewable energy systems, like photovoltaic or solar-thermal collectors, are allowed to be mounted on the roof. Nevertheless, a wheelchair ramp is required according to the Georgia Accessible Code. To minimize the impact on the optical appearance this ramp is planned to be behind a foot-high wall, covered by small bushes. Adding insulation in the existing exterior walls is also possible without any restrictions. As the exterior siding is damaged, the change is unavoidable. However, the existing siding is planned to be replaced by lookalike, weatherproof fiber-cement boards.

Windows are subject to be modernized and changed as well as entrance doors. To remain and keep the historic appearance of the building, single- and double-hung windows with shutters are supposed be used. Those windows will look like 1940's windows, but use double glazing and synthetic frames. Planned doors will have, like the original, a window with muntins in the upper third.

4.3.2 Implementation of EarthCraft Renovation Standards

According to EarthCraft inspectors, the building is allowed for being part of the EarthCraft renovation program, even it is going to be redesigned and furthermore used as a nonresidential building [S CORourke, 2014]. As the historic landmark is going to be a '*renovation that adds conditioned space without changing exterior shell of building'* [O EarthCraft GL, 2014], 120 points, according to the guidelines have to achieved. However, the work sheet for an 'EarthCraft Renovation' requires 75 for being certified and 125 for achieving platinum status for a square footage lower than 2500. [O EarthCraft WS, 2014] However, even those requirements differ; 120 points have been set as target. The renovation adds conditioned space, as the thermal system boundary moves from the ceiling to the inclined roof. The previously vented attic is about to be sealed and the roof insulated. Thus, the attic acts as semi-conditioned buffer between uninsulated ceiling and thermal system boundary.

Regarding the EarthCraft standards for their renovation program and the list items for the renovation work sheet [O EarthCraft WS, 2014], following points, listed in Table 5, are considered to be the most important for an upcoming renovation to achieve the required amount of points. This table does not include list items which do not accredit points, as they have to be done for every EarthCraft renovation and do not influence the final score for the certification.

Table 5: Suggested list items for EarthCraft renovation

List Item	Name	Points
CW 1.0	Waste management for wood, shingles, etc. 1)	**up to 12**
CW 1.3	Reuse of wood floor	**3**
RE 1.3	24" floor framing joist 2)	**3**
RE 1.4	24" wall spacing 2)	**3**
RE 3.0	No use of tropical wood	**4**
RE 3.4	Reclaimed wood flooring (>20 %)	**4**
DU 1.6	Close crawlspace	**3**
DU 1.9	40 year warranty siding	**1**
IAQ 2.4	Low VOC indoor paint Low VOC floor strains LOW VOC carpets	**2** **2** **2**
BE 0.3	HERS Rating Pre-renovation > 150 HERS Rating Post-renovation improvement< 50%	**10** **10**
BE 2.1	Receive < 5/4 ACH_{50} 3)	**10/15**
BE 3.8	Floor insulation > R19	**5**
BE 3.9	Wall insulation > R13 (no existing insulation)	**8**
BE 3.10	Roof insulation > R30	**8**
BE 3.15	Crawl space insulation > R5	**6**
BE 3.18	Grade II insulation quality	**1**
List Item	**Name**	**Points**
BE 4.4	Replace windows in > 90% of glazing area	**6**
BE 4.6	U-Value < 0.45 $Btu/h \cdot ft^2 \cdot °F$ and SHGC < 0.27	**2**
ES 1.12	EnergyStar AC System, SEER ≥ 16	**10**
ES 1.13	Variable speed blowers	**3**
ES 2.7	No ducts in exterior walls	**1**
ES 2.9	Ducts in conditioned space (attic)	**3**
ES 2.11	Dry and clean ductwork	**2**
ES 2.12	Air handler located in conditioned area (attic)	**4**
ES 3.1	Total leakage < 10%, outside leakage < 5%	**5**
ES 5.1	High efficiency water heater, Type A	**2**
ES 5.3	Hot water piping insulation ≥ R4	**2**
ES 6.3	EnergyStar energy saving bulbs or LED	**1**
ES 6.7	Automatic indoor lighting control Automatic outdoor lighting control	**2** **2**
WE 1.5	Kitchen sink faucet < 2.0 gpm	**3**
WE 2.6	Install rain barrel	**1**

1) Only few points in previous EarthCraft certifications in Savannah Gardens [S GMarr, 2014], thus, in first consideration, those points are neglected, but could be achieved. 2) Historic landmark has such a construction design. 3) New built homes in Savannah Gardens achieve, according to the testing sheets and a one-on-one interview with a certified EarthCraft inspector, 1.6 to 0.8 ACH_{50}. [S GMarr, 2014], thus, a desired ACH_{50} of 2 has

been set for the buildings simulations. The initial value for air tightness for the existing building has been set to 9 ACH_{50} (The renovated building has to reduce infiltration by 20% or achieve at least 7 ACH_{50}, it is assumed that the old building must have been at least weaker than 1.2 x 7 ACH_{50} = 8.4 ACH_{50}.).

As this building is built within a certain community, there are additional points granted for site planning. Additionally, as already applied for other projects and homes in Savannah Gardens [S GMarr, 2014]; tree and plant preservation is taken into account. Those list items and points are listed in Table 6.

Table 6: List items for site planning for EarthCraft renovation

List Item	Name	Points
SP 1.5	Walking distance to bus line < ¼ mile Walking distance to public green space < ¼ mile Walking distance to 4 or more mixed uses < ¼ mile	**3** **2** **4**
SP 1.6	Tree preservation and protection on site	**5**

All in all, the planned project score can be calculated summing up all credited points from Table 5 and Table 6. However, as already established projects show, not every planned points can be achieved and thus, a certain amount of the planned score is lost. Referring to EarthCraft inspector Garrison Marr, about 15 % fewer points have been credited at all homes, established in Savannah Gardens. This expected final score for this project is shown in Table 7.

Table 7: Expected final score for EarthCraft renovation

Name	Points
Credits from Table 5	134/139
+ Credits from Table 6	14
= Planned project score	**148/153**
- Uncertainty factor (15%)	22/23
= Expected final score	**126/130**

This score of minimum 126 points is high enough to fulfill EarthCraft requirements for platinum certification, referring to the work sheet, and for being certified, referring to the guidelines. As this building should be an outstanding example for an environmentally friendly renovation of an historic landmark, even a higher score should be targeted. Considering the small budget for this project, a higher project score is probably not in reach, as further implementations would cause high additional cost. Nevertheless, to achieve this goal both, good planning and realization of the proposed measures are of highest importance. The entire renovation worksheet is attached on the enclosed CD, titled *“EarthCraft_Renovation_Worksheet”*.

4.3.3 Proposed Layout

The proposed building will have some paths to and around the building with an additional bike stand in the rear, so this one does not affect the buildings appearance from the street. Additionally the heat pumps evaporator will be located on the back of the building. In further addition, this layout is supposed to have an accessible ramp on the south entrance, directly leading to the exhibition- and community room. Those features can be seen in the displayed figures above. The aforementioned exhibition- and community room also includes a small kitchen cabinet as well as a reception. Detailed information on the layout and features of the exhibition room can be found in *chapter 4.3.5* ‘Exhibition Room’.

The north entrance will directly lead to the offices conference room and break area. Heading south to the exhibition room a total of four offices and a one sales office can be accessed. Details on the office layout and configuration can be found in *chapter 4.3.4 ‘Office Configuration’*.

Several additional necessary improvements of the building shell do not affect the outer appearance, nor do they reduce or increase the buildings gross area. Insulation can be simply added to the existing frame structures to provide the mandatory R-values (wall and floor), additional constructions are necessary to ensure crawl space and roof insulation. However, those constructions do not affect the square footage of the building. Details for construction principles are explained and displayed in *chapter 4.3.6* ‘Construction *Principles’.*

Figure 45 displays the site plan of the proposed, renovated historic landmark. Additional architectural floor plans, elevations, sections and details, are attached as appendix A1.3 However, all these plans basically consider basic engineering and have to be checked by a state approved civil engineer and architect.

Figure 45: Rendered site plan of the proposed, renovated historic landmark (1" = 25')

Furthermore, Figure 46 to Figure 49 show selected 3D views of the proposed building, which are not included to the architectural plans in the appendix.

Figure 46: North-South view of the proposed building (front)

Figure 47: North-South view of the proposed building (back)

Figure 48: Street view of the proposed building

Figure 49: South-North view on proposed South entrance

4.3.4 Office Configuration

The sales office and two additional offices are proposed to be alongside the accessible route. Thus, more than 50 % of the office space could be used by wheelchair users. This is important as the team composition should not exclude wheelchair users in advance. Additionally the hallway to the conference and break room is 36” wide and hence, barrier-free and accessible. The conference room can be directly entered from the North entrance of the building and will contain of the two remaining chimneys. The break room, directly affiliated with the conference room, contains a small kitchenette for the office workers as well as a table and chairs to have lunch or coffee together. The ceiling is designed as acoustic tile to minimize noise transmission and shield staff room from the semi-conditioned attic.

Each planned office is designed to have one big window to increase the amount of daylight and to reduce the use of artificial lighting, while the lighting concept basically uses LED or fluorescent energy saving light bulbs. In further addition each office, except the sales office, is supposed be occupied by one person, executing light office work. The sales office is designed to occupy a maximum of three people for costumer advice and contract negotiations. Each office, furthermore, is proposed to have reused hard wood floor. If there is insufficient amount of reusable hard wood floor, carpet floor shall be added to the offices. However, at least conference room, corridor and sales office shall, as they are open to public, contain hard wood floor.

Following figures indicate the desired office spaces and recreation areas for office workers.

Figure 50: Rendering of the proposed sales office

Figure 51: Rendering of the proposed accessible office

Figure 52: Rendering of the proposed standard office

Figure 53: Rendering of the proposed conference room

Figure 54: Rendering of the proposed hallway (from South to North)

Figure 55: Rendering of the proposed break and recreation room

4.3.5 Exhibition Room

The exhibition and community room is proposed to be the biggest room within building. The exhibition room can be directly entered via the accessible South entrance and encompasses the reception and copy room. Sales office and accessible restroom are located next to the reception room and are open to public as well. However, this restroom has been designed according the Georgia Accessibility Code. The exhibition room is supposed to feature an exposition of the following historic constructions:

- **Indoor and outdoor wall:** A 7' long remaining of an indoor wall is proposed to be kept on its original position in the middle of the desired community room. The left side should display an historic indoor wall construction while the left side should feature some exterior cladding to represent an exterior wall. In the center of the exposed wall, Plexiglas shall expose the frame construction, which is the same for interior and exterior wall. Inspection by Johnson & Laux technicians during the second on-site visit on March, 26th 2014 outlined that the interior cladding contains a large amount of asbestos. However, even though asbestos is not banned as a substance in the United States [O EPA, 2014] the interior gypsum board, shall be replaced by new one without this toxic substance which can cause cancer. Asbestos has been used within drywall construction especially between 1950 and 1980 to strengthen the core and increase fire resistance [O AsebstosWatch, 2014]. The intense use of asbestos containing materials has been banned 1989, as § 763.163 of the Environmental Protection Agency prohibited any use of materials containing more than 1 % asbestos [O EPA, 2014, pg. 3 cont.]. However, in 1991 this ban has been overturned and thus, there are still asbestos containing products produced. Nevertheless, there are many manufacturers, producing asbestos free drywall boards [P EPA, 2014]. As the interior gypsum board will be demolished anyway, asbestos free replacement boards shall be used. Replacing the drywall for the exposed indoor wall should not be a problem, as asbestos-free and asbestos-containing materials look the same.

- **Chimney:** The existing smokestack has to sealed and closed. This applies for both chimneys as both have to be kept due to historic preservation requirements. There are no additional arrangements and preparations necessary, as the smokestacks are in very good condition.

- **Wood trusses and roof:** Right on top of the exposed wall an open attic is planned. Installing walls in exterior wall quality on the left of the right side of this exhibition area is necessary to fulfill EarthCraft requirements for the thermal shell. Additionally, as this exposed attic will retain the historic roof construction, the sight glass, which is proposed to replace the ceiling below the attic, has to have skylight quality. This glass, most certainly a double paned layer, also acts a thermal boundary to the unheated exposed attic. The original wooden trusses have to be abraded and lacquered to protect them to environmental influences. For highlighting this exhibition area several spots might be used to light the whole attic.

- **Floor construction***:* The framed flooring is not planned to be exposed, as the floor has to be insulated and insulation would be visible. However, as the historic wooden floor is about to be used, the whole floor can be seen as an exposed exhibition of 1940’s structures.

Besides the historical aspects of the exposed constructions within the exhibition room, the room shall also feature photographs of historic Savannah Gardens, as already previously described in *chapter 4.3.1 ‘Implementation of Historic Preservation Standards’.* In further addition, to design this room as well as a community room, a small kitchenette, couches, bar tables and dining furniture will be added. However, the following figures depict the desired and proposed exhibition room, accessible toilet and reception.

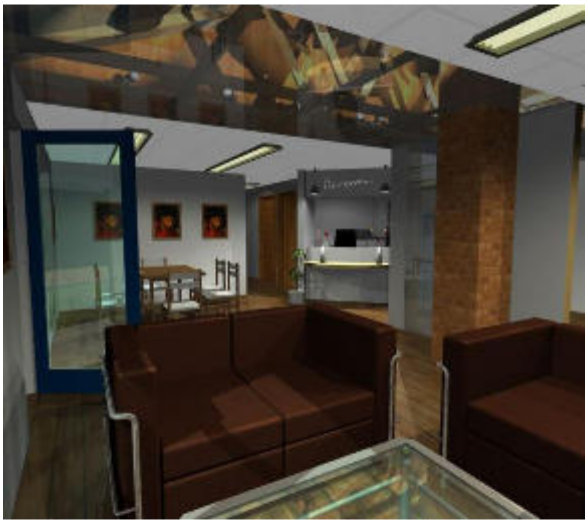


Figure 56: Rendering of the proposed exhibition room (South-North view)

Figure 57: Rendering of the proposed exhibition room (East-West view)

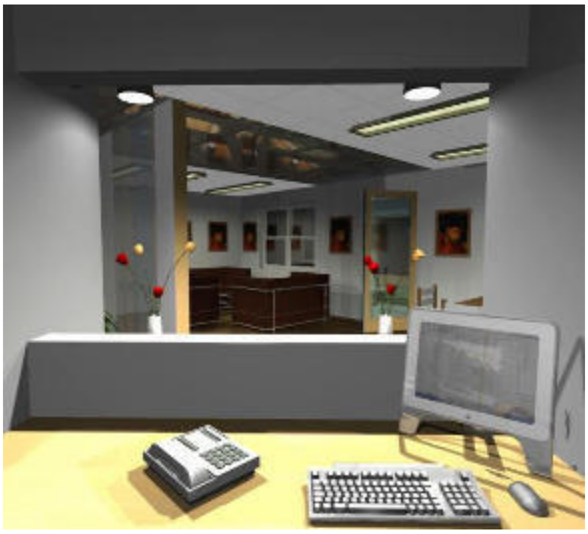


Figure 58: Rendering of the proposed exhibition room (view from reception)

Figure 59: Rendering of the proposed accessible restroom

4.3.6 Construction Principles

All following constructions have been drawn by the author and are suggestions for improving existing structures. To attain the necessary R-values for the thermal shell, existing structures can be simply modified. For insulating and improving the exterior wall, insulation, preferably mineral wool, can simply be added in-between the remaining timber frame, after removing the interior cladding. However, as already mentioned the interior gypsum board is crumbling off and contains asbestos, new, asbestos-free boards shall be installed.

As all those constructions, except the open crawl space, use non-homogenous layers, U- and R-values cannot be calculated as described and applied in *chapter 4.2.2 'Construction Principles'* for the historic landmark. Non-homogenous layers are structural elements with at least two different materials within their layer (e.g. mineral wool between wooden beams). Additional required formulas [P Riccabona, 2010, pg. 31 cont.] are displayed in Equation (4.3-1) to Equation (4.3-8).

$$f_a = \frac{a}{a + 2b}$$

Equation (4.3-1): Volumetric fraction of layer A

$$f_b = \frac{2b}{a + 2b}$$

Equation (4.3-2): Volumetric fraction of layer B

where f… fractional amount of layer in [%]

a… width of layer in between the beams in [m] or [in]

b… width of the beams in [m] or [in]

$$R_a = R_{si} + \frac{d_1}{\lambda_1} + \cdots + \frac{d_{ab}}{\lambda_a} + \cdots + \frac{d_n}{\lambda_n} + R_{se}$$

Equation (4.3-3): Thermal resistance of layer A

$$R_b = R_{si} + \frac{d_1}{\lambda_1} + \cdots + \frac{d_{ab}}{\lambda_b} + \cdots + \frac{d_n}{\lambda_n} + R_{se}$$

Equation (4.3-4) : Thermal resistance of layer B

$$R_T{}' = \frac{1}{\frac{f_a}{R_a} + \frac{f_b}{R_b}}$$

Equation (4.3-5): Fractional thermal resistance of non-homogenous constructions

where R… thermal resistance in [m^2K /W]

d… thickness of the layer in [m]

λ… thermal conductivity of the layer in [W/mK]

Rsi… thermal resistance of the inner adjacent air layer in [m^2K /W]

Rse… thermal resistance of the exterior adjacent air layer in [m^2K /W]

$$\overline{\lambda_i} = \lambda_a f_a + \lambda_b f_b$$

Equation (4.3-6): Mean thermal conductivity

for all homogenous layers: $\bar{\lambda}_i = \lambda_i$

$$\bar{R} = R_T'' = R_{si} + \sum_{i=1}^{n} \frac{d_i}{\bar{\lambda}_i} + R_{se}$$

Equation (4.3-7):
Mean thermal resistance

$$R = \frac{R_T' + R_T''}{2}$$

Equation (4.3-8):
Thermal resistance for non-homogenous constructions

All necessary thermo-physical properties for calculating the thermal behavior of the material and construction, like k- or λ-values, have again been taken from *'Baukonstruktionslehre 4'* by Christof Riccabona [P Riccabona, 2003, Table 1] and the Austrian Standards Institute [P ONV31, 2001, pg. 12 cont.] and are listed in Table 8.

Table 8: Building material characteristics for the proposed renovated landmark [P Riccabona, 2003, Table 1] [P ONV31, 2001, pg. 12 cont.]

Material	Conductivity k	Density ρ	Capacity c
	[W/mK]	*[kg/m³]*	*[kJ/kgK]*
Air	0.025	1	1.008
Asphalt shingles	0.700	2100	0.950
Bituminous sealing	0.190	1200	-
Bituminous felt	0.170	1200	-
Carpet	0.058	250	-
Cellular concrete	0.27	900	1.180
Exterior rendering	1.000	2000	1.100
Glazed tiles	1.300	2300	0.840
Gypsum board	0.210	900	1.050
Hard wood flooring[1]	0.200	800	2.500
Hollow concrete brick	0.490	1000	1.150
Mineral wool	0.036	60	1.030
OSB	0.120	640	1.70
Pine wood[1]	0.200	800	2.500
Polystyrene extruded (XPS) Polystyrene expanded (EPS)	0.031 0.035	35 30	1.450 1.450
Spray foam	0.050	70	1.500
Wood siding[1]	0.200	800	2.500

[1] As not every wood component is listed in the catalogue, general physical properties for hard wood are used.

Considering those properties and the heat transfer coefficient of the adjacent air layers, the R- and U-values for every component can be calculated. However, Table 4 summarizes those benchmark numbers for the historic landmark according to previously described equations.

Table 9: Calculated R- and U-values for the proposed renovated landmark

Component	U-value		R-value	
	[W/m^2K]	[$Btu/h\ ft^2\ °F$]	[m^2K/W]	[$h\ ft^2\ °F/Btu$]
Exterior wall	0.400	0.070	2.500	14.286
Roof (EPS) [1]	0.167	0.029	5.988	34.483
Roof (spray foam)	0.165	0.029	6.061	34.412
Floor (wood floor) [2]	0.248	0.044	4.032	22.727
Floor (carpet)	0.237	0.042	4.219	23.809
Floor (tiles)	0.254	0.045	3.937	22.222
Open crawl space AG[3]	0.700	0.123	1.429	8.130
Open crawl space BG[3]	0.720	0.127	1.388	7.874
Window	2.498	0.440	0.400	2.270
Skylight	4.259	0.750	0.235	1.333

[1] Using EPS as insulation is the desired construction. [2] Most of the surface are will be covered by hard wood floor, thus, this construction is used in further calculations. [3] AG indicates the open crawl space exposed to ambient air (above grade) while BG indicates the construction below grade, surrounded by ground.

Table 10 additionally compares the proposed and calculated R-values (US units) to the required values according to the '*EarthCraft Renovation*' [O EarthCraft WS, 2014] program, the requirements of the State of Georgia, referring to the International Energy Code [P IECC, 2012, Table C402.1.2] and ASHRAE guidelines [P ASHRAE 90.1-2010, 2012, pg. 26 cont.] and the R-values of the existing historic landmark. However, it has to be mentioned that there are no special requirements for renovating buildings in the State of Georgia. All values are basically valid for new homes, thus, it is assumed that EarthCraft requirements fulfill state requirements for renovations.

Table 10: R-values of the building in comparison to requirements

Component		R-Value			
		[$h\ ft^2\ °F/Btu$]			
		Georgia Code[1]	EarthCraft[2]	Existing[3]	Renovation[3]
Exterior wall		13	13	1.819	14.286
Roof	conditioned	38	30	1.543	34.483
Roof	Semi-heated	13	-	-	-
Open Crawl Space AG		0.877	5	3.401	8.130
Floor		19	19	2.289	22.727
Window		1.333	2	1.200	2.270
Skylight		0.735	1.333	-	1.333

[1] Requirements for newly built homes according to the Building Code [P IECC, 2012, Table C402.1.2]. [2] according to the ASHRAE guidelines [P ASHRAE 90.1-2010, 2012, pg. 26 cont.] [3] R values apply for assembled structures.

Nevertheless, an analysis concerning sustainability and environmental friendliness of the different proposed insulation materials has to be carried out.

Exterior wall construction:

On the exterior side of the wall, ½" of oriented strand board (OSB) shall be mounted on the wooden frame. In further addition, ½" x 2" strips have to be added directly above the vertical frame studs. The exterior siding, ½" fiber cement, has also been used for other, newly built housing units in Savannah Gardens [S GMarr, 2014] and exactly looks like wooden siding. This assembly of material creates a vented façade and thus, vapor can be easily removed by an upward air stream. As this construction only adds one inch of thickness to the exterior side and hence, doesn't affect the usable gross area of the building. Additionally a vapor barrier can be added behind the interior cladding. However, this barrier is not necessarily required but still reduces vapor transmission from outside to inside. This proposed wall structure, which is suggested in the EarthCraft renovation guidelines [O EarthCraft GL, 2014], fulfils both, EarthCraft and historic preservation standards, and is furthermore displayed in Figure 60.

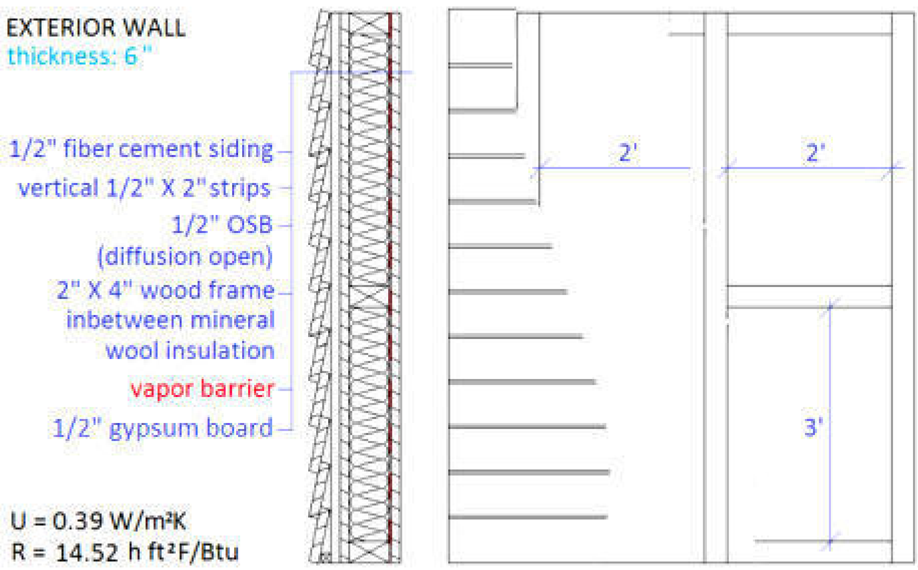


Figure 60: Proposed exterior wall construction for the renovated landmark

Windows are proposed neither to be the changed in position nor in size. Thus, no special or new constructions for added windows are required. However, all windows have to be replaced. EarthCraft requires windows having a U-value lower than 0.50 Btu/h ft^2 F (2.839 W/m^2 K) for climate zone 2 and a maximum solar heat gain coefficient of 0.30 (represents roughly a g-value of 0.3) [O EarthCraft WS, 2014]. As it is planned to implement better windows to achieve a better EarthCraft score, U-values lower than 0.45 Btu/h ft^2 F (2.555 W/m^2 K) and SHGC lower than 0.27 shall be used. Nevertheless, further considerations, calculations and simulations use windows with a U-value of 0.40 Btu/h ft^2 F (2.271 W/m^2 K) and a solar heat gain coefficient of 0.27.

Open crawl space and framed floor construction:

For insulating the floor, insulation, preferably mineral wool, can simply be added to the existing timber floor construction. However, the construction has to be sealing from crawl space side by mounting additional gypsum or wood board on the frame. The crawl space itself has to be sealed, and thus any vapor barrier/bituminous sealing has to be added. Additionally, 1” of expanded polystyrene (XPS) has to be mounted on the existing crawl space construction to provide sufficient thermal resistance. Holes within the hollow concrete bricks can be closed using light cellular concrete or cement. Both proposed improvement do not affect the landmarks gross area, as they only add additional material to the exterior side of the construction or are not part of the thermal boundary. Furthermore those suggestions are part of EarthCraft’s high performance building envelope recommendations [O EarthCraft, 2014]. This construction is depicted in Figure 61.

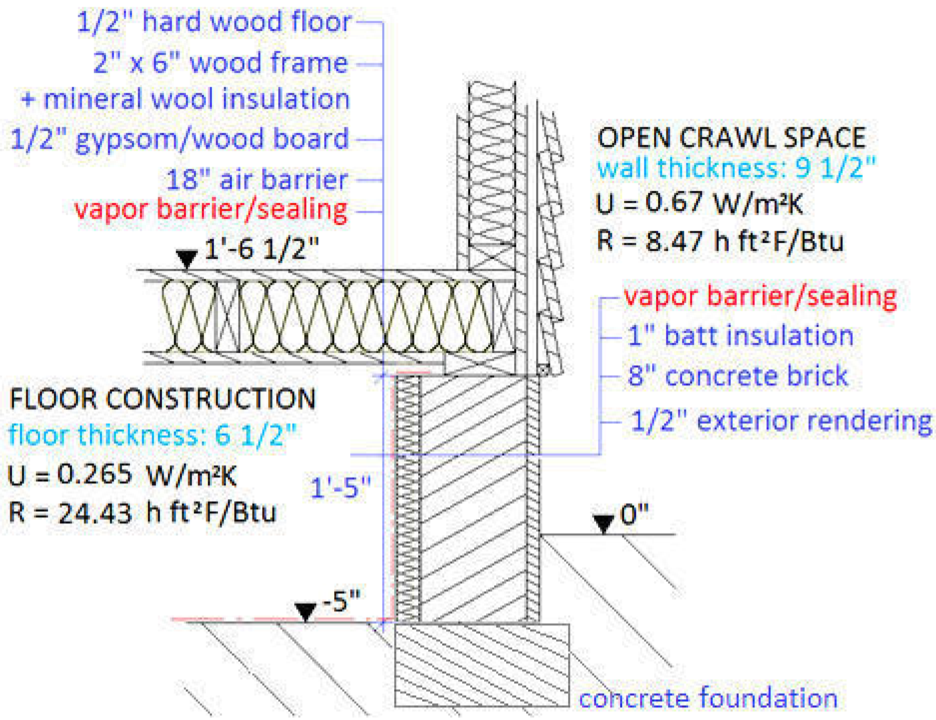


Figure 61: Proposed floor and open crawl space construction for the renovated landmark

Ceiling/Roof construction:

As the thermal boundary is moving from the ceiling to the roof, no insulation or special treatment of the ceiling is required. As the roof has not been insulated before and EarthCraft requirements for pitched roofs are strict [O EarthCraft WS, 2014], roof renovation requires additional constructions. However, as the roof has been directly mounted on the wood trusses, a first insulation layer, preferably 3 ½" of mineral wool, can be simply added in between those trusses. The inner side of the timber beams has to be closed, using oriented strand board or similar.

To fulfill EarthCraft requirements [O EarthCraft WS, 2014] an additional timber frame construction would be necessary if mineral wool would be used. In further addition, to avoid condensate within the roof construction, inside sealing is necessary. As the load-bearing roof trusses and wall frames shall all be reused, and further adding of mass should be avoided. Thus, it is suggested to either use a 5" layer of extruded polystyrene (EPS) and a sealing or heavy spray foam in an R-value equivalent thickness (7"). Nevertheless, the attic knee wall, again to avoid additional wood constructions, shall be insulated using spray foam, as this is most practicable and uncomplicated. As the heavy spray foam (closed cell) is labeled as Class II Vapor Diffusion Retarder and is hence a barrier of bituminous quality and seals vapor very good [O EnergyGov, 2014], no additional sealing is required However, neither spray foam nor EPS insulation boards are environmentally friendly. As this building is intended to be a green building, even insulation materials should be renewable and sustainable. Thus, an environmental analysis, comparing EPS, spray foam and mineral wool (attached as mineral wool insulation batt, which can be glued or easily fixed on surfaces) has to be carried out.

For creating the 1940's look either reclaimed or new, lookalike asphalt shingles can be used for covering the wooden board. Figure 62 shows the planned and proposed insulation of the roof in detail.

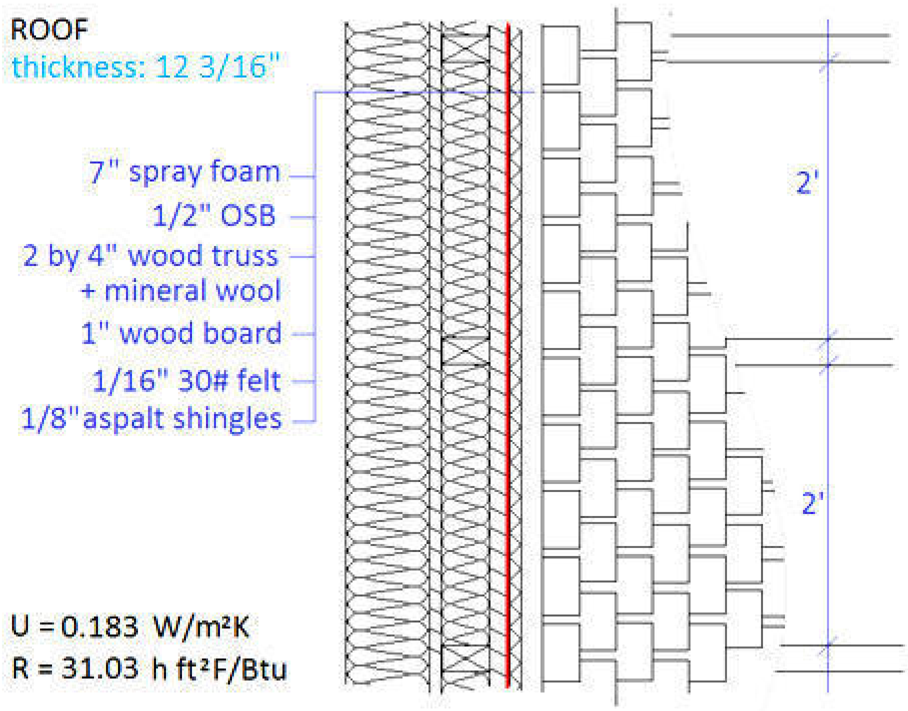


Figure 62: Proposed roof construction for the renovated landmark

Since the sight glass to the exposed attic area marks a window within the upper thermal boundary it is defined as skylight. However, skylights are required to have a U value of minimum 0.75 Btu/h ft² F (4.259 W/m² K) and a SHGC of maximum 0.3. As the skylight is not exposed to sunlight, the SHGC might be increased, if allowed by EarthCraft inspectors. This measure would not affect the thermal properties of the building component but would significantly reduce cost.

4.3.7 Mechanical and Thermal System

For energy efficient energy distribution and to reduce the input of primary energy several mechanical and thermal systems have to be considered. As Savannah has very large quantity of sun hours, it is desired, using the sun as primary energy source to provide thermal and electrical energy. However, due to restrictions concerning historic preservation, neither solar thermal collector nor photovoltaic panels are allowed to be installed. Anyway, photovoltaic panels could be installed on other, nearby buildings to generate local, green electricity. Additionally a local heat supply system could be established. This heat, generated solar thermal, could be used for heating purposes in winter, hot water preparation in winter and summer, as well as for thermal cooling applications using absorption refrigeration systems. However, as those systems require huge encroachments in the existing infrastructure and would overrun the targeted budget they are no longer taken into consideration.

To avoid usage of gas, oil or other depleting resources, either air or ground source heat pumps are suggested. Those could use local generated electrical energy which is free of CO_2 emissions and nuclear energy. For achieving best energy efficiency at reasonable investment cost, a ground source heat pump has been chosen. As most air source heat pumps require additional gas furnace systems, air source heat pumps have been neglected in further consideration. However, such ground-loop systems may have higher investment cost, but reduced operation cost, as they work more efficient as air source heat pumps. For designing the required mechanical system, offices and community space have to be designated certain activities, accomplished by the office workers, to set mandatory air change rates and to define the interior loads.

Each office worker is basically supposed doing light office work like typing. This activity level results in a metabolic factor MET of 1.1 with an internal gain of 20 Btu/h ft^2 [P ASHRAE 55-2010, 2010, Table 5.2.1.2]. Each office worker is anticipated using one desktop computer with LCD screen and desk lamp. Some offices are additionally equipped with a small multifunctional printer. Each office employee is furthermore supposed to wear light office clothes. Those clothes might be trousers and a long sleeve shirt (clothing factor clo = 0.61) or a knee-long skirt, long sleeve shirt (clo = 0.67) [P ASHRAE 55-2010, 2010, Table B1 5.2.2.2A].

Additionally, Table 6.1 of the ASHRAE standards requires at least 5 cfm per person and office or 0.06 cfm/sqft [P ASHRAE 62.1-2010, 2013, Table 6.1]. As the smallest designed office has a gross area of 88 sqft (8.2 m^2) and a volume of 682 cft (19.31 m^3) the required air change, according to those regulations, would yield in an air change rate of 0.440 1/h (for 5 cfm per person) + 0.464 1/h (for 0.06 cfm/sqft) [P ASHRAE 62.1-2010, 2013, Table 6-1, pg. 14] and thus 0.904 1/h. Three of the five designed offices exceed this surface area and thus, an air change rate of 2 1/h has been set, to secure sufficient amount of fresh air in each office. Even the sales office might accommodate three people at once; this air change rate is acceptable as only 1.277 ACH are required.

The kitchen area in the break room is required, according to Table 6-1 of the ASHRAE standards 62.1, to have an exhaust rate of at least 0.30 cfm/sqft [P ASHRAE 62.1-2010, 2013, Table 6-4, pg. 17]. As the kitchenette covers only 34 sqft, a total of 10.2 cfm is necessary. Referring to the volume of 263 cfm, an air change rate of at least 2.32 1/h is mandatory. Thus, the air change rate has been set to 5 1/h to secure a sufficient air change rate.

The conference room is designed to host a maximum of six persons, executing light work. The required ventilation rate for conference and meeting rooms is the same as for offices – 5 cfm per person. Thus, a minimum ventilation rate of 30 cfm is required [P 62.1-2010, 2013, Table 6-1, pg. 14], as long as the conference is occupied. As the room is directly connected to the break room, which won't host any office workers during meetings, and the corridor, the effective air volume for this room is about 3680 cft. However, as during a conference a maximum of 100 sqft might be used and occupied. Thus, 30 cfm (for 6 persons á 5 cfm) and additional 6 cfm (for 0,06 cfm/sqft) are required. This results in an air change rate of 0.579 1/h, based on the total volume of 3680 cft. Again, as wells as for the offices, an air change rate of 2 1/h has been set.

The break room, classified as a dining room, required a minimum ventilation rate of 7.5 cfm per person [P ASHRAE 62.1-2010, 2013, Table 6-1, pg. 14] and is designed to accommodate every office worker. Thus, a maximum of six people us the break room at the same time and a maximum ventilation of 45 cfm is necessary. The break room covers a total of 139 sqft, another 25 cfm (0,18 cfm per square foot [P ASHRAE 62.1-2010, 2013, Table 6-1, pg. 14]). As this room covers the same air volume as the conference room, the minimum necessary air change rate for this room is 1.142 1/h. However, this room's air supply duct, to reduce cost, is planned to be the same as for the conference room. Thus, the same air change rate as for the conference room – 2 1/h – has been set.

The exhibition room is open to public and might only be used for parties and family celebrations as well, which can be held Friday night, Saturday or Sunday. Those parties are suggested having a maximum of 20 people (due to limited place) and thus, affect the heating and cooling load of this room. During office time, this room is supposed to be visited by no more than 5 persons at the same time. However, the minimum ventilation change for maximum occupancy for this exhibition room, which is in further consideration declared as a 'museum' or 'gallery', is required to be at least 7.5 cfm per person and additional 0.06 cfm per sqft [P ASHRAE 62.1-2010, 2013, Table 6-1, pg. 14]. Thus, a total of an air change rate of 2.169 1/h (190.68 cfm) is necessary to fulfill fresh air requirements for parties and community activities while only 0.891 1/h are necessary during the exhibition hours. To provide enough air, air change rates of 2 1/h, respectively 5 1/h, for events, have been set.

Table 11 and Table 12 summarize the total required amount of fresh air per room and the maximum loads for the total building at different operation modes (office and evening schedule).

Table 11: Maximum air change rates for 'office schedule'

Room		SALES	COMM	BREAK	CORR	OFFICES	CONF	REST A	REST B	SUM
A useful	*[sqft]*	143	681	139	165	436	205	32	79	**1769**
V useful	*[cft]*	1108	5278	1077	1279	3379	1589	248	612	**13710**
A useful	*[m2]*	13	63	13	15	41	19	3	7	**164**
V useful	*[m3]*	31	149	31	36	96	45	7	17	**388**
ACH	*[1/h]*	2	2	5	2	2	2	5	5	**2.24**
Vdot	*[cfm]*	37	176	90	43	113	53	21	51	**583**
Vdot	*[m3/h]*	63	299	153	72	191	90	35	87	**868**

Table 12: Maximum air change rates for 'evening schedule'

Room		SALES	COMM	BREAK	CORR	OFFICES	CONF	REST A	REST B	SUM
A useful	*[sqft]*	143	681	139	165	436	205	32	79	**1769**
V useful	*[cft]*	1108	5278	1077	1279	3379	1589	248	612	**13710**
A useful	*[m^2]*	13	63	13	15	41	19	3	7	**164**
V useful	*[m^3]*	31	149	31	36	96	45	7	17	**388**
ACH	*[1/h]*	0	5	0	2	0	0	0	5	**2.11**
Vdot	*[cfm]*	0	440	0	43	0	0	0	51	**533**
Vdot	*[m^3/h]*	0	747	0	72	0	0	0	87	**820**

Considering previously mentioned thermal boundary structures, defined internal gains and necessary air change rates, in Table 13 listed components have been selected for the HVAC system.

Table 13: Proposed HVAC system components

	Manufacturer	Type
Heat Pump	FHP	FHP EP036 1HZ/VT [O FHP HP, 2014]
Evaporator Coil	Goodman	CHPF 3743D6 B [O Goodman EC, 2014]
Air-Handler	Goodman	ASPT 36C14 [O Goodman AH, 2014]

According to the AHRI, the Air-Conditioning, Heating and Refrigeration Institute, certificate No. 3920301 [P AHRI 3920301, 2014, pg. 1] this product is allowed to operate in EarthCraft certified buildings. Table 14 lists relevant key data for thermal and energy efficient considerations.

Table 14: Key data for ground source heat pump [P AHRI 3920301, 2014, pg. 1]

	US Units	*SI Units*
SEER (for cooling)	19.7	4.69
HSPF (COP for heating)	14.0	4.1
Cooling Capacity[1]	37,500 BTU/h	10.97 kW
Heating Capacity[1]	26,000 BTU/h	7.62 kW

Having those high efficiencies for this system and depicted capacities, sufficient thermal energy for the desired building, if indoor temperatures are set to 68 °F in winter and 78 °F for the cooling season, can be provided. Those temperatures indicate the upper and lower boarder of the thermal comfort zone [P ASHRAE Handbook, 2009, pg. 9.19].

In further addition, the air handler uses multiple speed levels and is able to supply the office and community space with a total of up to 1470 cfm (6 ACH) [O Goodman AH, 2014]. Moreover, for estimating the built-in fan's power consumption and input power, fan characteristics are necessary, as there are no numbers given by the manufacturer. This data is integrated as a table in the products datasheet [O Goodman AH, 2014] and displayed in Figure 63 for potential speed levels, using Microsoft Excel.

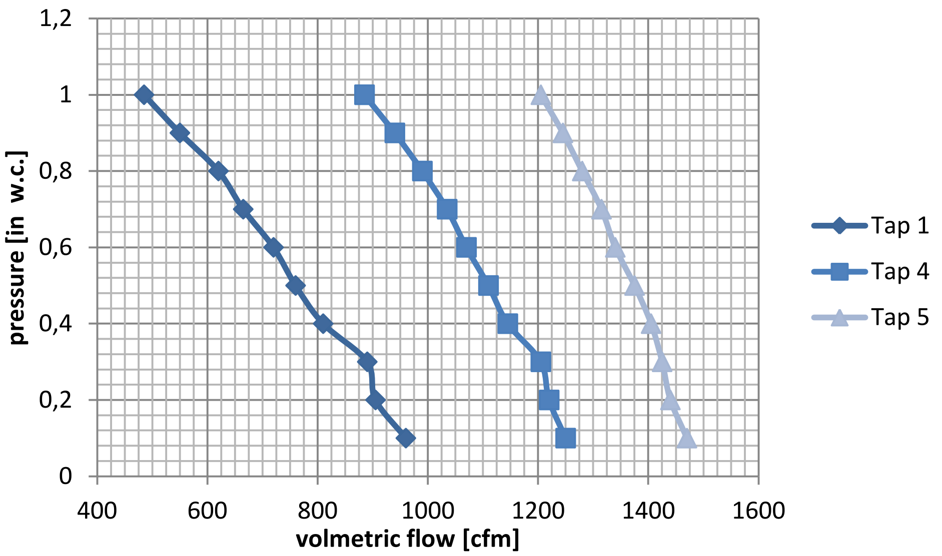


Figure 63: Air handler fan characteristics for potential speed levels, based on [O Goodman AH, 2014]

As there is furthermore no fan efficiency given in any datasheet, an average fan efficiency of 65 % has been assumed, as according to ASHRAE Fundamentals efficiencies vary between 50% and 70% [P ASHRAE Handbook, 2009, pg. 18.33]. For calculating the required fan input power, Equation (4.3-9) and Equation (4.3-10) [P ASHRAE Handbook, 2009, pg. 18.33] are required.

$$P_A = 0.000157\, Vp$$

Equation (4.3-9): Air power

$$P_F = \frac{P_A}{\eta_F}$$

Equation (4.3-10): Fan power

where P_A... air power in [hp]

P_F... electrical input power in [hp]

V... volumetric flow in [cfm]

Δp... increase in pressure by the fan in [inch of water]

η_F... fan efficiency in [%]

Considering this efficiency and mentioned equation, in Figure 64 indicated power – fan speed characteristics can be derived.

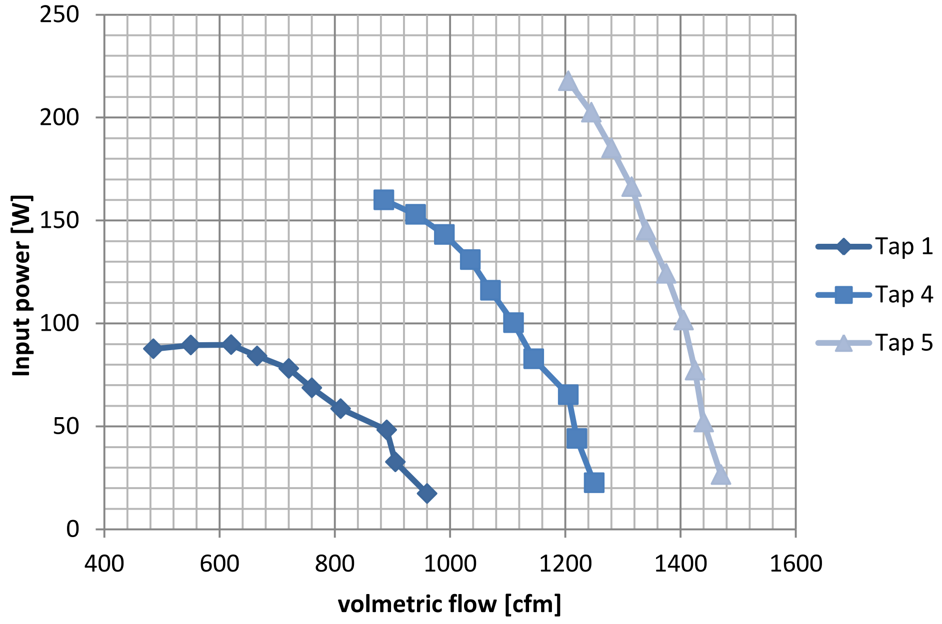


Figure 64: Air handler fan input power - speed characteristics, based on [O Goodman AH, 2014]

In addition, Equation (4.3-11) and Equation (4.3-12) [P Bachner, 2012, pg. 56 cont.] can be used to determine electricity consumption and resulting electricity costs.

$$W = P\,t$$

Equation (4.3-11): Energy consumption

$$C = W\,c$$

Equation (4.3-12): Energy costs

where W… electrical energy in [Wh]

t… operation time in [hrs]

C… absolute costs in [$]

c… specific costs in [$/kWh]

4.3.8 Cooling Strategy

Besides active cooling, passive cooling is an integral component of this buildings cooling strategy. Following features are supposed to be implemented in the renovated and restored historic landmark;

i. Internal shading devices

Internal shading devices, horizontal or vertical window blinds, are about to be planned to implemented for each window. Even outdoor blinds would be more efficient, they are prohibited to be installed by historic preservation requirements, as they would significantly affect the outer appearance of the building. Those internal blinds are supposed to be 50% closed in summer, to reduce solar irradiation and still guarantee sufficient daylight. However, no automatic control is planned for this application, to minimize space requirements within the walls and reduce installation cost.

ii. External shading devices

As mentioned before, external shading devices, like blinds, are not allowed to be installed. Nevertheless, for the same reason as those are not allowed, external window shutters have to be installed. As windows are not allowed to be changed in size, position and look, lookalike models have to be used. Detailed research showed all previous homes along Crescent Drive, shown in Figure 65, had some shutters installed on the East and West side of the buildings. However, it is supposed that those external shutters, which have to be operated manually, are more used for decoration than for operation purposes. Thus, in further consideration and with reference to the cooling strategy, exterior shading takes a secondary role.

Figure 65: Historic duplex in Savannah Gardens with visible installed, bluish window shutters in the background [O SavannahNow, 2011]

iii. Daylight control

For reducing internal gains and for greater overall energy efficiency, a daylight control is planned to be integrated. As internal shading devices are manually controlled, a control mechanism for every office is mandatory. Switching on light, only when necessary, can significantly reduce electricity demand for lighting purposes and reduces furthermore internal, thermal gains.

iv. Night ventilation

The main passive cooling concept for this building is proposed night ventilation and basically a cooling concept, using outside air for adjusting the indoor temperature, whenever possible. This concept enables cooling the building during night hours down to a minimum level of 68 °F, which is according to ASHRAE [P ASHRAE Handbook, 2009, pg. 9.19] the lowest allowed indoor temperature for thermal comfort. Thus, cooling demand can be significantly reduced in the morning hours. In further addition it is possible to cool peak loads in winter (high mid-day sun elevation, high irradiation and high internal gains) with cool outdoor air, without switching on air conditioning.

For implementing this passive cooling strategy, outside air shall be blown into the desired rooms with 5 ACH. As there is an air change of 5 1/h set for several rooms, duct sizes don't have to be adjusted and no further installation cost are required. The required volumetric flow, listed in Table 15, can be either, according to Figure 63 handled on the fourth or fifth speed level, whereof the fifth is considered of being realistic, as a high volumetric flow causes greater pressure drops.

Table 15: Air change rates for night ventilation

ROOMS		SALES	COMM	BREAK	CORR	OFFICES	CONF	REST A	REST B	SUM
A useful	*[sqft]*	143	681	139	165	436	205	32	79	**1769**
V useful	*[cft]*	1108	5278	1077	1279	3379	1589	248	612	**13710**
A useful	*[m2]*	13	63	13	15	41	19	3	7	**164**
V useful	*[m3]*	31	149	31	36	96	45	7	17	**388**
ACH	*[1/h]*	5	5	5	5	5	5	5	5	**5.00**
Vdot	*[cfm]*	92	440	90	107	282	132	21	51	**1214**
Vdot	*[m3/h]*	157	747	153	181	478	225	35	87	**1941**

However, to remain sufficient temperature difference between the incoming airstream and the building, outdoor temperature has to be at least two degree below indoor temperature. In further addition, outdoor humidity has to be considered. As cool temperatures especially in the summer months always have higher humidity as a side effect [O NREL, 2014], additional dehumidification might be necessary, or night ventilation shall only be performed for an outdoor humidity lower than 65 %. 65 % relative humidity has been set as an allowed maximum to provide ASHRAE conforming indoor air quality [P ASHRAE 62.1-2010, 2011, pg. 40].
In further addition, a well-established controlling mechanism and temperature and humidity sensors would be necessary to implement this kind of night ventilation. However, those are necessary anyway (except the humidity sensor) to guarantee energy and resource efficient fresh air supply. Thus, there are no effective further installation costs, but a great potential for energy savings and cooling load reduction.

4.3.9 Energy Modeling and Thermal Simulation

Considering all previously mentioned improvements, strategies and designed equipment, different energy models can be generated. However, two models have been designed for comparison issues and different analyses. For calculating United States specific and required values, REM|*Rate* [SW REMRATE, 2014] has been used to calculate the HERS rating as well as heating and cooling loads. As REM|*Rate* and the HERS index in general are designed for domestic homes rather than for commercial and mixed use buildings and internal gains cannot be defined exactly, an addition simulation has been carried out. Thus, 3D models have been generated in Google SketchUp [SW SketchUp, 2010] and simulated in TRNSYS 16 [SW TRNSYS, 2012]. Nevertheless, due to restrictions in the trial versions, several simplifications had to be adopted. Table 16 lists restrictions by the program, how they affect the simulation and which simplifications were necessary to avoid errors.

Table 16: TRNSYS trial restrictions and resulting simplifications

Restriction	Impact on simulation	Simplification
Only two thermal zones can be modeled.	The building's rooms have different occupation at different times. In further addition there are rooms with east facing windows, rooms with west facing windows and both. Furthermore the attic as semi-conditioned space has different characteristic and thermal behavior. Thus, every room and the attic area should be simulated as thermal zones and a total of 12 zones would be necessary	Every office has been simulated separately with its own unconditioned attic above, as displayed in Figure 66 and Figure 67 below. Benefit of this simulation is that different size, irradiation, internal gains and occupation can be simulated but, however, inter-dependencies with other, adjacent offices are neglected.
A maximum of five components within the simulation process	Building-file, TMY-data, and two necessary plotters, to display results of the different units, already are four of maximum five components. For a detailed, well established and accurate control mechanism for lighting, heating and air conditioning several further components would be essential.	The cooling strategies had to implement in a simple way without any closed control loop. As there is no control loop, the system tends to be instable and thus, values had to be calculated on an hourly basis.
A maximum of three windows per thermal zone	The big rooms, especially the community room, have multiple windows in each wall.	All windows on one side have been gathered together and simulated as one big window. Those changes do not affect the results of the simulation, as the thermal zones have only been separate rooms.

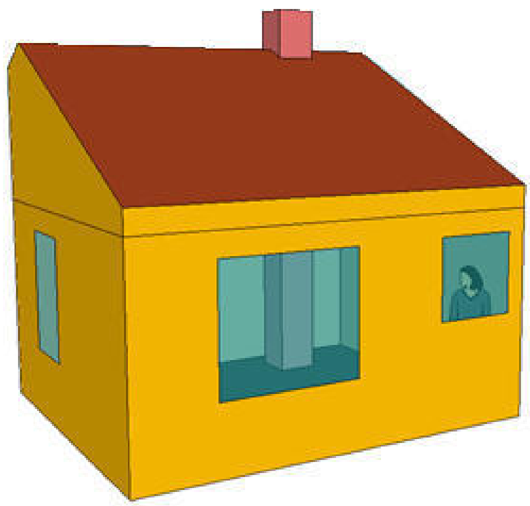


Figure 66: SketchUp model of the conference room for TRNSYS (two thermal zones)

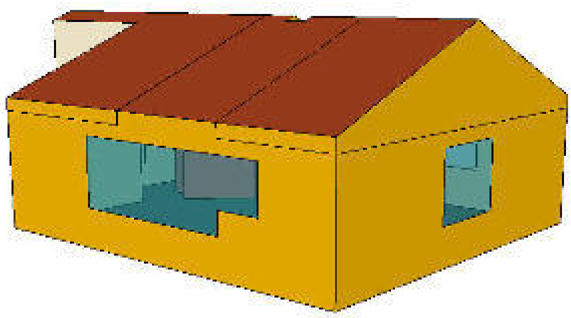


Figure 67: SketchUp model of the community area and reception for TRNSYS

Besides simulating heating load, cooling load and indoor temperatures, the TRNSYS model has furthermore been used to calculate a comfort level, PPD (predicted percentage of dissatisfaction), each room without and including passive cooling strategies. This simulation should outline, if the night ventilation concept also affects the occupants wellbeing in a negative or positive way.

Input parameters for the HERS rating and simulation in REM|*Rate* (renovated building and historic landmark) are attached on the enclosed CD, titled *'B1.1_InputParameter_REMRate _for_proposed_building'* and *'B1.2_InputParameter_REMRate_for_as-built_building'*. A third simulation simply matches different, observed adjusted temperature levels (75 °F for heating and 69 °F for cooling) while a fourth one simply matches temperatures to the TRNSYS model (71 °F for heating and 79 °F for cooling) and adds a 'whole house ventilation' fan. Input parameters for an exemplary room, the sales office, for the TRNSYS simulation (every room has the same boundary conditions and input parameters) are attached on the CD, titled *'TRNSYS_ SimulationStudio_InputFile_Sales_Office'* and *'TRNSYS_TRNBuild_Input File_Sales_Office'* as those files contain up to 30 pages.

4.4 Cost Analysis

For calculating a yearly benefit of the implementation of passive cooling and, especially, night ventilation, electricity costs have to be analyzed. However, according to City of Savannahs previous monthly electricity bills since 2008 [P Saxon, 2014, sheet 1 and 2] have been taken into account. Figure 68 displays derived specific energy costs and energy cost development over the past six years which are listed in tabular form in the City of Savannahs recordings [P Saxon, 2014, sheet 1 and 2].

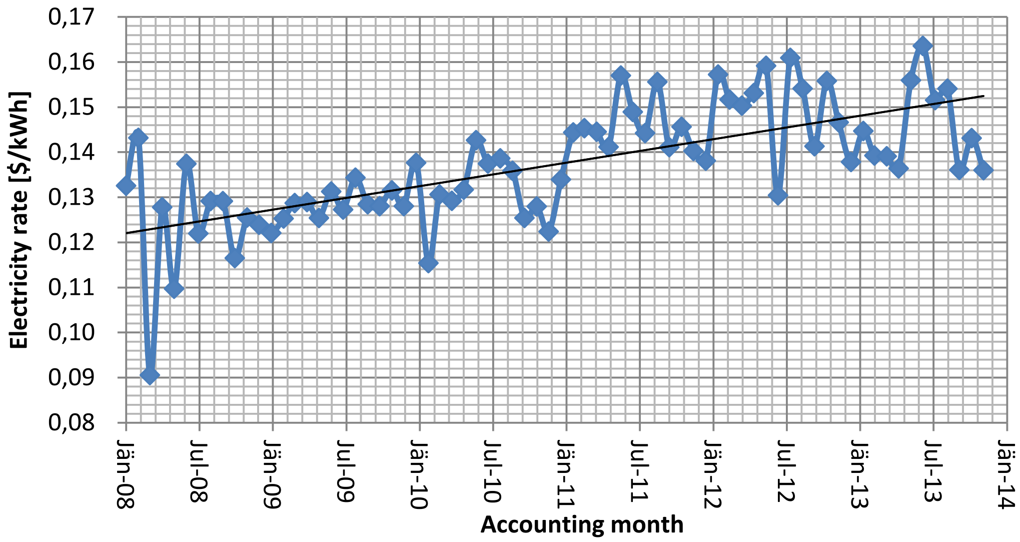


Figure 68: Electricity rate development for Savannah's municipal buildings since 2008 [P Saxon, 2014, sheet 1 and 2]

As it can be seen from Figure 68, electricity rates have significantly increased over the last couple of years. Having a price of $ 0.1242 per kWh in 2008, cost increased to an average of $ 0.1452 per kWh in 2013. Considering the rise in electricity rates of 16.9 % with the last six years, costs are still likely to increase in the next couple of years, which represents an annual growth in electricity rate of 2.64 %. Nevertheless, according to the *"Average Retail Price of Electricity to Ultimate Customers"*, published by the U.S. Energy Information Administration [P EIA, 2013, Table 2.4], the average increase in electricity rate for the commercial sector over from 2012 to 2002 has been 2.49 %. This 10 year period has been taken into account as it considers developments over longer a longer time frame.

For more detailed cost analysis and for calculating a payback period, a net present value (NPV) method has been used. Applying investment cost as given, the inflation rate as adequate target rate and mentioned electricity rate and hence, saving as expected cash flow, net present values after each year can be calculated applying following equations, derived from Schneider et al. [P Schneider et al., 2006, 152 cont.]:

$$NPV(0) = -I + \sum_{t=0}^{n} \frac{CF(t)}{(1+i)^t}$$

Equation (4.4-1): Net Present Value

where NPV(0)… Net Present Value at time zero in [$]

I… investment cost in [$]

CF(t)… expected cash flow due to savings [$]

i… adequate target rate [%]

t… time in [a]

The increase in cash flow due to increasing electricity rates can be determined by:

$$CF(t) = E * c(0) * (1 + i)^t$$

Equation (4.4-2): Cash flow for increasing electricity rate

where E… saved energy in [kWh]

c(0)… electricity at time zero in [$/kWh]

i… increase in electricity rate in [%]

The annual GDP deflector has been acquired from World Bank statistics for the United States [O WorldBank GDPd, 2014] for the last 20 years of recording. However, a longer timeframe than 10 years has been taken into account to compensate the effects of the financial crisis and thus, increased inflation. The development of the GPD deflector from 1992 to 2012, derived from the World Banks data source, is shown in Figure 69.

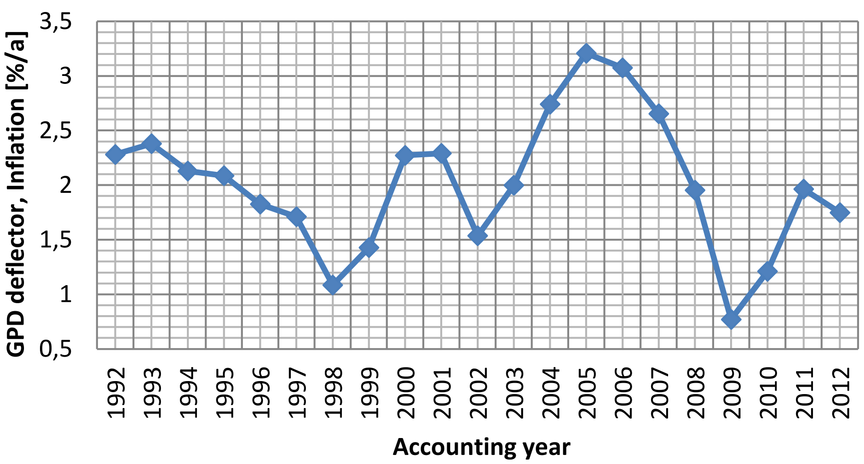


Figure 69: Inflation rate development of the United States [O WorldBank GDPd, 2014]

Considering the mean average value of the past two decades, an average inflation rate of 2.02 % has been present in the United States. In further addition, an average rate of $ 0.1375 per kWh has been used for calculating annual savings, as there are strong fluctuations within the price and $ 0.1452 per kWh with an annual increase of 2.49 % for calculating net present value calculations and payback period.

4.5 Environmental Analysis of Building Materials

For analyzing different building components, an environmental analysis has been carried out. Therefore, input of primary energy and global warming potential in kg CO_2 equivalent per square meter as well as sulfur dioxide emissions are compared. Therefore online software, baubook eco2tech [SW baubook, 2014] has been used to evaluate these environmental factors for both, proposed and quoted wall structures by reconstructing the thermal building shell for a 100 year cycle.

5 Results and Discussion

This chapter displays delivered results by simulation and investigation during research.

5.1 Final Quote and Implemented Improvements

The first proposal by Laux and Johnson, submitted with a 6 week delay, is of a total value of **$ 562,101.97**. [P JohnsonLaux, 2014, pg. 2] and its cover sheet and cost breakdown are attached as appendix F1.1 while the full proposal is only included on the enclosed CD, titled *'Savannah Gardens Duplex Renovation Project Work Order Package 5-19-14'.*

This leads to investment costs of $ 274.46 per square foot ($ 2954.21 per m^2). Newly built homes in Savannah Gardens had investment costs of roughly $ 100.00 per square foot [S MFretty, 2014]. Those additionally had high quality geothermal heat pumps, which cause additional cost, high impact windows and recycled materials [S BRovolis, 2014]. Without those, investment cost would amount a total of circa $ 80.00 per square foot [S MFretty, 2014]. Thus, costs would be 3.5 times higher than for a newly built, energy efficient home.

However, analyzing this quote, which about $ 300,000 to $ 350,000 above the city's budget, it can be outlined that site work and landscaping (three clearing items á $ 36,990.32, $ 87,544.06 $ and $ 8,770.00) and architecture and engineering (AE) (one clearing item á $ 96,862.87) are responsible for a total of $ 230,167.25, which represents a total of 41 % of the total proposal value. These costs for AE and landscaping should be dramatically reduced, as much proposed work is either not necessary or way to expensive and available for lower cost (e.g. AE for about $ 25,000.00 [S LChacon, 2104]).

Costs for energy improving measures to meet EarthCraft requirements are in contrast not outstanding. Thermal Insulation and moisture protection represent $ 52,748.91 and all opening, including door and windows debit the city's budget with a total of $ 52,822.96. However, lastly mentioned costs do also already include required historic preservation measures and list items for thermal and moisture protection do not significantly differ from code requirements. Thus, there are almost no additional costs for thermal insulation. The only outstanding and more expensive list items are the windows. Home Depot, for example, lists comparable windows in size and thermal properties for $ 149.00 (excl. taxes) [O HomeDepot, 2014], while used windows in the proposal cost $ 557.50 (excluding 8%

taxes but including labor). Even the Home Depot windows are PVC and no wood windows, there is a saving potential in costs. For other thermal relevant components, like insulation material, Johnson & Laux already list low cost materials like spray foam.

The HVAC system, including air source heat pump, air handler and ductwork, are responsible for $ 38,353.95 of the total project value. However, the air handler, chosen by the contractor, is worth $ 4770.00 (excl. 8 % taxes) while the desired and proposed ventilation unit would only be $ 792.99 [O AlpineHomeAir, 2014]. Thus, further costs could be easily reduced by using other products. Additionally the projected air handler is able to deliver 2000 cfm, which represents an air change rate of 8.23, while a maximum 2.24 ACH would be necessary without the passive cooling strategy.

Installation of the SEER 19.7 ground source heat pump would cause additional costs, as the installation is linked to more effort. Nevertheless, the projected SEER 16 heat pump has a 5 ton (60 kBtu/h) capacity, while, as simulation showed, 3 tons (36 kBtu/h) would be required. Thus, this heat pump is 66 % oversized and costs and operation could most probably furthermore optimized. However, according to EarthCraft [O EarthCraft WS, 2014] and ASHRAE [P ASHRAE Handbook, 2009, pg 39.1 ff] thermal load calculations using *"Manual J"* are necessary or desired for designing HVAC equipment. This calculation model is not uncontroversial as energy experts often criticize the approaches "Manual J" certified software, as those tend to oversize equipment [S BBrainerd, 2014]. Thus, a Manual J simulation has been carried out in further consequence to compare thermal loads and thermal demands for both, proposed and quoted building. Therefore, Energy Gauge [SW EnergyGauge, 2014], an energy and economic analysis software, has been used to compare results. Heating equipment is not specified within the proposal, but points are credited for having a HSPF, using this heat pump, greater than 8.2. Thus, it is assumed, as other components exactly meet specified criteria, the designed air source heat pump is able to work at a heating season performance factor of 8.2.

Furthermore this Quote has been accomplished, using the EarthCraft *"Light Commercial"* and not the "*Renovation"* program. Thus, another amount of points and other key-list items are lost. However, the main difference is that several efficiency requirements do not apply and, the renovation process itself, for example reducing HERS rating, improving HVAC efficiency and air tightness, is of lower priority und thus, fewer points are credited. This program only rewards 5 points for reusing the hard wood floors, but more than 40 points for existing home improvements are 'lost'. For implementing further improvements and to achieve necessary points, high cost points have been chosen, while low cost and simply achievable points have been neglected. In addition the submitted worksheet for the *"Light Commercial"* program is incorrect, as for some proposed categories and list items not the full amount of points, and only parts, have been planned. However, points are either achieved or not. There, full or no points are credited, as there are no part approaches.

Considering the constructions, following structures have been chosen to accomplish thermal and moisture protection:

- **Floor:** A 4" R21 closed cell spray foam insulation in-between the wooden slats of the floor construction as well as a polyethylene vapor barrier below to provide air sealing in the open crawl space are planned to be installed. The hard wood floor is planned to be reused in the lobby and community space area whereof everywhere else, except the rest rooms, new wood floors are planned.

- **Crawl space**: The crawl space is subject to be closed. However, no insulation is planned to be attached to the construction.

- **Roof:** Insulation shall be provided by a 3" R16 open cell spray foam in-between the rafters and trusses. The trusses are about to be covered by hard wood boards and finished with a 45# felt and architectural asphalt shingles. Additionally drywall is planned being installed to shield cover the rafters.

- **Exterior walls:** 3" of R12 open cell spray foam in-between the frame construction shall provide required insulation. Moisture resistant drywall shall form the interior cladding, while exterior siding is about to be replaced by lookalike fiber cement lap siding.

Furthermore double-hung metal clad wood windows by Jeld-Wen with low emission glass are used. These windows have a U-value of 0.35 Btu/h ft^2 °F (1.987 W/m^2K) and a SHGC of 0.24 [P Jeld-Wen, 2013, pg. 2] including exterior and interior grills with spacers. Those windows additional have outside "Tapco Hurricane Shields", which also operate as sun screens and are mounted like shutters. Moreover the windows have a transparent security and safety glazing film on the outside.

Using previously used values for thermal conductivity from Table 8 and Equation (4.3-1) to Equation (4.3-8), in Table 17 listed U-values can be achieved, using these constructions.

Table 17: U-values for the proposed and quoted landmark

Component	U-Values	
	[Btu/h ft² °F]	
	Johnson & Laux	**Proposed Layout**
Exterior wall	0.079	0.070
Roof	0.067	0.029
Crawl space	0.290	0.123
Floor	0.051	0.044
Window[1]	0.350	0.440

[1] Windows in the submitted quote have SHGCs of 0.24, while proposed windows only match requirements and have a solar heat gain coefficient of 0.27.

It is shown that quoted constructions, in exception of the windows, use constructions with lower U-values that proposed. However, U-values for exterior walls and the floor are still comparable and the crawl space, as surface area is small and outside of the thermal boundary, does not considerably affect the thermal behavior. However, the roof encompasses almost 45 % of the total exterior surface and, as the thermal resistance has been reduced by 57 %, projected construction by Johnson & Laux will significantly affect thermal losses. However, in turn U-value and SHGC for windows have been improved.

Despite those modifications in constructions and HVAC design, the proposed layout adopted. Nevertheless the quote has one further weakness – restrooms use handicapped lavatories, which, according to the Georgia Accessibility Code, should be avoided.

To compare the thermal behavior and HERS rating of this designed building to the proposed, this building has also been simulated for 71 °F and 79 °F set temperatures. Further input parameters have been set as required by the EarthCraft *"Light Commercial"* program, unless not otherwise specified in their self-elaborated worksheet. For easier comparison between this set of plans to the proposed ones, energy consumption of any equipment, lighting and fan schedules have not been changed.

5.2 HERS Index and Energy Consumption

The HERS index of the historic building, listed in **Fehler! Ungültiger Eigenverweis auf Textmarke.**, referred to the US standard climate and ASHRAE set temperatures, can be significantly decreased by adding required insulation and making the building air tight (target: 2 ACH_{50}) (row 'Renovated Landmark' and 'Renovated Landmark – Contractor). However, integration of passive cooling systems doesn't further affect the HERS rating but reduces total energy consumption for cooling and heating, with reference to the 71/79 °F simulation of the renovated building, by 9 %.

Table 18: Results for HERS ratings and loads of conducted REM/*Rate* simulations

	Temperatures	Passive cooling	HERS rating	Cooling demand[1]	Heating demand[1]	Thermal demand[1]
	[°F]		*[-]*	*[mmBtu/a]*	*[mmBtu/a]*	*[mmBtu/a]*
Historic Landmark	68/78	no	254	56.60	57.40	114.00
Renovated Landmark	68/78	no	61	8.50	2.30	10.80
	71/79	no	61	6.70	3.30	10.00
	71/79	yes	61	5.80	3.30	9.10
	75/70	no	61	9.50	4.70	14.20
	75/70	yes	61	9.00	4.70	13.70
Renovated Landmark – Contractor	71/79	no	72	9.20	7.00	16.20
	71/79	yes	72	7.70	7.00	14.70

[1] Demands represent electrical requirements and no thermal demands.

A reduction from 254 to 61 does furthermore match the desired EarthCraft points, as, on the one hand, the pre-renovation HERS rating was greater than 150 and, on the second hand, HERS rating has been reduced by more than 50 % due to the renovation process. Moreover, renovating the building like proposed would save 39 % in comparison to a newly built, requirement fulfilling, domestic home. Nevertheless, it has to be considered that this building is not a domestic but commercial building. Thus, HERS ratings and energy simulation software's like REM/*Rate* lead to different thermal demands as another program, designed for commercial buildings, do. As internal gains cannot be modeled within REM/*Rate* and those gains are defined by entering the number of bedrooms, results are inaccurate. Additionally electrical lighting is calculated in REM/*Rate* but no number of light bulbs or similar can be entered.

Observation during the stay in the United States furthermore showed that thermostat defaults have set-point for heating of 76 °F during the heating season and 69 °F during the cooling period. Thus, an additional simulation with REM/*Rate* has been carried out, to analyze how such thermostat default values affect the total energy demand of the proposed building and if a good established control loop or set-points close to the ASHRAE standards can reduce thermal loads. However, due to restrictions in REM|*Rate*, which doesn't allow such extreme set-temperatures, set-temperatures of 75/70 °F have been set. All in all a minimum of 4.20 mmBtu of additional thermal energy is required to keep the building at those conditions. Even tough 14.20 mmBtu/a for the total thermal energy demand would still mean an enormous reduction in comparison to the historic landmark, they also mean an increase of at least 42 % in thermal energy demand for the optimized versions.

Nevertheless, this simulation and building operation mode leads to the same HERS rating. This outlines that the HERS rating does not, like several other benchmarked and standardized key values, give any information about energy efficiency within a build, as the efficiency always depends on how this building is used. Thus, it is necessary to have automatically adjusted thermostats and to instruct the building users how to use this building.

Comparing the desired results to the quote provided by the contractor, the contractors design has similar structures from a thermal point of view – only the roof insulation has been dramatically reduced. Floor structures and windows a slightly weaker than proposed but, nevertheless, the HERS rating increased from 61 to 72. However, this increase is not primarily caused by changes in thermal insulation. The main problem is caused by replacing the geothermal/ground source heat pump based system by an air source heat pumps and thus, reducing SEER and HSPF. This simple modification almost doubles the buildings energy consumption concerning thermal energy.

Furthermore the heating and cooling equipment seems to be oversized. As mentioned in the previous chapter, design load calculations have to fulfil accomplished compliant to "Manual J". However, results for the design loads calculations, in comparison to Rem|*Rate,* are listed in Table 19.

Table 19: Comparison of design loads and demands

Design	Program	Cooling demand[1]	Heating demand[1]	Thermal demand[1]	Design load
		[mmBtu/a]	[mmBtu/a]	[mmBtu/a]	[kBtu/hr]
Proposed	Rem|*Rate*	6.7	3.3	10.0	28.5
	Energy Gauge	10.8	9.5	20.3	48.8
Quoted	Rem|*Rate*	9.2	7.0	16.2	35.8
	Energy Gauge	15.6	14.4	30.0	49.2

[1] Demands represent electrical requirements and not thermal.

As already evidenced, REM|Rate's results for thermal demands are relatively exactly and match those of professional energy analysis tools. Nevertheless, Energy Gauge and thus, "Manual J" conforming calculations doubles the energy demand and in further consequence lead to increased design load. For both, the proposed and the quoted building design, a 3 ton heat pump would be sufficient. However, for the quoted design a 36 kBtu/hr system could be too small, as eventually greater temperature differences on the design day could not be managed.

According to "Manual J" for both design approaches not even a 4 ton heating and cooling system would be adequate, as the design load exceeds 48 kBtu/hr. Hence, a 4.5 ton, if available, or a 5 ton system, as proposed by the contractor, would be necessary to provide ASHRAE thermal comfort conditions. Result sheets for these "Manual J" calculations in Energy Gauge are attaches as appendix D1.1 and D1.2.

This outlines that "Manual J" confirming calculations do oversize the thermal system. However, equipment has to be sized within a certain margin of these simulations, otherwise it would not be approved by technical advisors. This means in effect that even when more detailed and exact simulation in other programs would be carried out, as it applies in this case, the thermal system has be designed according to "Manual J". Thus, a huge energy and cost saving potential is given, as all designed HVAC system are oversized.

Overall, energy consumption concerning thermal energy increases by 52% (not considering a passive cooling strategy), when implementing quoted constructions and thermal system. Nevertheless, this building would still consume more energy for thermal purposes if a ground source heat pump would be used, as the reduction in insulation in the sloped roof has a greater impact than the improvement of other components. This shows that efficient provision of thermal energy can have a very big impact on the buildings overall thermal behavior and the HERS rating and thus, is of as high importance as a high performance building envelope.

HERS index cover sheets for the historic landmark, the renovation with and without passive cooling and night ventilation, as well as for the design by Johnson & Laux are attached as appendix C1.1 to C1.4.

5.3 Detailed Thermal Simulation

The detailed thermal simulation in TRNSYS showed that cooling is necessary, as temperatures above 26 °C (79 °F) cannot be avoided over longer periods. Thus, there is no thermal comfort given, as a maximum temperature of 79 °F is allowed by regulations [P ASHRAE 55-2010, 2010]. Indoor temperature development on an hourly basis for the sales office is depicted in Figure 70.

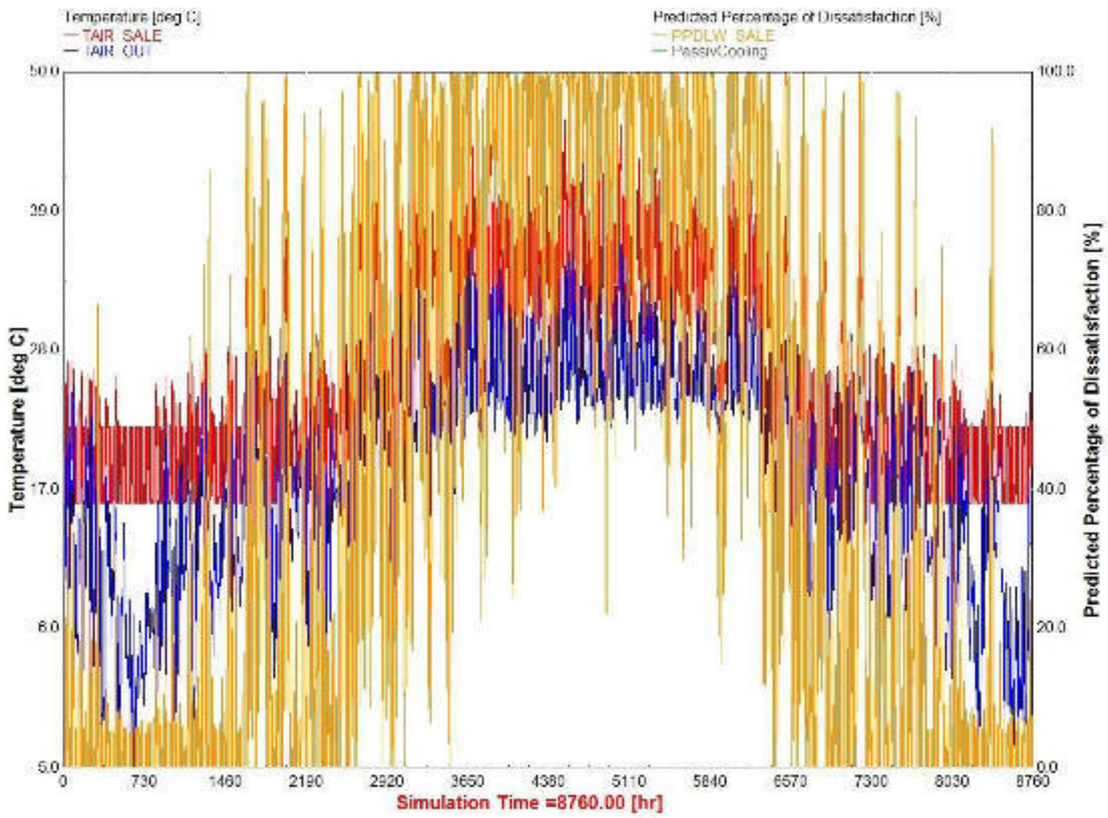


Figure 70: Indoor and outdoor temperatures and PPD for sales office without cooling

It can be seen that due to internal gains and incident solar radiation, indoor temperature increases to temperatures greater 40 °C (104 °F) in the worst case. Those temperatures cannot be reduced by outdoor air ventilation, as outdoor air also exceeds 35 °C (95 °F) and the office cannot be cooled to an appropriate thermal comfort level. Considering the predicted percentage of dissatisfaction, there is not a single person left, which feels comfortable with temperatures this high. However, this analysis outlines that active cooling absolutely required in this case.

However, this is a counterpart of well insulated and tight homes. As a simulation of this office before the renovation showed, indoor temperatures significantly increase as there is lower air infiltration and transmission through walls. This also influences energy requirements during winter, but, as there are fewer heating than cooling days, air tightness and insulation have more impact on cooling. Figure 71 depicts the correlation between in- and outdoor temperature for the same office for historic constructions and outlines how those temperatures align.

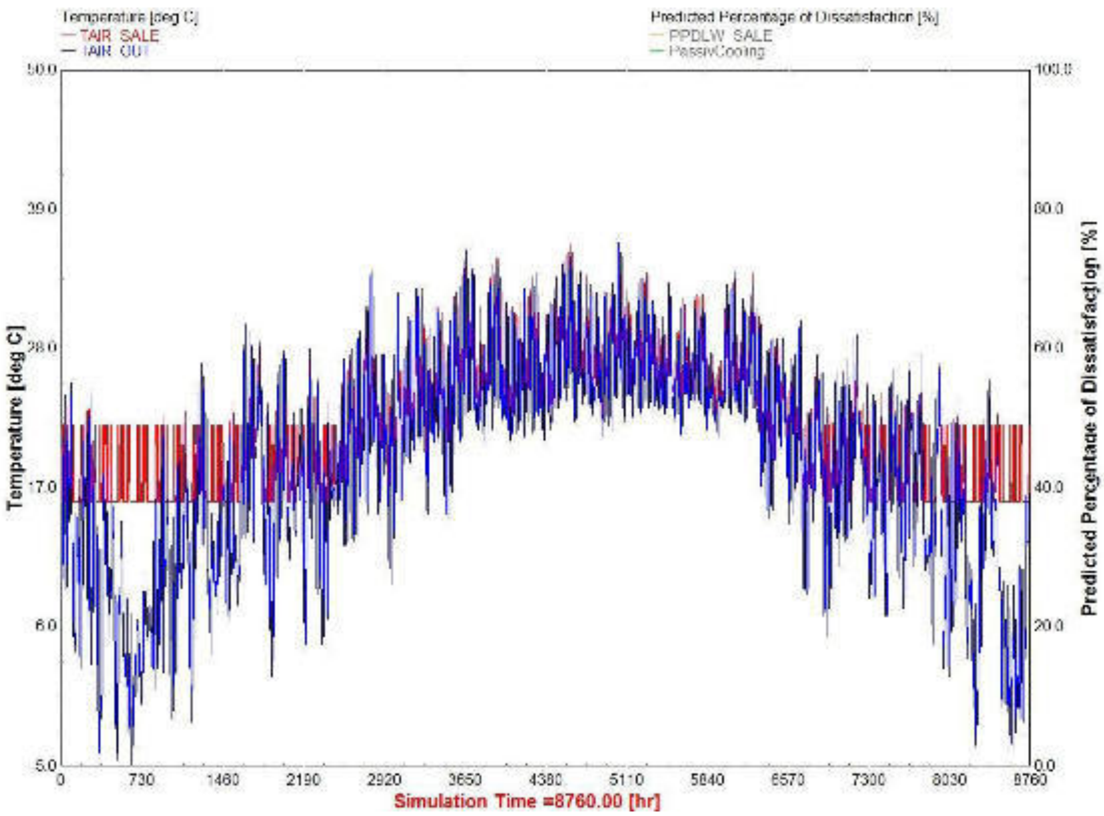


Figure 71: Indoor and outdoor temperatures for sales office without cooling and historic constructions

As the thermal behavior of a building is very sensitive, a detailed thermal analysis, using the thermal simulation software TRNSYS, has been carried out and key results, in comparison to the results in REM|*Rate* are shown in Table 20.

Table 20: Results of thermal simulation with TRNSYS

	Temperatures	Passive cooling	Cooling load[1]	Heating load[1]	Thermal load[1]
	[°F]		*[mmBtu/a]*	*[mmBtu/a]*	*[mmBtu/a]*
REM|*Rate*	71/79	no	6.70	3.30	**10.00**
	71/79	yes	5.80	3.30	**9.10**
TRNSYS	71/79	no	7.06	2.81	**9.87**
	71/79	yes	5.38	2.99	**8.36**

[1] Loads represent electrical loads and not thermal loads

The set temperatures for these simulations, however, do not meet ASHRAE standards and thus, this calculation cannot be used as a certified official calculation of cooling and heating load, which is required for EarthCraft certification. Anyway, such a simulation needs to be executed by a certified HVAC engineer or technician, while these detailed simulations can be used as point of reference for expected heating and cooling demand. Nevertheless, these temperatures are more realistic for being set as inside temperatures in the desired building.

This simulation shows that REM|*Rate* simulations for the proposed, renovated landmark without passive cooling basically match with TRNSYS results. However, there are still significant difference and deviations in heating and cooling load, even the all over yearly energy consumption is roughly the same. The deviations between both results can be assigned to following two main reasons:

- Boundary conditions on interior walls equal room conditions. Thus, interactions between single rooms and offices are neglected within the TRNSYS simulation, as those could not be designed within the trail version.

- Different designed internal gains in both models. REM|*Rate* calculated internal gains only via the number of bedrooms, while TRNSYS allows to model number of occupants, activity level and used equipment. However, this difference in gains is most certainly the resulting difference in both, heating and cooling demand. As higher internal gains due to equipment and, especially during evening hours in the community space, reduce heating load and increase cooling demand. However, in further addition it is not known, when occupants leave and enter the building in REM|*Rate.* TRNSYS can simply modify occupancy of certain rooms by defining customized schedules.

Nevertheless, savings by implementing passive cooling are greater using the TRNSYS simulation. REM|*Rate*'s option of a whole house fan simply uses ventilation whenever indoor temperature exceeds 78 °F and outdoor conditions allow a cooling process by simple air transfer. This model is the most accurate model to select in REM|*Rate* to modify night ventilation and passive cooling of peak loads. However, it is impossible to set a defined fan speed and thus, a resulting air change rate. TRNSYS on the other hand enables a fully developed, user defined integration of night ventilation. Additionally it is possible to adjust more efficient control of the interior blinds. Another important fact is, as already mentioned before, that time of occupation is not known within the REM|*Rate* simulation. Though, it can be assumed that REM|*Rate* has higher internal gains during evening and night hours, as there are a defined number of bedrooms and those beds might be occupied. Thus, night ventilation cannot be as effective, as sleeping people still emit thermal energy and hence, low temperature differences between out- and inside won't cause a cooling effect.

Furthermore, it can be observed that using the passive cooling system in TRNSYS, heating demand slightly increases. This effect is undesired and easy to explain. As the simulated building part had no well-established control loop due to trial version restrictions, a simulation on hourly basis lead to this error. Once the simulated room exceeds the maximum allowed temperatures, the system starts outdoor air ventilation. However, as the program calculates and iterates the next temperature an hour afterwards, outdoor air is blown in for an hour, which, in turn, could result in an indoor temperature lower the set minimum temperature. This problem shouldn't occur, using better control loops and a fully licensed version of TRNSYS.

This tight and well insulated office and community duplex additionally causes further issues, which should be basically avoided in a designing approach. As it can be seen in Figure 72, cooling is necessary during heating season, even the passive cooling is considered. This problem is caused by having high internal gains in a small office. Thus, the room reaches temperatures greater 79 °F even without active heating. Using passive cooling with 5 ACH in this case, cold and high velocity airstreams would not meet the ASHRAE 55 standards for thermal comfort and would furthermore increase the heating demand in consequence of the simulation on hourly basis. Additionally, it was not possible to model a lower air change rate for this special case of application during the heating period due to program restrictions.

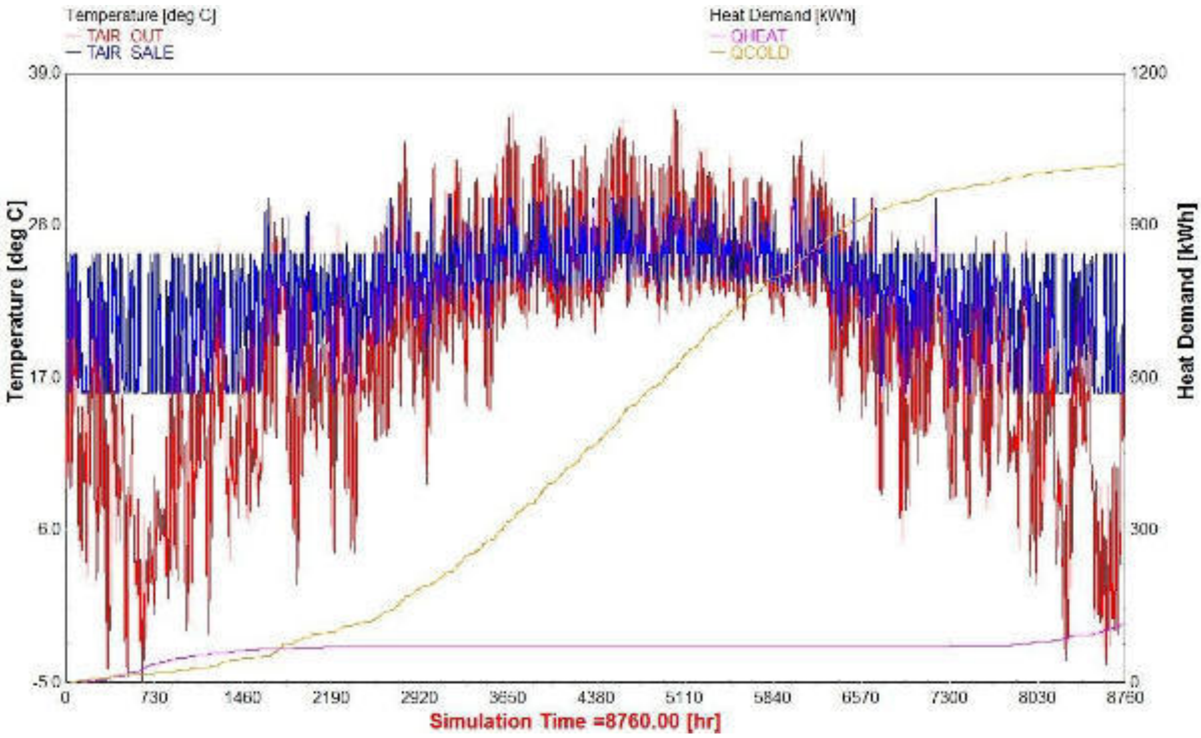


Figure 72: Temperature and heating and cooling demand with passive cooling for the smallest office

All in all the passive cooling concept does again reduce the total thermal energy demand, considering the TRNSYS simulation with passive cooling, to 8.36 mmBtu/a. This equals a further reduction in energy consumption by 17.4 % in regard to the basic version of the renovated property simulated in REM|*Rate* using the same set temperatures. Thus, it is possible to reduce the energy requirements from 10.8 mmBtu/a to 8.36 mmBtu/a, a reduction by 22.7 %, by simply adjusting set temperature and introducing a passive cooling concept without extra installation cost. However, even this modified, energy efficient building uses 22.7% less energy than the basic version, it would be benchmarked with the same overall HERS rating of 61.

However, those energy requirements only represent the electrical loads and electricity consumption for the heat pump. Thermal requirements for this building per square-foot and square-meter are listed in Table 21

Table 21: Annual thermal loads per area

	Cooling load			Heating load			Thermal load		
	[mmBtu]	*[kWh/sqft]*	*[kWh/m²]*	*[mmBtu]*	*[kWh/sqft]*	*[kWh/m²]*	*[mmBtu]*	*[kWh/sqft]*	*[kWh/m²]*
REM|*Rate*[1]	**38.68**	6.03	64.96	**13.53**	2.11	22.72	**52.21**	8.15	87.68
	33.49	5.22	56.23	**13.53**	2.11	22.72	**47.02**	7.33	78.95
TRNSYS[1]	**40.78**	6.36	68.48	**11.51**	1.80	19.32	**52.28**	8.16	87.80
	31.04	4.84	52.12	**12.25**	1.91	20.57	**43.28**	6.75	72.69

[1] The first line represents the thermal demand without and the second line the demand with integrated passive cooling.

Benchmarking the results clearly shows that even the building has a very good HERS rating, specific annual loads are still relatively high. Hence, this basically high efficient building with a HERS rating of 61, still requires, considering the basic calculation in REM|*Rate* which is used for classification and certification, almost 90 kWh/m^2.

Despite the possibility of reducing cooling demand, passive cooling furthermore affects the thermal comfort with air conditioned rooms. As confrontation of the thermal comfort and temperature profile over the simulated year shows, not only temperature profile changes but also the predicted percentage of dissatisfaction. The profiles depicted in Figure 73 and Figure 74 indicate that peak dissatisfaction is significantly reduced and thus, the possibility of feeling comfortable for a standard occupant, executing light office work and wearing long pants and a long sleeve shirt (or a skirt and a long sleeve blouse) is increased. A 30 percent line helps visualizing the differences between the two simulations, as the PPD values for the simulation without passive cooling exceeds this 30 % margin very often and by far whereof the percentage of dissatisfaction with passive cooling strategies pass this line rarely.

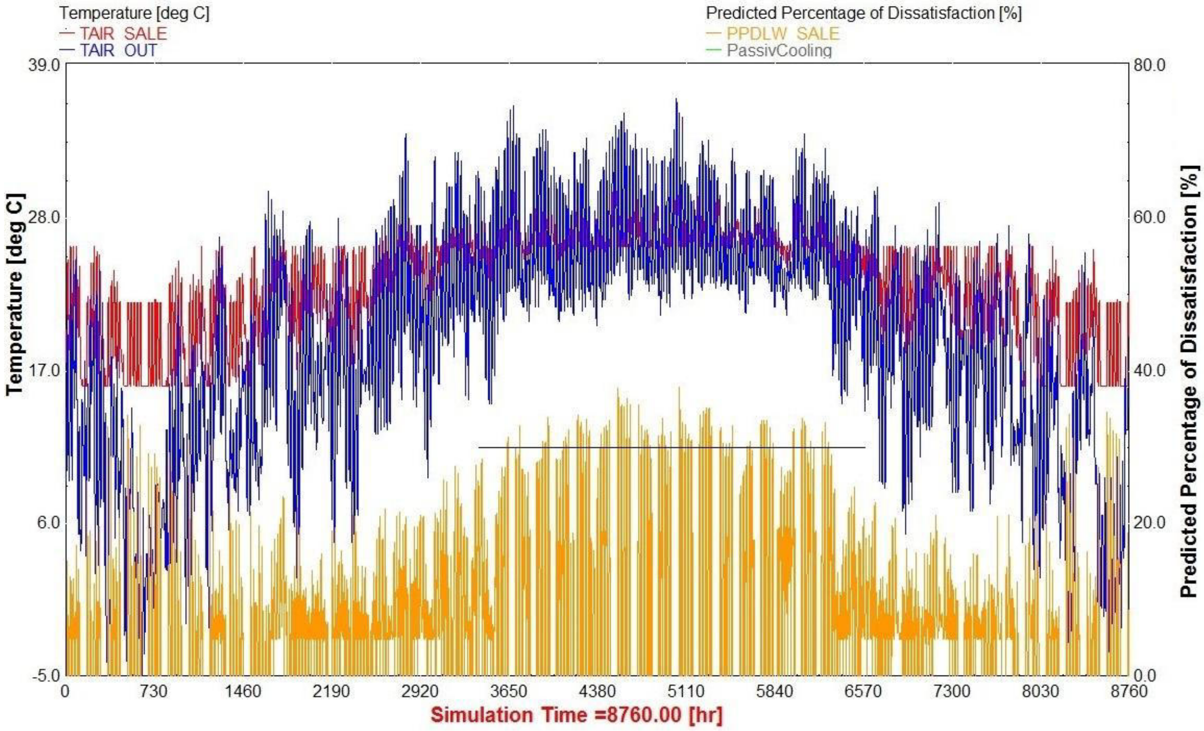


Figure 73: Temperature and PPD for the sales office without passive cooling

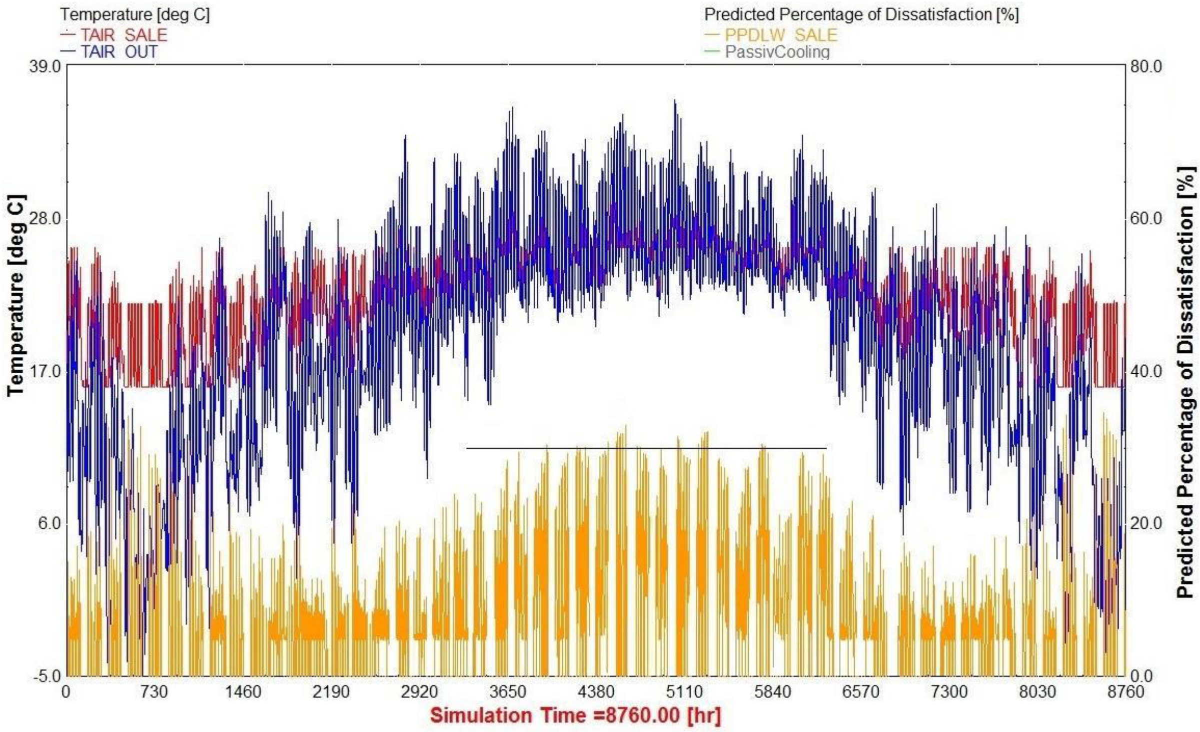


Figure 74: Temperature and PPD for the sales office with passive cooling

Considering these exemplary results for the sales office, peak dissatisfaction can be reduced from 37 % to 32 %. As night ventilation, using the HVAC equipment, is active when the office is not occupied, fresh air is circulating within the office and does not directly affect the office worker. However, it is possible to keep offices at a more decent and comfortable thermal and air quality levels over night. This reduces the peaks, which basically occur during the morning hours. This effect can be observed throughout the whole simulation.

Nevertheless all simulated values apply for the role model building user. To achieve those results, office workers and other buildings users need to be instructed on how to operate the air conditioning effectively.

Detailed results for heating and cooling demand and resulting energy cost for thermal energy for each simulated room as well as for the total building, with and without passive cooling, are attached as MS Excel worksheet in appendix E1.1.

5.4 Cost Benefit

Despite savings in energy demand for the heat pump introducing night ventilation as well as general saving when improving the thermal shell of the building, additional costs apply. Feasibility in terms of financial benefit is discussed in the following chapter.

5.4.1 Passive Cooling and Air Ventilation

Implementing night and peak load ventilation the air handling unit has increased hours of operation on a higher speed level. Thus, additional costs apply. As the building could only be simulated room-wise, hours of operation have been taken from the rooms with the highest demand. Considering an average electricity rate of $ 0.1375 per kWh, following, in Table 22 summarized, operating costs for air ventilation occur.

Table 22: Energy costs for mechanical air handling with and without passive cooling

		Passive cooling			Normal mode	
		5 ACH *1214 cfm*	**2.11 ACH** *533 cfm*	**2.24 ACH** *585 cfm*	**2.11** *533 cfm*	**2.24 ACH** *583 cfm*
Input power [1]	*[W]*	202.58	89.49	89.67	89.49	89.67
Hours of operation [2]	*[hrs/a]*	1427	1422	2349	1872	2536
Energy consumption	*[kWh/a]*	289.08	127.26	210.64	167.53	227.41
Operating cost	*[$/a]*	39.75	17.50	28.96	23.04	31.27
Total operating cost	***[$/a]***	**86.21**			**54.30**	

[1] Input power of the closest designated speed level, listed in the data sheet. [2] Hours of operation are taken from the rooms with highest operation hours of same schedule.

As it can be seen from Table 22, passive cooling and outdoor air ventilation reduces the total hours for 2.11 ACH and 2.24 ACH by 637 hours. This means in effect that outdoor air ventilation can significantly reduce the operation time of the heat pump. Effectively this strategy can decrease the need of air conditioning by 14.5 %. Nevertheless, additional, high velocity and power consuming ventilation is required. Thus yearly operation cost for the air handler increases from $ 54.30 to $ 86.21 – additional cost of $ 31.91, which represents an increase by 58. 8%. However, Table 23 faces savings by reducing thermal energy demand and reducing operational costs for the heat pump and additional costs for air ventilation.

Table 23: Financial benefits for passive outdoor air ventilation concept

	Cost
	[$/a]
Operation costs heat pump	$ 398.00
Operation costs fan	$ 54.30
	$ 452.30
Savings heat pump	-$ 60.76
Additional costs fan	$ 31.91
	-$ 28.86
Final costs w. passive concept	**$ 423.45**
Reduction of cost by	***6.38%***

All in all, even though the fan causes additional costs, overall savings of $ 28.86 per year can be saved, implementing this strategy. This represents a reduction in operation costs 6.38 % due to effective usage and control systems without having any additional installation cost. Certainly, all those values are valid for an electricity rate of $ 0.1375 per kWh. Table 24 outlines cost development considering increasing electricity rates, but no inflation and dynamic processes.

Table 24: Cost reduction by ventilation strategy for different electricity rates

	Cost [$/a]		
Electricity rate [$/kWh]	*0.1375*	*0.1452*	*0.1242*
Operation costs heat pump	$ 398.00	$420.28	$359.50
Operation costs fan	$ 54.30	$57.35	$49.05
	$ 452.30	**$477.63**	**$408.55**
Savings heat pump	-$ 60.76	-$64.16	-$54.88
Additional costs fan	$ 31.91	$33.69	$28.82
	-$ 28.86	**-$30.47**	**-$26.06**
Final costs w. passive concept	**$ 423.45**	**$447.16**	**$382.49**
Reduction of cost by	***6.38%***	***6.38%***	***6.38%***

It can be seen, that a change in electricity rate only affects the absolute amount of cost saving but do not have any influence on the relative savings. Both, additional costs and savings change evenly and thus, the saving percentage remains the same. Referring to these results it can be stated that this passive thermal concept reduces both, thermal energy demand and operation costs without having additional installation cost.

5.4.2 Thermal Boundary

All in all costs for improving the thermal boundary, including sealing, foils and insulation labor, but excluding any work which would be necessary from an historic preservation and buildings stability standpoint and required anyway (new siding and shingles), amount to a total of $ 30,498.26. In addition to that windows account a total of $ 25,734.85 and the HVAC system (including duct work and connections) $ 38,353.95.

Considering these finance investments for the contractors building, and previously mentioned electricity rates as well as an increase in electricity rate, following, in Table 25 summarized payback periods can be calculated.

Table 25: Cost Analysis for thermal boundary and quoted HVAC system

	Energy consumption	Savings		Investment cost		Payback
	[mmBtu/a][1]	[mmBtu/a][1]	[$/a][2]	[$]	[$/sqft]	[a]
Historic landmark	124.9	-	-	-	-	-
Improvements						
Windows	101.0	23.9	1017.76	25,734.85	12.62	23
Insulation and sealing	31.4	93.5	3981.61	30,498.26	14.95	7
Insulation and windows	23.4	101.5	4322.29	56,233.11	27.57	12
Insulation, windows, HVAC	16.2	108.7	4628.89	94,587.06	46.37	19

[1] Savings in energy as well as total energy consumption refer to the consumption of electricity to provide thermal energy for heating and cooling. [2] The latest energy rate of $ 0.1452 per kWh has been set initial electricity rate. Those listed values only show the savings within the first year.

It is clearly shown that improving the thermal boundary, especially adding insulation and providing adequate air and moisture sealing, does add value to the building buy significantly decreasing the energy consumption and investment cost pay back within 7 years. However, including all improvements, energy consumption can be further reduced, but the payback period increases to 19 years due to expensive quoted HVAC systems and windows. Assuming a 30 year lifetime of all components, all savings will conclude to a net present value of $ 59,280.96. This net present value represents a saved value in operation cost from today's currency value. Even though an amortization within 19 years seems long

Detailed net present value calculation for the thermally improved building including the new HVAC system, is attached as appendix G1.1.

5.4.3 HVAC System

As shown in chapter 5.2 *"HERS Index and Energy Consumption"*, the suggested air source heat pump consumes more electricity due to decreased system efficiency. However, to be able to compare, how beneficial a ground source heat pump would be for the quoted building, another REM|*Rate* simulation has been carried out, using proposed heat pumps efficiency for the quoted building. As the buildings thermal load doesn't significantly increase, a 3 ton heat pump would still be sufficient. Table 26 lists the potential energy saving by using the suggested ground source heat pump.

Table 26: Cost Analysis for air and ground source heat pumps

		Proposed		Quoted	Max. difference
		incl. passive	*excl. passive*		
Consumption heat pump	*[mmBtu/a]*	11.70	13.00	16.20	4.50
Operation cost heat pump [1]	*[$/a]*	471.81	524.24	653.28	181.47
Operation cost fan [2]	*[$/a]*	86.21	54.30	54.30	-31.91

[1] Operation costs are calculated using an average electricity rate of $ 0.1375 per kWh. [2] It is assumed that the quoted air handler need the same amount of electrical energy, as no separate data was given. However, as the fan would be bigger, he might also consume more electrical energy. As this is an uncertain assumption, it has not been applied for this comparison.

As it can be seen, a total of $ 149.56, which can be saved on average over a year, could be spent yearly on additional costs for installing a ground source heat pump.

Therefore, an independent company has been asked for issuing a quote for the proposed HVAC system, including all necessary coils, refrigerant, connections and labor to compare the contractors quoted heat pump and air handler to the desired one. However, a quote has not been submitted by the desired local manufacturer until the end of August. Thus, it was not possible to analyze the feasibility of a ground source heat pump. Nevertheless a cost benefit analysis of ground source heat pumps in comparison to air source heat pumps would be desirable for further research.

5.5 Environmental Analysis of Building Materials

For analyzing the total environmental impact of the total building, each component and construction has to be taken into account. Table 27 lists different windows materials and their effect on the environment on a 100 year cycle, according to conducted analysis using baubook [SW baubook, 2014]. However, for this calculation, the total window area has been used. Nevertheless all results are based on European databases, as already mentioned in chapter 4.5 *'Environmental Analysis of Building Materials'* and as the there is a different fraction of energy sources with the US electricity, results from US databases might vary.

Table 27: Results for environmental analysis for different windows using baubook

Materials	PEI[1]	GWP100	AP
	[kWh]	*[kgCO$_2$equ./m^2]*	*[kg SO$_2$]*
Wood	144.0	27.136	0.193
Wood/Aluminum	150.0	27.900	0.198
PVC	253.1	45.013	0.205

[1] Only primary energy input of non-renewable energy sources are considered

An environmental analysis showed that wood windows, even with aluminum cladding are the preferable option from an environmental standpoint. However, it has to be mentioned that wood/aluminum windows require a high amount of additional primary energy input from renewables and thus, the effective energy input of PVC windows and wood/aluminum windows is roughly the same.

For every construction, spray foam has been quoted as the main insulation material. In further consequence, Table 28 to Table 30 show the different environmental impacts of every mentioned construction for wall, floor and roof.

Table 28: Results for environmental analysis for different wall constructions using baubook

Insulation materials	PEI[1]	GWP100	AP
	[kWh]	*[kgCO$_2$equ./m^2]*	*[kg SO$_2$]*
Mineral wool	71.9	5.319	0.119
Spray foam	333.0	41.800	0.230

[1] Only primary energy input of non-renewable energy sources are considered

Table 29: Results for environmental analysis for different floor constructions using baubook

Insulation materials	PEI[1]	GWP100	AP
	[kWh]	*[kgCO$_2$equ./m^2]*	*[kg SO$_2$]*
Mineral wool	112.8	-0.133	0.212
Spray foam	523.0	66.800	0.378

[1] Only primary energy input of non-renewable energy sources are considered

Table 30: Results for environmental analysis for different roof constructions using baubook

Insulation materials	PEI[1]	GWP100	AP
	[kWh]	[kgCO_2equ./m^2]	[kg SO_2]
Mineral wool	603.7	29.502	0.549
Mineral wool and spray foam[2]	1119.8	110.267	0.800
Mineral wool and EPS board[2]	676.1	35.111	0.476
Spray foam	1,288.0	146.000	0.815

[1] Only primary energy input of non-renewable energy sources are considered. [2] Considering one layer of mineral wool and one layer of spray foam/EPS, as described in chapter 4.3.6 'Construction Principles' for the proposed renovation.

It is clearly shown that the application of spray foam might me cost effective and relatively easy, but has a huge impact on the environment. Detailed analysis concerning the components itself outlined that for providing the same effective insulation using spray foam, roughly 4.5 times more primary energy is necessary and the global warming potential is more than 2 times higher. Nevertheless, spray foam is more likely to be introduced to the building than full wood construction, as it is common practice.

Furthermore Table 29 outlines an interesting aspect of environmentally friendly and sustainable construction - the floor construction, consisting of mineral wool, wooden framing, boards and floor has a negative global warming potential. This is why wooden constructions with mineral wool or cellulose insulation should be preferably used. As the wood, used for framing, captures CO_2 from the atmosphere, builds up biomass and releases oxygen again before being cut down, the timber construction has a negative GWP, as it works against the greenhouse effect. As the mineral wools global warming potential is also relatively low, to total construction has an overall negative GWP.

The roof constructions are very energy intensive and burden the environment in general. Main reason therefore is the energy intensive production of the asphalt shingles and the bituminous felt. Nevertheless, the foamless constructions are preferable. A further interesting point this analysis outlined, is that an additional construction with EPS insulation boards is significantly less energy intensive in the production and has a considerably lower contribution to global warming. However, the thermal properties are comparable to those of spray foam.

Finally, Table 31 summarizes results for the environmental analysis for the entire building.

Table 31: Environmental Analysis – Entire building

Version	PEI[1]	GWP100	AP
	[kWh]	*[kgCO_2equ./m^2]*	*[kg SO_2]*
Optimal version (only wood and mineral wool)	932.4	61.823	1.073
Proposed building (with additional spray foam on attic)	1,557.7	160.465	1.335
Proposed building (with additional EPS board on attic)	1,114.0	85.309	1.012
Quoted building	2,294.0	282.500	1.620

[1] Only primary energy input of non-renewable energy sources are considered

It is clearly indicated that a construction using only wood and mineral wool would be best possibility for renovating this building from an environmental point of view. Nevertheless, this concept would require additional heavy timber construction which would be most certainly too heavy for the existing bearing walls. Hence, additional EPS insulation board for the roof insulation would be the best possibility to achieve both, energy efficiency and environmentally friendly building design. The quoted building does not only require double primary energy to provide the same/similar thermal quality, it furthermore has a global warming potential 3.3 times higher than the proposed building with EPS insulation board.

All in all spray foam application shall be avoided. It may be the easiest and most cost effective way to add insulation, but the application of the foam harms the environment. Thus, the renovated landmark can only be an energy efficient and green building if insulation is free of CFC, HCFC and other air pollutants. Furthermore oil containing insulation material shall basically be avoided as those cause further problems when demolishing the building. Thus, not only spray foam, but also EPS and XPS boards shall be avoided in a green building approach.

6 Conclusion

It has been outlined that a total of 728,000 panelized domestic wooden homes have been built before 1950. As only a negligible fraction of those has been renovated and thus, have a thermal boundary of proper quality, readapting and redesigning those historic buildings is desirable. However, as this research carried out, such transformations of old buildings into energy efficient office and community spaces, is easy to accomplish and financially feasible.

Almost 75 % of the energy demand in offices within the United States is used for HVAC (50 %) and lighting purposes. Therefore the main focus on such a renovation has to be on the thermal shell, the HVAC system and the usage of artificial lighting, while still considering aspects of historic preservation. Implementing certification criteria required by EarthCraft, a South-Eastern green building label, for the given object, only a total of 10.0 mmBtu/a primary energy input are demanded for heating and cooling. This represents an energy requirement of 4.9 mBtu/sqft gross area, while average office buildings consume 11.8 mBtu/sqft and thus, request roughly 140 % more energy for heating and cooling purposes in the same climate zone.

Further investigation carried out that passive cooling, in this case night ventilation, can save another 1.64 mmBtu/a and moreover reduce the total energy consumption for thermal purposes to 4.1 mBtu/sqft. Implementation of this system does not only reduce the energy consumption by 16 %, it furthermore increases the thermal comfort with in the building. Nevertheless, attention to outdoor humidity has to be paid, as high humidity can have a negative impact on the overall percentage of dissatisfaction and thermal comfort.

However, historic preservation only minimally affects energy related design issues, as it main targets the outer appearance of the building. Insulation and all further improvements of the thermal shell as well as requirements for accessible design can be easily implemented. However, it is not possible using on-site energy generation, like solar thermal or photovoltaic panels.

For accomplishing these huge energy savings, following key items have been implemented and can furthermore be adopted for the remaining 727,999 buildings:

- Frame-thick insulation between the frame constructions (R-13 for walls, R-19 for the floor and R-38 for the roof) can be added without additional effort, when revitalizing an old building. Those insulation improvements can save up to 75 % of thermal energy and pay back in no longer than 7 years, when proper air sealing measurements are included and execution is clean.
- Closing open crawl and vented attic, if applicable, for minimizing thermal losses through the floor and roof and provide higher thermal comfort.
- Windows need to have low solar heat gain coefficients and shutters preferable (in this case necessary for historic preservation) to provide additional shading.
- Installation of high efficiency HVAC units is as of same importance as providing a high performance building shell. Oversized HVAC components can, even the single components are certified as energy saving products, can lead to a more than 50 % higher overall electricity demand due to bad efficiencies and thus, affect the buildings overall performance.

However, not all of the proposed energy efficiency improving measures has been adopted by the engaged contracting company. Thus, total electricity requirements to provide thermal energy have increased from 10.0 mmBtu/a to 16.2 mmBtu/a (7.9 mBtu/sqft) – an increase of 62 %. Furthermore quoted costs and list items have to be reviewed as $ 230,167.25 of the total proposed $ 562,101.97 arise for architectural and engineering work, as well as for landscaping. Those costs can be dramatically reduced. In addition to that some efficiency enhancing measures, for example windows and HVAC system, display cost saving potentials.

Having total costs for building performance improvements of only $ 94,587.06 ($ 46.37 per sqft) and a total electricity demand reduction for thermal purposes of 108.7 mmBtu/a, the whole investment pays back within a period of 19 years. Those improvement measures led to a decrease in energy demand, only considering thermal energy, of 87 %.

Nevertheless, the remaining energy demand for heating and cooling could be furthermore reduced 16.2 mmBtu/a to 13.0 mmBtu/a using a more efficient ground source heat pump and in moreover to 11.0 mmBtu/a if an additional passive cooling and ventilation system would be applied. Implementing passive cooling strategies for this building is feasible and does not require increasing the proposed duct system. Thus, it is possible to save money without having additional investment cost. Introducing both, passive ventilation and a ground source heat pump, a total of $ 149.56 can be saved in terms of HVAC. However, if a ground source heat pump would be feasible could not be determined due to this research, as no quotes could be obtained during the research period.

This research furthermore led to the result that the approach of designing sustainable high performance building does not only require a sufficient amount of insulation. The type of insulation is as important. As buildings are basically insulated using spray foam, as this is the cheapest and most practicable and common method. However, common used spray foam contains a lot of chlorofluorocarbons and thus, harms the environment. The amount of released carbon dioxide during application and primary energy input in producing this insulation material is way greater as for other easily attachable insulation materials like mineral wool. Nevertheless, the quoted building may not be titled as “green building”, as the used insulation has a huge environmental impact.

Moreover the HERS rating is an easy achievable building performance indicator and delivers good results for heating and cooling demands for domestic buildings. Nevertheless, buildings with different uses (like offices) are hard to design and improved performance optimization strategies like passive cooling by night ventilation hardly implementable. Detailed thermal analysis showed that thermal demands, calculated in REM|*Rate*™ for determine the HERS rating, are comparable to results of transient thermal simulation tools like TRNSYS. Besides this there is a strong deviation in results as soon night ventilation concepts are integrated.

However, the HERS rating does only consider the basic definition of the thermal shell. Hence, bad adjusted or pre-set thermostats and varying user behavior can end up with and additional energy consumption of 42 % while ventilation strategies reduce the demand by 16 %. Certainly both simulations lead to the same HERS rating, even there is a total difference in energy consumption of 58 %.

To get permission to build a new building and to implement a new thermal system, it is required by law to conduct “Manual J” conforming calculation. The results of these calculations are the fundamentals for sizing HVAC components, as those have to meet calculated design loads. Certainly, as shown in the thesis, “Manual J” calculations tend to oversize the HVAC equipment. Those oversized components, “Manual J” design loads exceeded design loads calculated in other software by a maximum of 71 %, lead to higher investment cost and, as the system operates far from its optimum operation point, might also cause additional operation cost. However, an increase in operation cost could not be proven during this research, as manufactures do not provide sufficient data for detailed analysis.

Passive cooling measures, as for example night ventilation, are possible and feasible, even though the climate is hot and humid. Nevertheless, high quality control loop and humidity control are absolutely necessary. Night ventilation concepts can save, depending on the building, up to 16 % of energy and, considering extra cost for the fan, 6.38 % of overall energy costs for HVAC. In addition to energy savings, passive cooling via night ventilation increases thermal comfort. As buildings can be cooled during night hours, without having additional energy requirements for cooling, temperatures can be lowered and thus, offices are cooler and more comfortable when office staff arrives.

However, despite researched outcomes further possibilities for having green and energy efficient buildings shall be investigated. If historic preservation requirements are not given, solar thermal and photovoltaic panels could be a potential provider of thermal and electrical energy. Furthermore, as the hot and humid climate has a great number of cooling degree days and a lot of sun shine hours, potentials of solar-thermal cooling, using solar-thermal panels and ad- or absorption-type refrigeration systems and desiccant evaporative cooling need to be researched.

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Housing Department, City of Savannah
One-on-one interview and local inspection on June 23rd, 2014
Thomas Gamble Building, 6 E Bay St, Savannah, GA 31401

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Housing Department, City of Savannah
One-on-one interview and local inspection on March 13th, 2014
Savannah Gardens, 520 E Crescent Drive, Savannah, GA 31401

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Architectural coordinator and project manager, City of Savannah
E-mail from Monday, March 31, 2014 2:07 PM
Sent from CORourke@Savannahga.Gov

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Sustainable Development, City of Savannah
One-on-one interview on March 10th, 2014
Thomas Gamble Building, 6 E Bay St, Savannah, GA 31401

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7.1.4 Software

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7.2 Table of Figures

Figure 1: Energy flow chart for the United States in quadrillion Btu [O EIA Flow, 2014]..........1
Figure 2: Energy use within the commercial sector [O EIA AEO A5, 2014] 2
Figure 3: Energy usage in offices [O EIA AEO A5, 2014] 2
Figure 4: Location of Savannah Gardens [O Google Maps, 2014] 4
Figure 5: Proposed plans of Savannah Gardens, 1942 [P Keber, 2011, pg. 103] 4
Figure 6: Constructing historic Savannah Gardens, October 1942 [P Keber, 2011, pg. 104]....5
Figure 7: Historic Savannah Gardens in July 1943 [P Keber, 2011, pg. 63] 6
Figure 8: Proposed master plan for new Savannah Gardens [Thomas&Hutton, 2009, pg. 1] ..7
Figure 9: One of the last remaining buildings is demolished [O SavannahNow, 2013] 8
Figure 10: Community hub of new Savannah Gardens [P Daise, 2012, pg. 11] 8
Figure 11: Wheelchair ramp requirements [P GAC 120-3-20-.19, 1987, pg. 46] 13
Figure 12: Handrail requirements [P GAC 120-3-20-.19, 1987, pg. 47].................................13
Figure 13: Hallway clear-width requirements for door openings [P GAC 120-3-20-.13, 1987, pg. 55] 14
Figure 14: Hallway clear-width requirements for passing [P GAC 120-3-20-.13, 1987, pg. 26 and 27] 14
Figure 15: Minimum door clear-width regulations [P GAC 120-3-20-.24, 1987, pg. 55].........15
Figure 16: Layout of an accessible restroom [P GAC 120-3-20-.27, 1987, pg. 66] 15
Figure 17: Side toilet approach [P GAC 120-3-20-.27, 1987, pg. 63]......................................16
Figure 18: Diagonal toilet approach [P GAC 120-3-20-.27, 1987, pg. 63]..............................16
Figure 19: Clear-space underneath an accessible lavatory [P GAC 120-3-20-.35, 1987, pg. 77] 17
Figure 20: Clear-space underneath work surface [P GAC 120-3-20-.43, 1987, pg. 127].........18
Figure 21: Maximum side reach over obstruction [P GAC 120-3-20-.43, 1987, pg. 93]..........18
Figure 22: EarthCraft logo [O Earthcraft, 2014]...19
Figure 23: HERS index [O RESNET, 2014]...21
Figure 24: Location of the historic landmark [O Google Maps, 2014] 26
Figure 25: Photograph of the historic landmark, North-West elevation (March 13th, 2014) 27
Figure 26: Photograph of the historic landmark, North elevation (March 13th, 2014)..........27
Figure 27: Photograph of the historic landmark, South-East Elevation (March 26th, 2014)..27
Figure 28: Photograph of the roofed North entrance of the historic landmark (March 13th, 2014) 27
Figure 29: Photograph of the existing open crawl space construction (March 13th, 2014)...28
Figure 30: Photograph of the existing wall construction (March 13th, 2014) 28
Figure 31: Photograph of the existing floor frame construction (March 26th, 2014)............28
Figure 32: Photograph of the existing wood trusses and roof construction (March 26th, 2014) 28
Figure 33: Photograph of the smokestack in the historic landmark (March 26th, 2014) 29

Figure 34: Photograph of the crumbling interior wall cladding in the historic landmark (March 26th, 2014) 29
Figure 35: Photograph of the crumbling ceiling gypsum boards and open attic in the historic landmark (March 13th, 2014) 29
Figure 36: Photograph of one of the remaining windows and trash covered floor (March 13th, 2014) 29
Figure 37: Roof construction of the historic landmark 31
Figure 38: Ceiling construction of the historic landmark 32
Figure 39: Exterior wall construction of the historic landmark 33
Figure 40: Floor and open crawl space construction of the historic landmark 34
Figure 41: Rendered site plan of the historic building (1” = 25’) 35
Figure 42: ArchiCAD rendering of the North-South view for the existing building (front) 36
Figure 43: ArchiCAD rendering of the North-South view for the existing building (back) 36
Figure 44: ArchiCAD rendering of the street view for the existing building 36
Figure 45: Rendered site plan of the proposed, renovated historic landmark (1" = 25') 42
Figure 46: North-South view of the proposed building (front) 42
Figure 47: North-South view of the proposed building (back) 42
Figure 48: Street view of the proposed building 43
Figure 49: South-North view on proposed South entrance 43
Figure 50: Rendering of the proposed sales office 44
Figure 51: Rendering of the proposed accessible office 44
Figure 52: Rendering of the proposed standard office 44
Figure 53: Rendering of the proposed conference room 44
Figure 54: Rendering of the proposed hallway (from South to North) 45
Figure 55: Rendering of the proposed break and recreation room 45
Figure 56: Rendering of the proposed exhibition room (South-North view) 47
Figure 57: Rendering of the proposed exhibition room (East-West view) 47
Figure 58: Rendering of the proposed exhibition room (view from reception) 47
Figure 59: Rendering of the proposed accessible restroom 47
Figure 60: Proposed exterior wall construction for the renovated landmark 51
Figure 61: Proposed floor and open crawl space construction for the renovated landmark 53
Figure 62: Proposed roof construction for the renovated landmark 54
Figure 63: Air handler fan characteristics for potential speed levels, based on [O Goodman AH, 2014] 59
Figure 64: Air handler fan input power - speed characteristics, based on [O Goodman AH, 2014] 60
Figure 65: Historic duplex in Savannah Gardens with visible installed, bluish window shutters in the background [O SavannahNow, 2011] 61
Figure 66: SketchUp model of the conference room for TRNSYS (two thermal zones) 64
Figure 67: SketchUp model of the community area and reception for TRNSYS 64

Figure 68: Electricity rate development for Savannah's municipal buildings since 2008 [P Saxon, 2014, sheet 1 and 2] 66
Figure 69: Inflation rate development of the United States [O WorldBank GDPd, 2014] 67
Figure 70: Indoor and outdoor temperatures and PPD for sales office without cooling 76
Figure 71: Indoor and outdoor temperatures for sales office without cooling and historic constructions 77
Figure 72: Temperature and heating and cooling demand with passive cooling for the smallest office 80
Figure 73: Temperature and PPD for the sales office without passive cooling....82
Figure 74: Temperature and PPD for the sales office with passive cooling 82

7.3 Table of Tables

Table 1: Units and Conversion Table [O MIT, 2007] 6
Table 2: On-site visit 25
Table 3: Building material characteristics for the historic landmark [P Riccabona, 2003] [P ONV31, 2001]....30
Table 4: R- and U-values for the historic landmark 31
Table 5: Suggested list items for EarthCraft renovation....39
Table 6: List items for site planning for EarthCraft renovation 40
Table 7: Expected final score for EarthCraft renovation 40
Table 8: Building material characteristics for the proposed renovated landmark [P Riccabona, 2003, Table 1] [P ONV31, 2001, pg. 12 cont.] 49
Table 9: Calculated R- and U-values for the proposed renovated landmark 50
Table 10: R-values of the building in comparison to requirements 50
Table 11: Maximum air change rates for 'office schedule'....57
Table 12: Maximum air change rates for 'evening schedule' 58
Table 13: Proposed HVAC system components....58
Table 14: Key data for ground source heat pump [P AHRI 3920301, 2014, pg. 1]....58
Table 15: Air change rates for night ventilation 62
Table 16: TRNSYS trial restrictions and resulting simplifications 64
Table 17: U-values for the proposed and quoted landmark 72
Table 18: Results for HERS ratings and loads of conducted REM/*Rate* simulations....73
Table 19: Comparison of design loads and demands 75
Table 20: Results of thermal simulation with TRNSYS....78
Table 21: Annual thermal loads per area 81
Table 22: Energy costs for mechanical air handling with and without passive cooling 83
Table 23: Financial benefits for passive outdoor air ventilation concept 84
Table 24: Cost reduction by ventilation strategy for different electricity rates....85
Table 25: Cost Analysis for thermal boundary and quoted HVAC system 86
Table 26: Cost Analysis for air and ground source heat pumps 87

Table 27: Results for environmental analysis for different windows using baubook 88
Table 28: Results for environmental analysis for different wall constructions using baubook 88
Table 29: Results for environmental analysis for different floor constructions using baubook 88
Table 30: Results for environmental analysis for different roof constructions using baubook 89
Table 31: Environmental Analysis – Entire building 90

7.4 Table of Equations

Equation (0-1) : Conversion for thermal resistance 7
Equation (0-2) : Conversion for U-value 7
Equation (0-3) : Conversion for volumetric flow 7
Equation (0-4) : Conversion factor for energy 7
Equation (4.3-1): Volumetric fraction of layer A..48
Equation (4.3-2): Volumetric fraction of layer B..48
Equation (4.3-3): Thermal resistance of layer A 48
Equation (4.3-4) : Thermal resistance of layer B 48
Equation (4.3-5): Fractional thermal resistance of non-homogenous constructions 48
Equation (4.3-6): Mean thermal conductivity 48
Equation (4.3-7): Mean thermal resistance..49
Equation (4.3-8): Thermal resistance for non-homogenous constructions 49
Equation (4.3-9): Air power 59
Equation (4.3-10): Fan power 59
Equation (4.3-11): Energy consumption 60
Equation (4.3-12): Energy costs 60
Equation (4.4-1): Net Present Value 66
Equation (4.4-2): Cash flow for increasing electricity rate 67

8 Appendix

Plans:

A1.1	Layout Master-plan by Thomas & Hutton	*1 page*
A1.2	As-built building plans (A3)	*6 pages*
A1.3	Proposed building plans (A3)	*9 pages*

Input Parameters:

B1.1 to B1.4 are only included on attached CD

HERS Ratings:

C1.1	As-built building	*1 page*
C1.2	Proposed renovation	*1 page*
C1.3	Proposed renovation with ventilation concept	*1 page*
C1.4	Quoted renovation	*1 page*

Manual J:

D1.1	Proposed renovation	*3 pages*
D1.2	Quoted renovation	*3 pages*

TRNSYS Results:

E1.1	Results for room-wise simulation in Excel Spreadsheet	*3 pages*

Quotes:

F1.1	Coversheet and index of contractor quote	*2 pages*

NPV:

G1.1	Payback period and NPV calculation for all improvements	*1 page*

Savannah Gardens

Savannah, Georgia

A CHSA Project
in Partnership with
The City of Savannah

March 2012

Playground & Building Type Key

- (A) Playground - Ages 2 to 5
- (B) Playground - Ages 6 to 12
- (C) Playground - Ages 2 to 12
- (D) Playground - Private

- Single Family - Attached
- Single Family - Detached
- Multi-Family
- Mixed Use

Walking Scale: 0 — 1 Min. — 2 Min. — 2.5 Min.

Distance Scale: 0 50' 100' 250' 500'

NORTH

THOMAS & HUTTON
Engineering | Surveying | Planning | GIS | Consulting

Sheet Index			
Layout ID	**Layout Name**	**Published**	**Remark**
	Sheet Index	☐	
A.01.1	Floor plans	☐	
A.02.1	East and West Elevation	☐	
A.02.2	North and South Elevation	☐	
A.03.1	Sections	☐	
A.03.2	Details	☐	

Georgia Insititute of Technology
210 Technology Circle
Savannah,
GA 31407,
United States

Drawn by
Andreas Karl

Date
4/8/2014

Checked by

Date

Drawing Name
Sheet Index

Drawing Status
As-built drawings

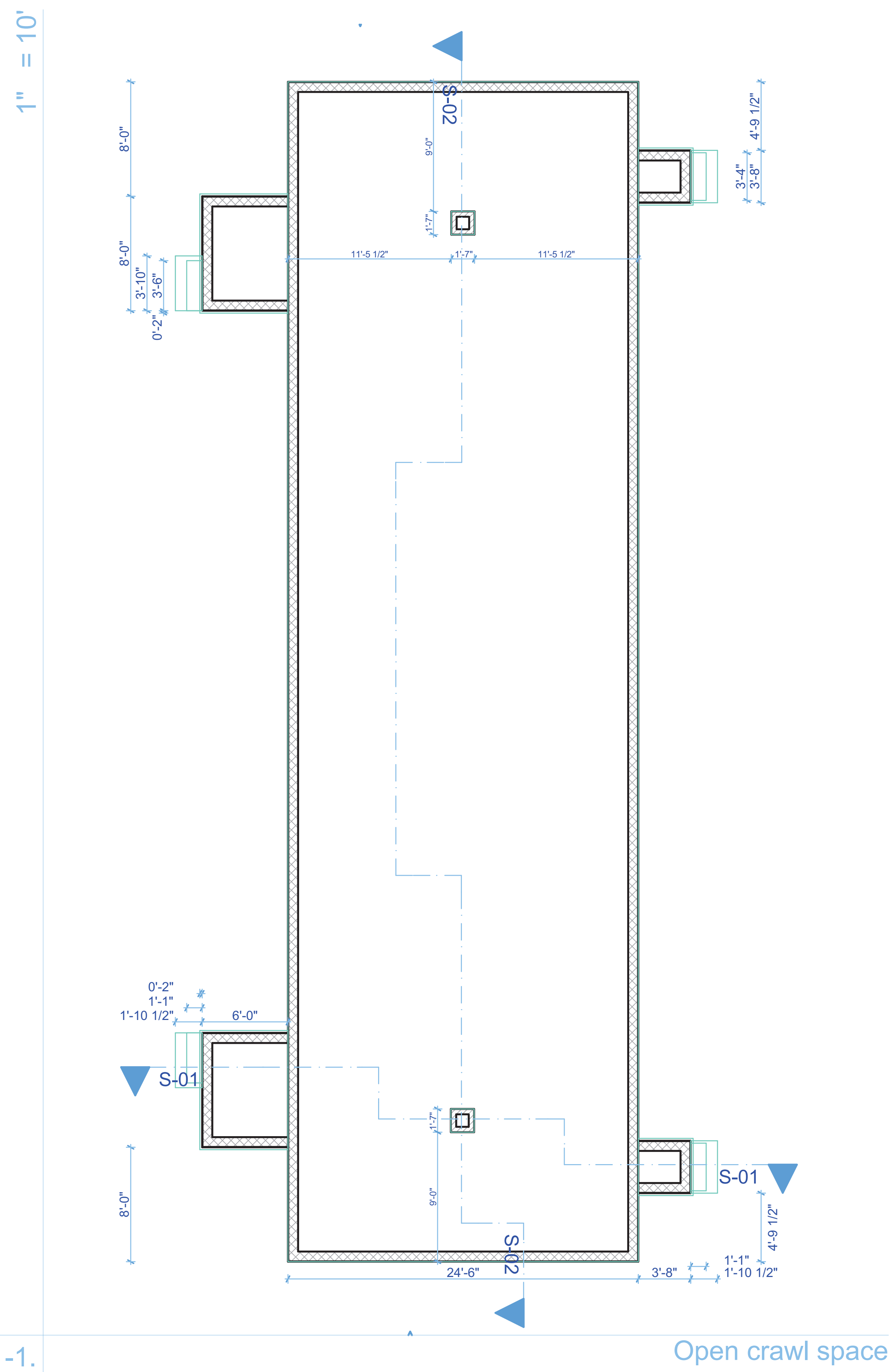
City of Savannah
6 E Bay St
Savannah,
GA 31401,
United States

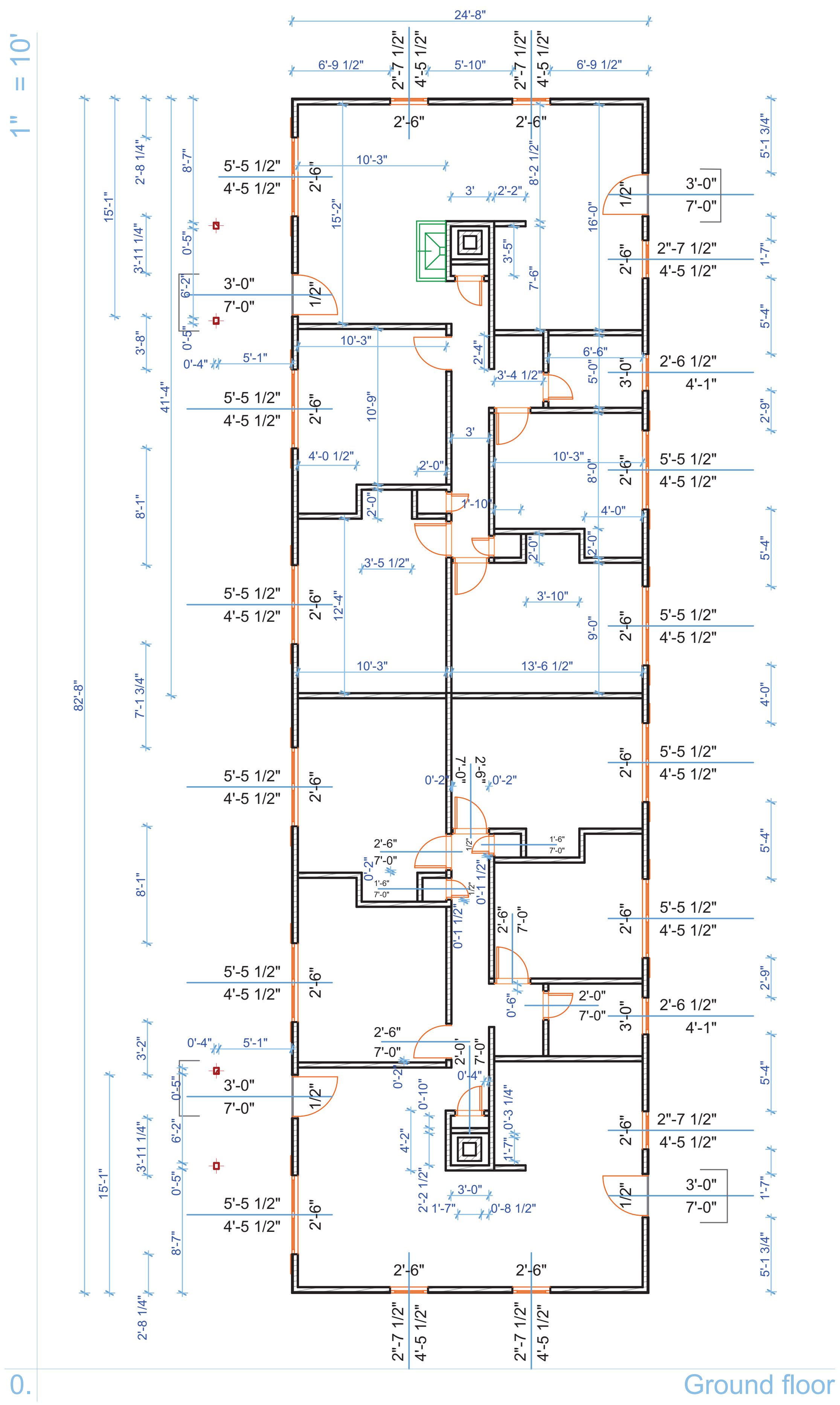
Redesigning 1940's duplex

Drawing Scale
varies

Layout ID	Status	Revision

ARCHICAD EDUCATION VERSION
GRAPHISOFT.





Company Title

Georgia Insititute of Technology
210 Technology Circle
Savannah,
GA 31407,
United States

Job Title
Redesigning 1940's duplex
City of Savannah
6 E Bay St
Savannah,
GA 31401,
United States

Drawing Name
Open crawl space, Ground floor

Drawing Status
As-built drawings

Drawn by	Date
Andreas Karl	**04/10/2014**
Checked by	Date

Drawing Scale
ISO A3, 1" = 10'

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ARCHICAD EDUCATION VERSION
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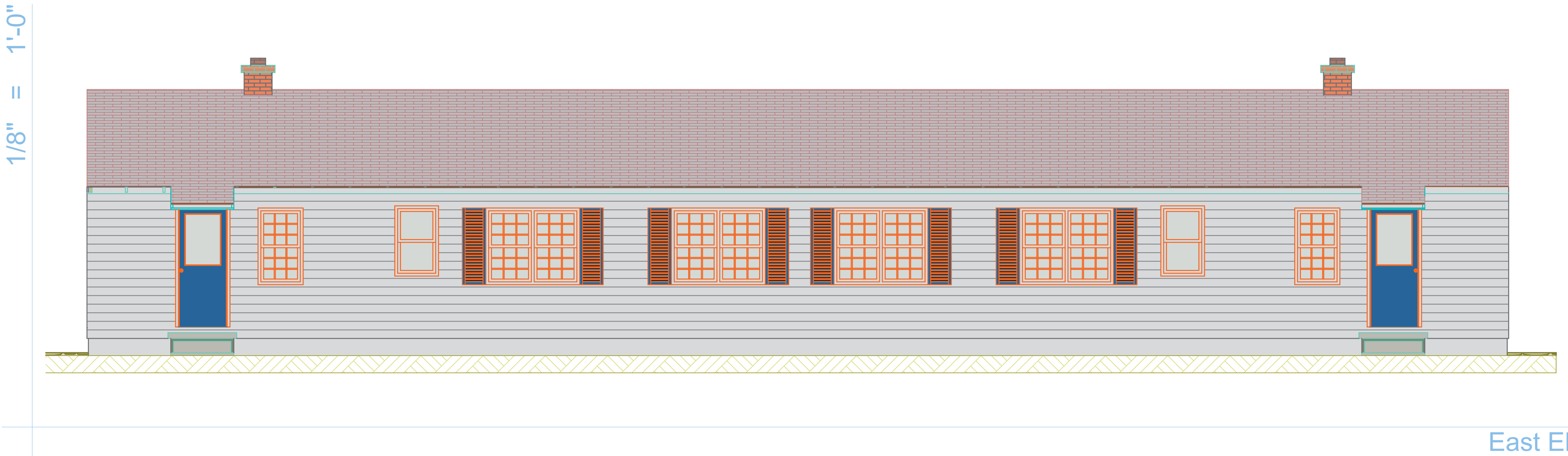

East Elevation

West Elevation

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Georgia Insititute of Technology
210 Technology Circle
Savannah,
GA 31407,
United States

Job Title
Redesigning 1940's duplex
City of Savannah
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Savannah,
GA 31401,
United States

Drawing Name
East Elevation, West Elevation

Drawing Status
As-built drawings

Drawn by: **Andreas Karl** | Date: **04/10/2014**

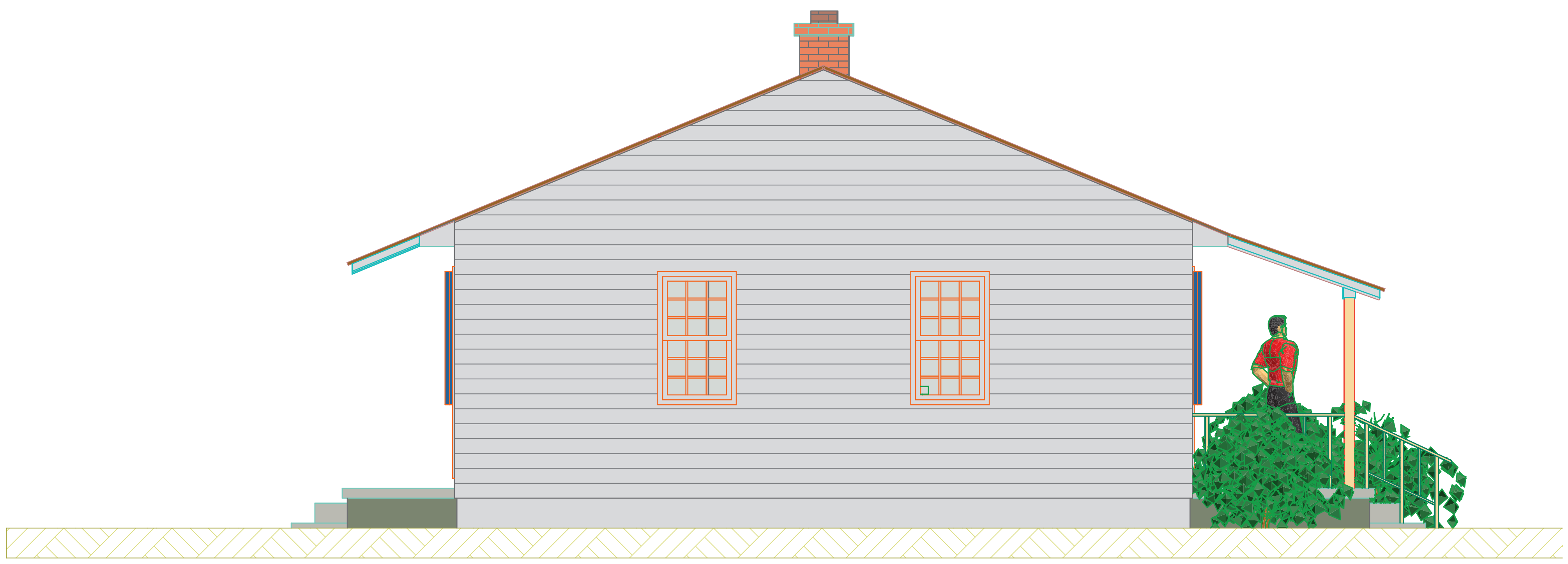
Checked by | Date

Drawing Scale
ISO A3, 1/8" = 1'-0"

Layout ID: **A.02.1** | Status | Revision: **2.0**

ARCHICAD EDUCATION VERSION
GRAPHISOFT

1" = 5'



North Elevation

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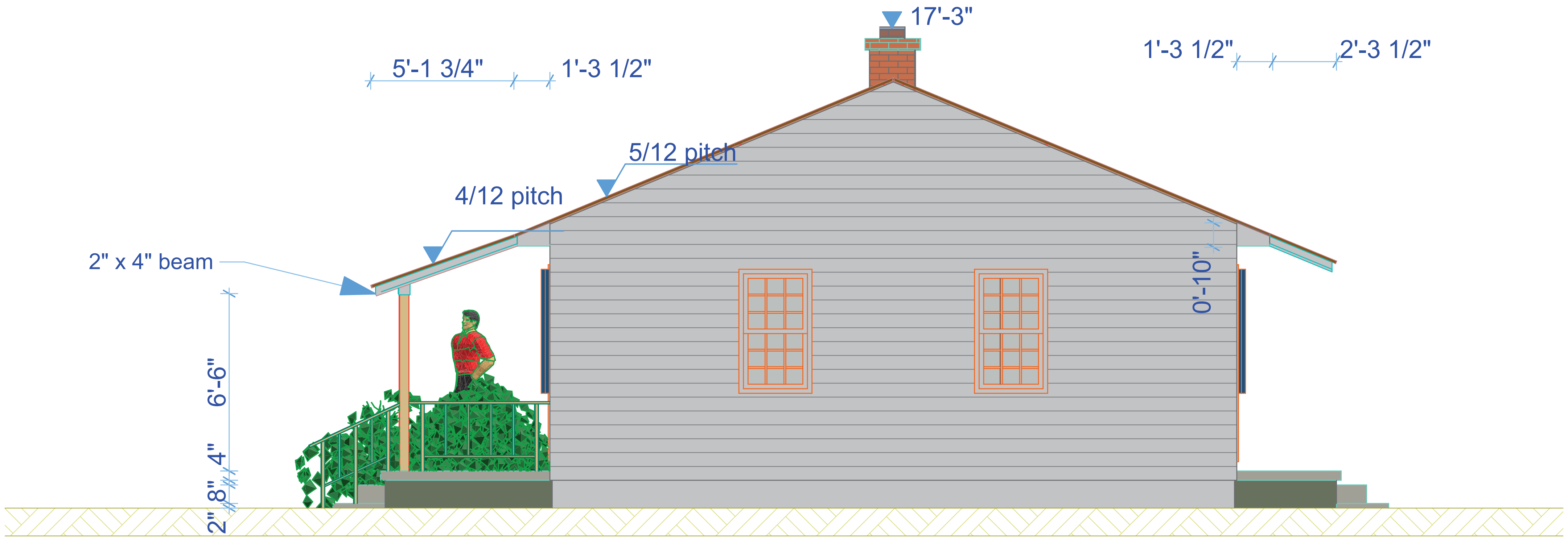

South Elevation

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210 Technology Circle
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GA 31407,
United States

Job Title
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City of Savannah
6 E Bay St
Savannah,
GA 31401,
United States

Drawing Name
North Elevation, South Elevation

Drawing Status
As-built drawings

Drawn by	Date
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Checked by	Date

Drawing Scale
ISO A3, 1" = 5'

Layout ID	Status	Revision
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ARCHICAD EDUCATION VERSION
GRAPHISOFT.

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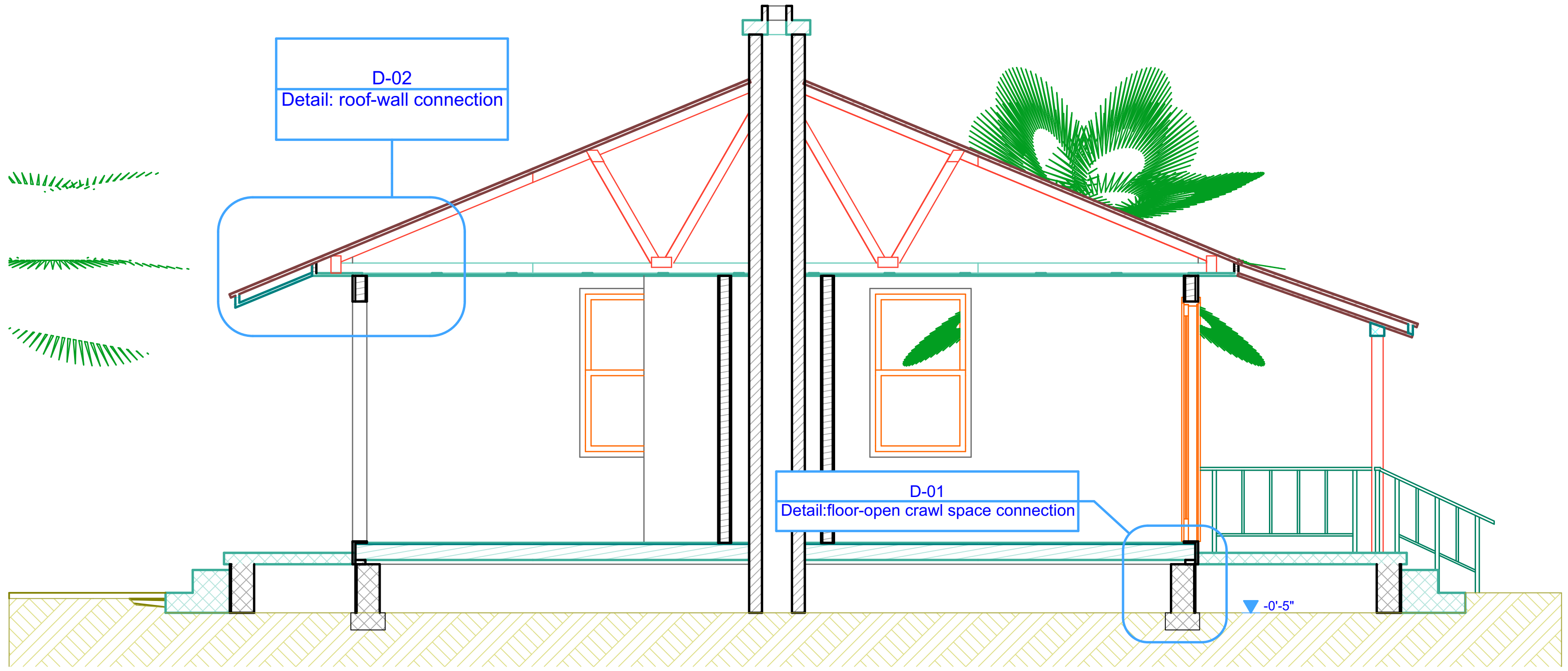
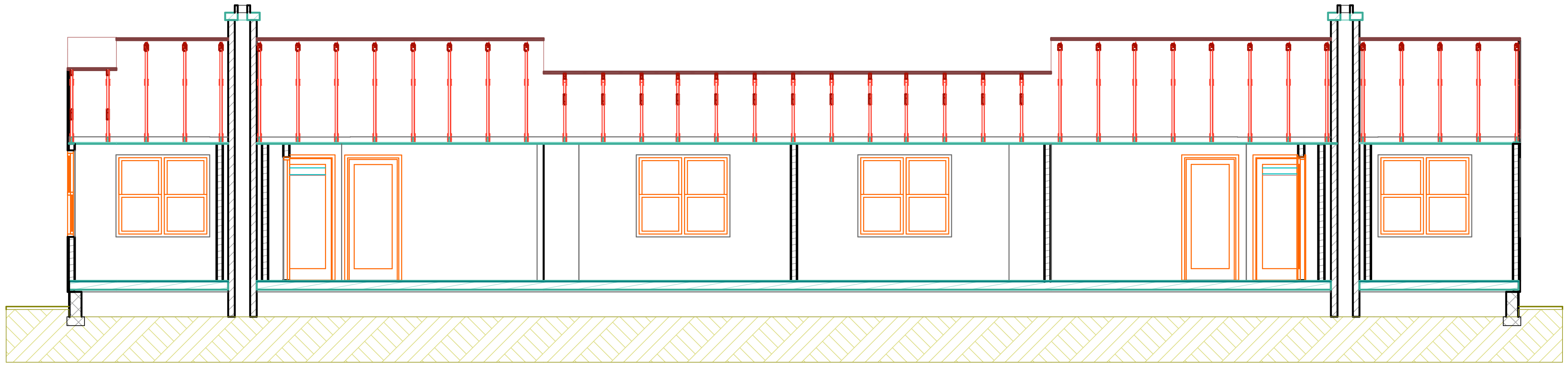


S-01 West-East Section (N to S)

1/8" = 1'-0"



S-02 North-South Section (W to E)

Company Title

Georgia Institute of Technology

Georgia Insititute of Technology
2010 Technology Circle
Savannah,
GA 31407,
United States

Job Title
Redesigning 1940's duplex
City of Savannah
6 E Bay St
Savannah,
GA 31401,
United States

Drawing Name
West-East Section (N to S), North-South Section (W to E)

Drawing Status
As-built drawings

Drawn by	Date
Andreas Karl	**09/14/2014**
Checked by	Date

Drawing Scale
ISO A3, 1" = 5', 1/8" = 1'-0"

Layout ID	Status	Revision
A.03.1		**2.1**

ARCHICAD EDUCATION VERSION
GRAPHISOFT.

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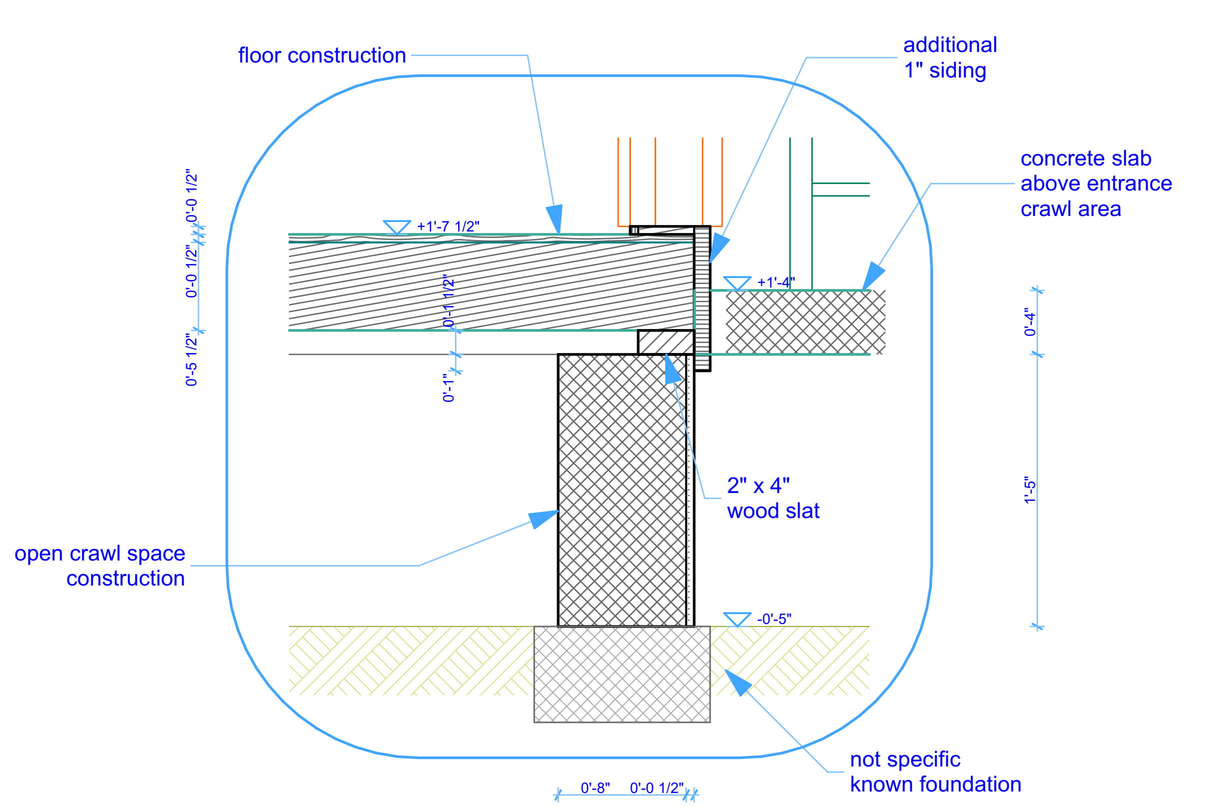
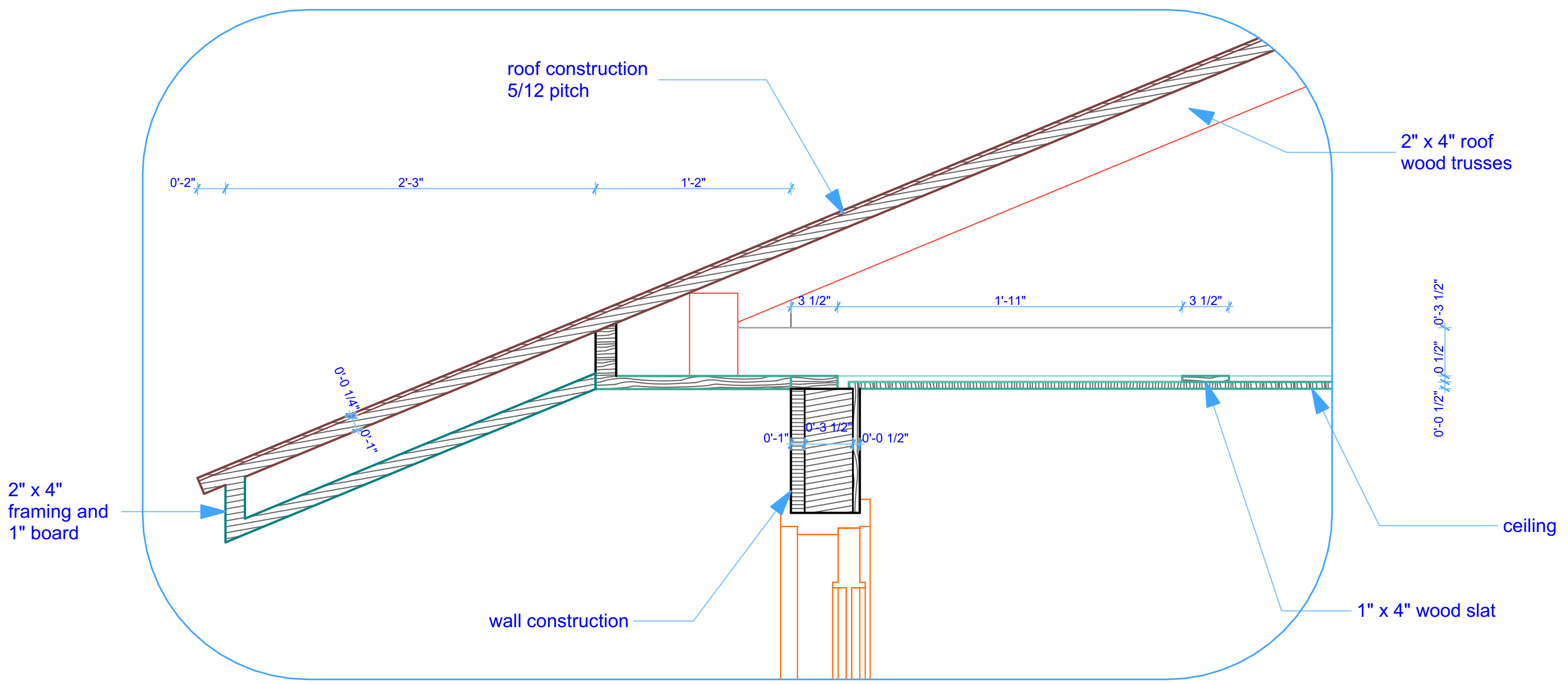


D-01

Detail:Floor to open crawl space connection

1" = 1'-0"



D-02

Detail:Roof to wall connection

Company Title

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Georgia Insititute of Technology
2010 Technology Circle
Savannah,
GA 31407,
United States

Job Title

Redesigning 1940's duplex
City of Savannah
6 E Bay St
Savannah,
GA 31401,
United States

Drawing Name

Detail:Floor to open crawl space connection, Detail:Roof to wall connection

Drawing Status

As-built drawings

Drawn by	Date
Andreas Karl	**09/14/2014**
Checked by	Date

Drawing Scale

ISO A3, 1" = 1'-0"

Layout ID	Status	Revision
A.03.2		**2.1**

ARCHICAD EDUCATION VERSION
GRAPHISOFT.

Sheet Index

Layout ID	Layout Name	Published	Remark
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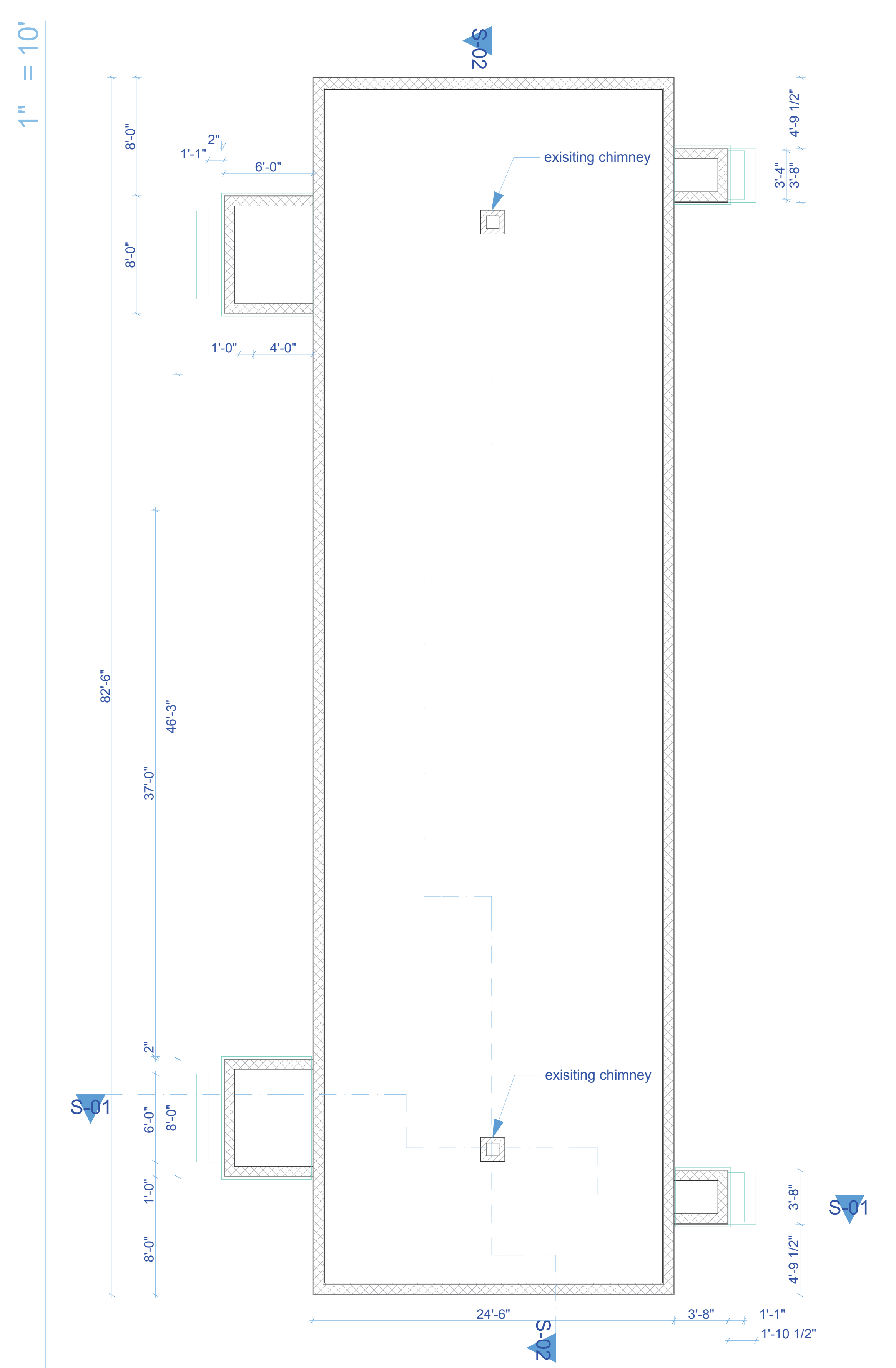
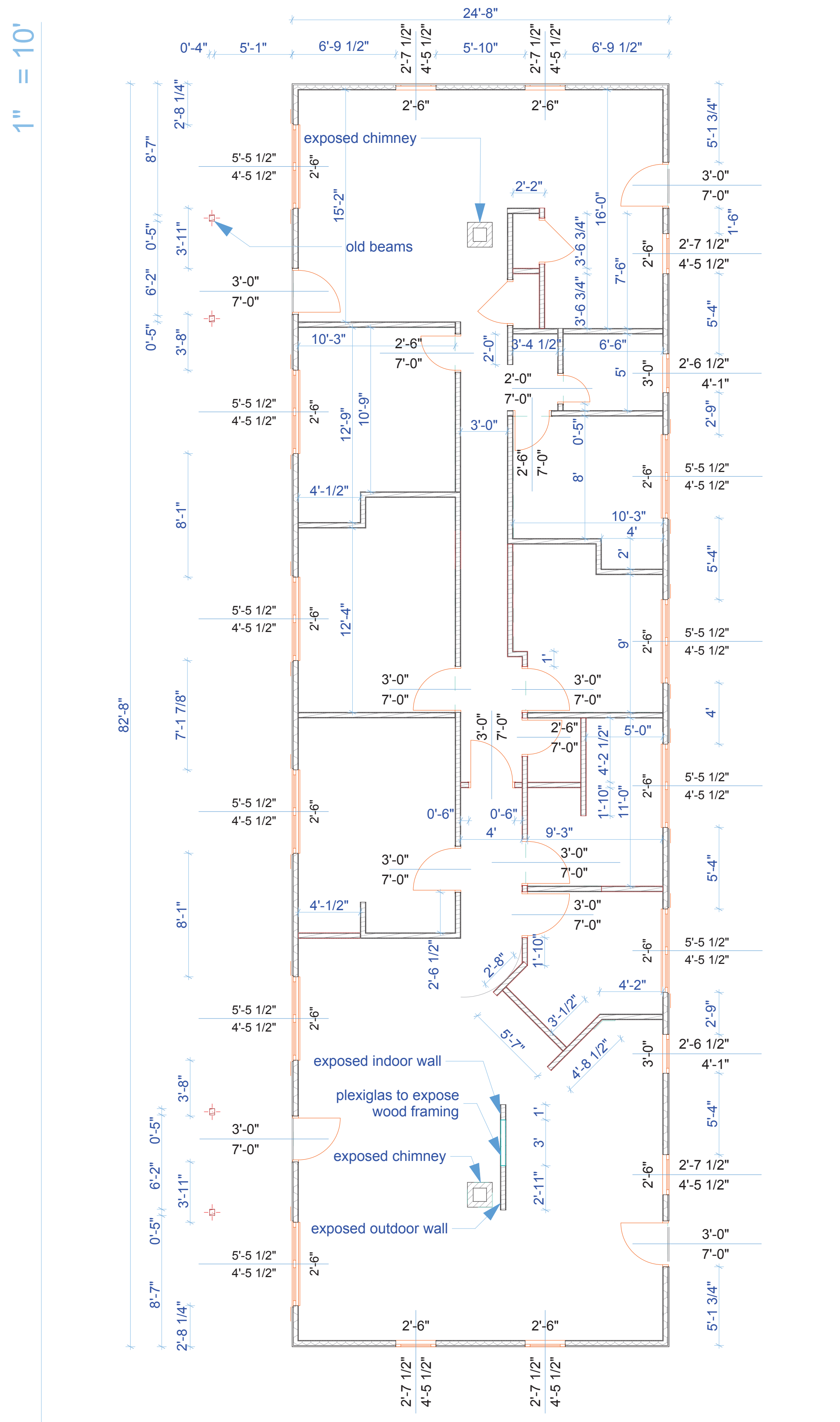
A.01.1	Floorplans	☐	
A.01.2	Roof and Ceiling	☐	
A.01.3	Furnishing Plan	☐	
A.01.4	Zoning Plan	☐	
A.02.1	Sections	☐	
A.02.2	Details	☐	
A.03.1	East and West Elevation	☐	
A.03.2	North and South Elevation	☐	

Georgia Insititute of Technology 210 Technology Circle Savannah, GA 31407 United States	Drawn by **Andreas Karl** — Date **04/16/2014** Checked by — Date	Drawing Name **Sheet Index** Drawing Status **Proposed plans**
City of Savannah 6 E Bay St Savannah GA 31401, United States	**Redesigning 1940's duplex**	Drawing Scale **varies** Layout ID — Status — Revision

ARCHICAD EDUCATION VERSION
GRAPHISOFT.



-1. open crawl space



0. ground floor

Company Title

Georgia Insititute of Technology

210 Technology Circle
Savannah,
GA 31407,
United States

Job Title

Redesigning 1940's duplex City of Savannah

6 E Bay St
Savannah,
GA 31401,
United States

Drawing Name

open crawl space, ground floor

Drawing Status

Proposed plans

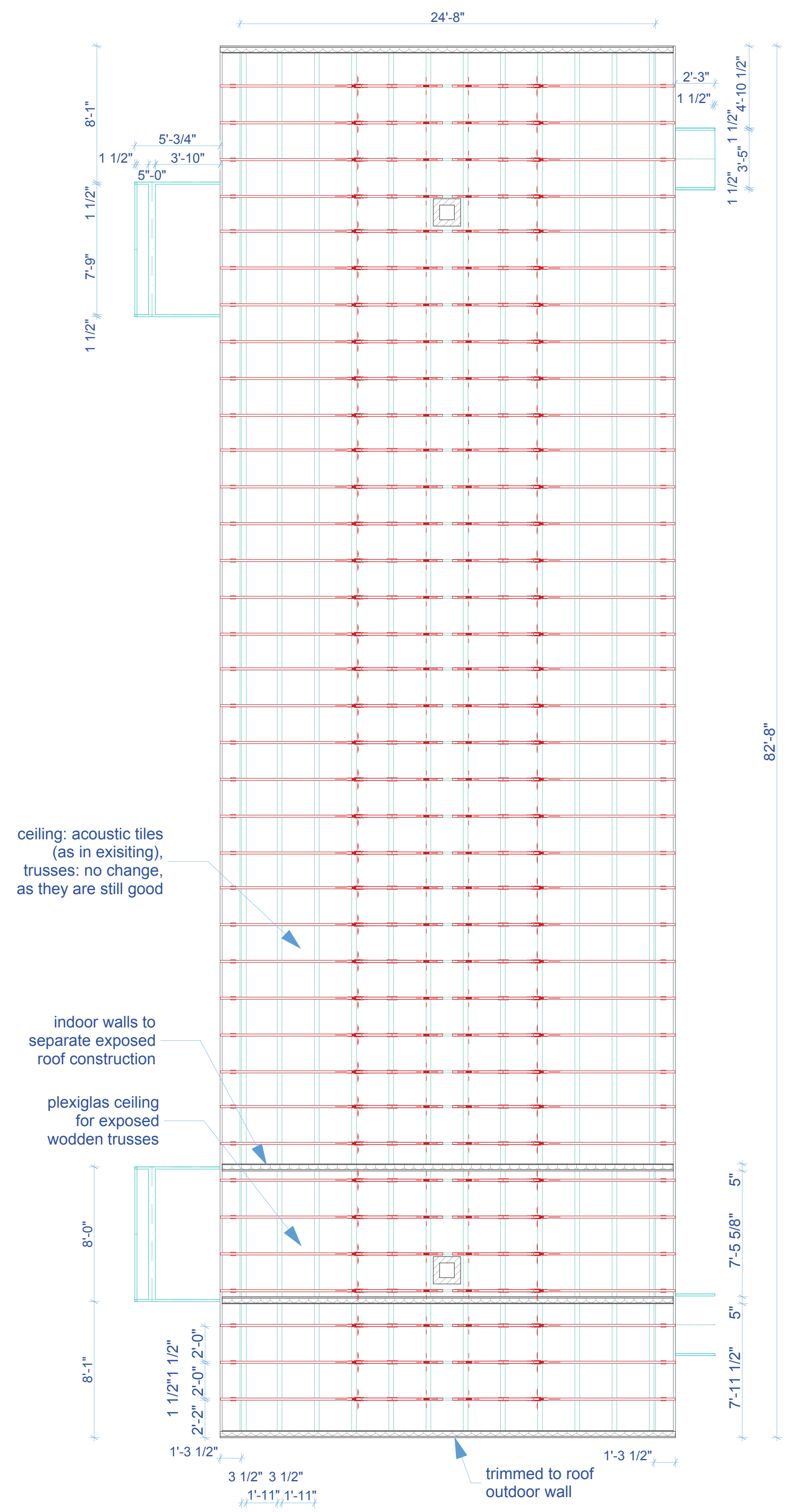
Drawn by	Date
Andreas Karl	**04/10/2014**
Checked by	Date

Drawing Scale

ISO A3, 1" = 10'

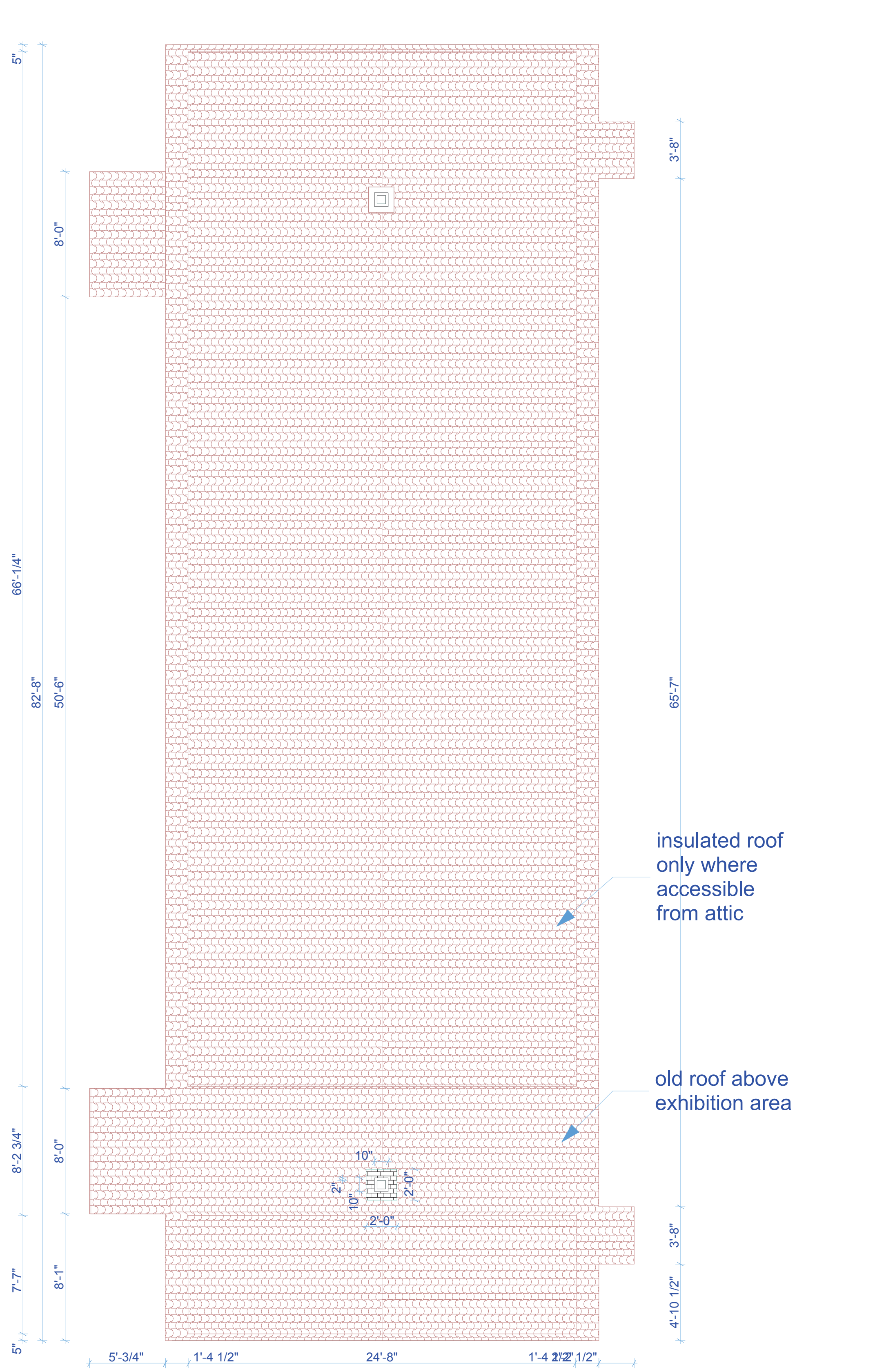
Layout ID	Status	Revision
A.01.1		**2.0**

1" = 10'



1. attic

1" = 10'



2. roof

Company Title

Georgia Institute of Technology

Georgia Insititute of Technology
210 Technology Circle
Savannah,
GA 31407,
United States

Job Title
Redesigning 1940's duplex
City of Savannah
6 E Bay St
Savannah,
GA 31401,
United States

Drawing Name
attic, roof

Drawing Status
Proposed plans

Drawn by	Date
Andreas Karl	**04/10/2014**
Checked by	Date

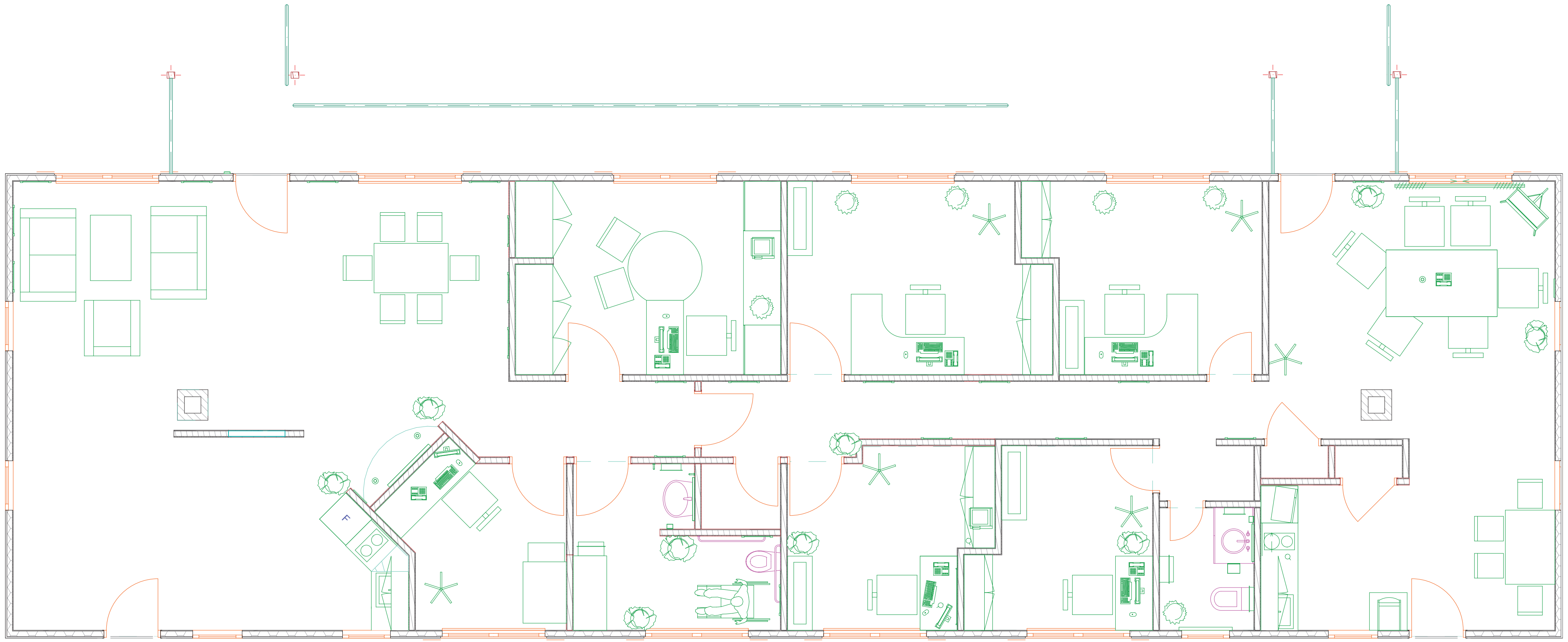
Drawing Scale
ISO A3, 1" = 10'

Layout ID	Status	Revision
A.01.2		**2.0**

ARCHICAD EDUCATION VERSION
GRAPHISOFT

0.

1/8" = 1'-0"



ground floor furnished

Company Title

Georgia Insititute of Technology
210 Technology Circle
Savannah,
GA 31407,
United States

Job Title
Redesigning 1940's duplex
City of Savannah
6 E Bay St
Savannah,
GA 31401,
United States

Drawing Name
ground floor furnished

Drawing Status
Proposed plans

Drawn by	Date
Andreas Karl	**04/10/2014**
Checked by	Date

Drawing Scale
ISO A3, 1/8" = 1'-0"

Layout ID	Status	Revision
A.01.3		**2.0**

ARCHICAD EDUCATION VERSION
GRAPHISOFT

Company Title

Georgia Institute of Technology
210 Technology Circle
Savannah,
GA 31407,
United States

Job Title

Redesigning 1940's duplex City of Savannah

6 E Bay St
Savannah,
GA 31401,
United States

Drawing Name

Ground floor zoning, Attic zoning

Drawing Status

Proposed plans

Drawn by: **Andreas Karl**
Date: **04/10/2014**

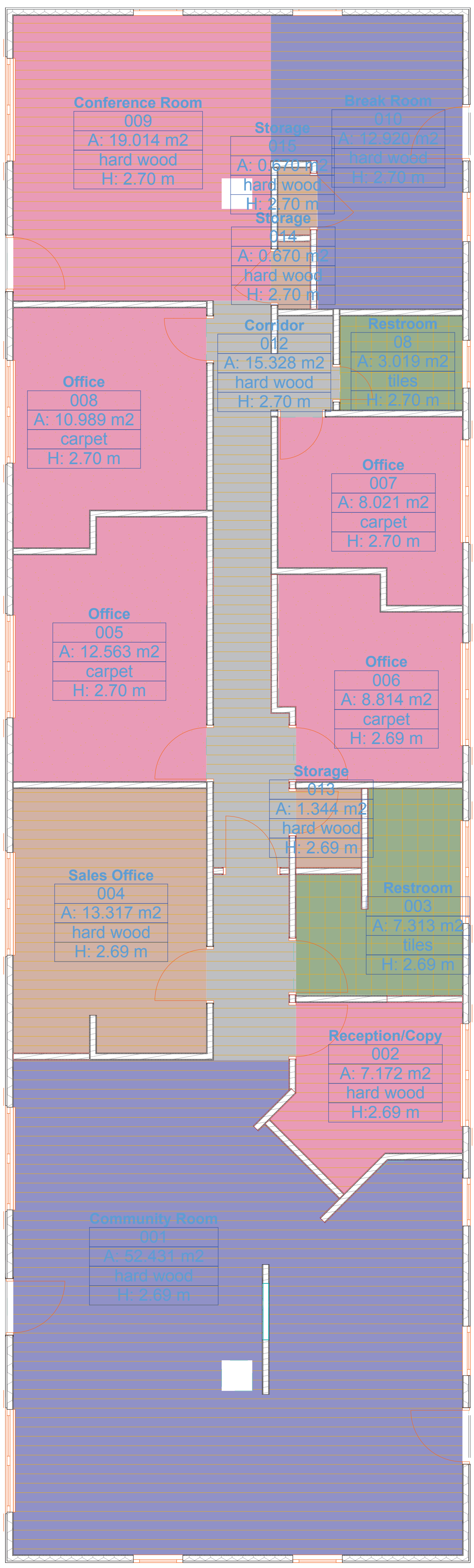
Checked by
Date

Drawing Scale

ISO A3, 1/8" = 1'-0"

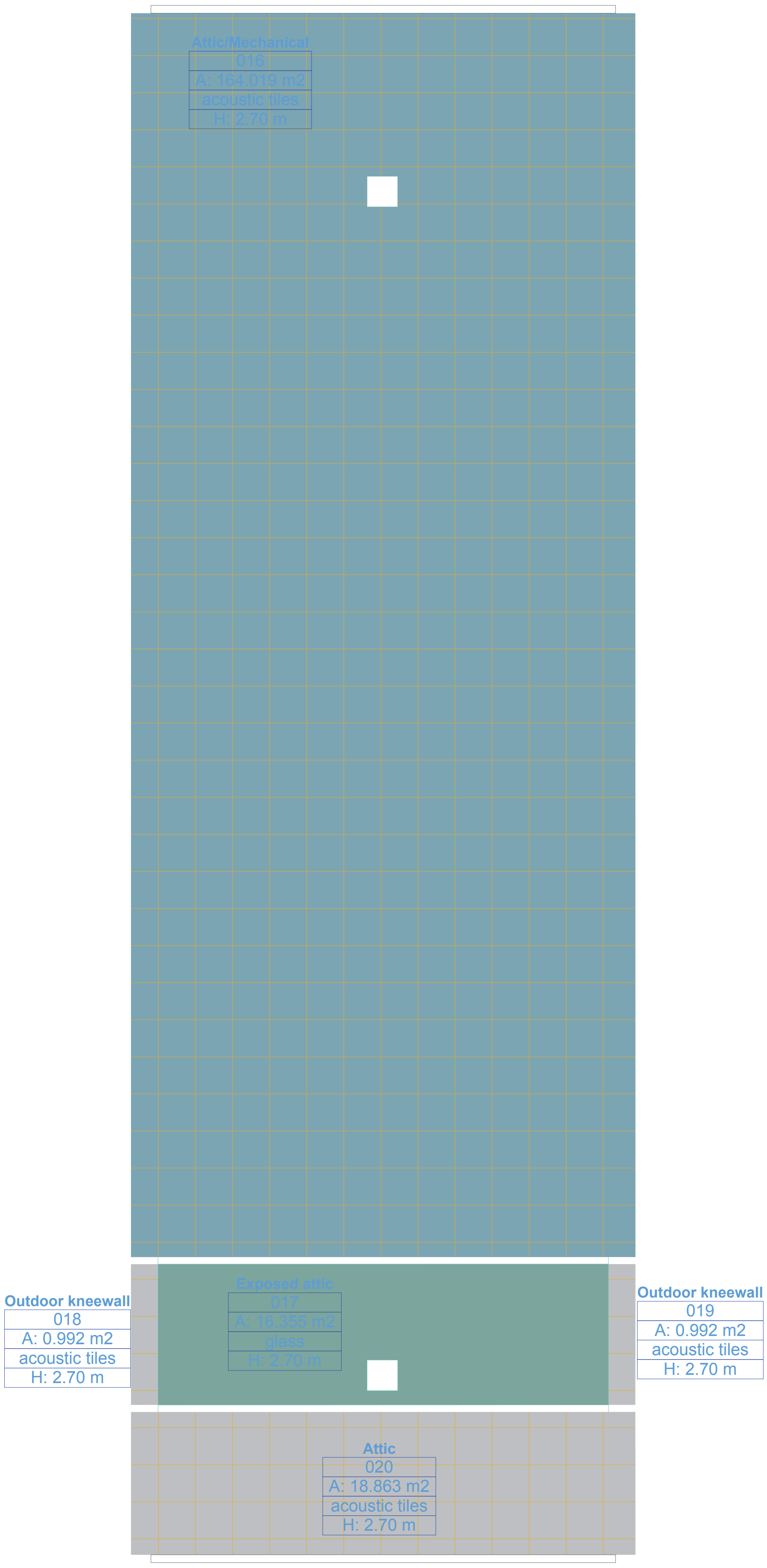
Layout ID: **A.01.4**
Status
Revision: **2.0**

1/8" = 1'-0"



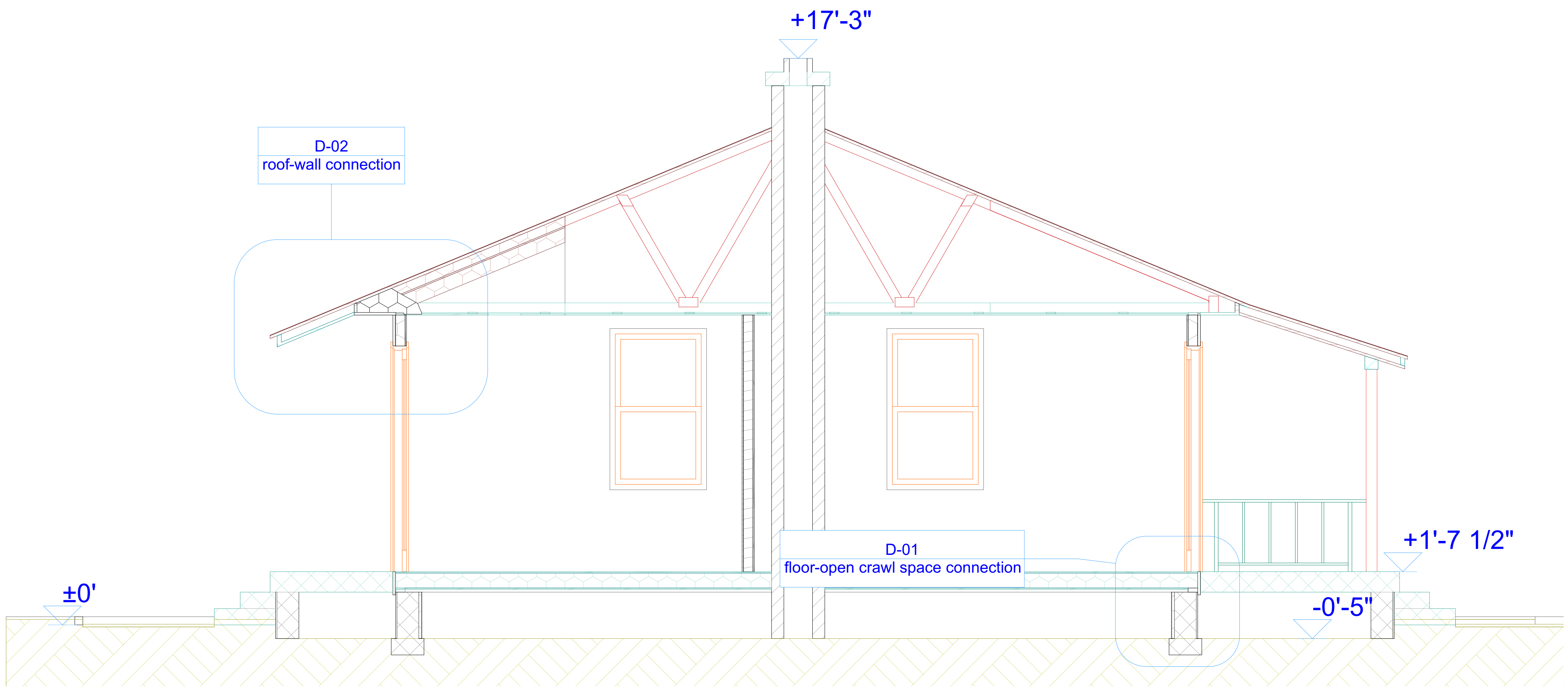
0. Ground floor zoning

1/8" = 1'-0"

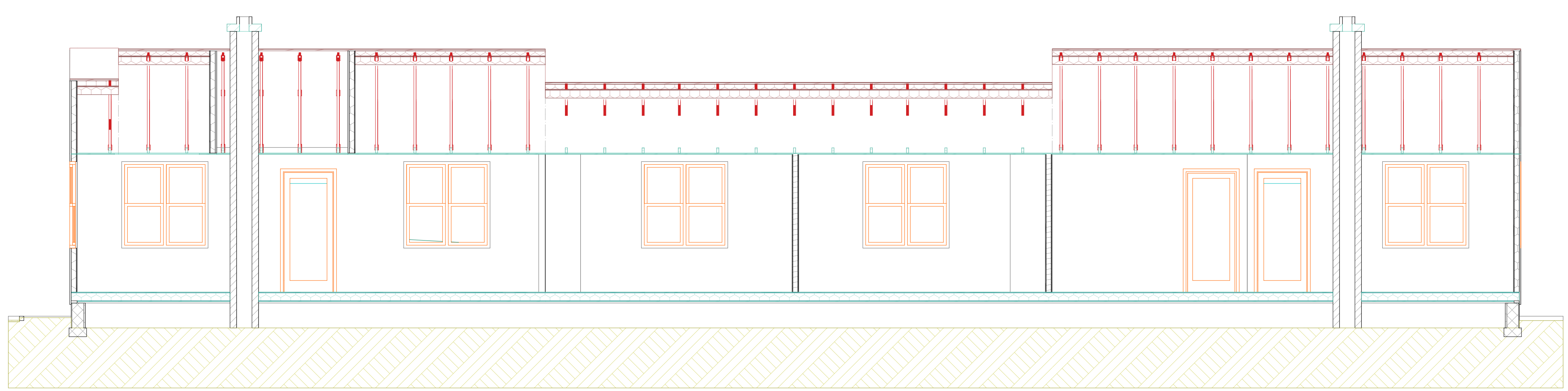


1. Attic zoning

ARCHICAD EDUCATION VERSION
GRAPHISOFT.



S-01 North-South Section (W to E) 1/4" = 1'-0"



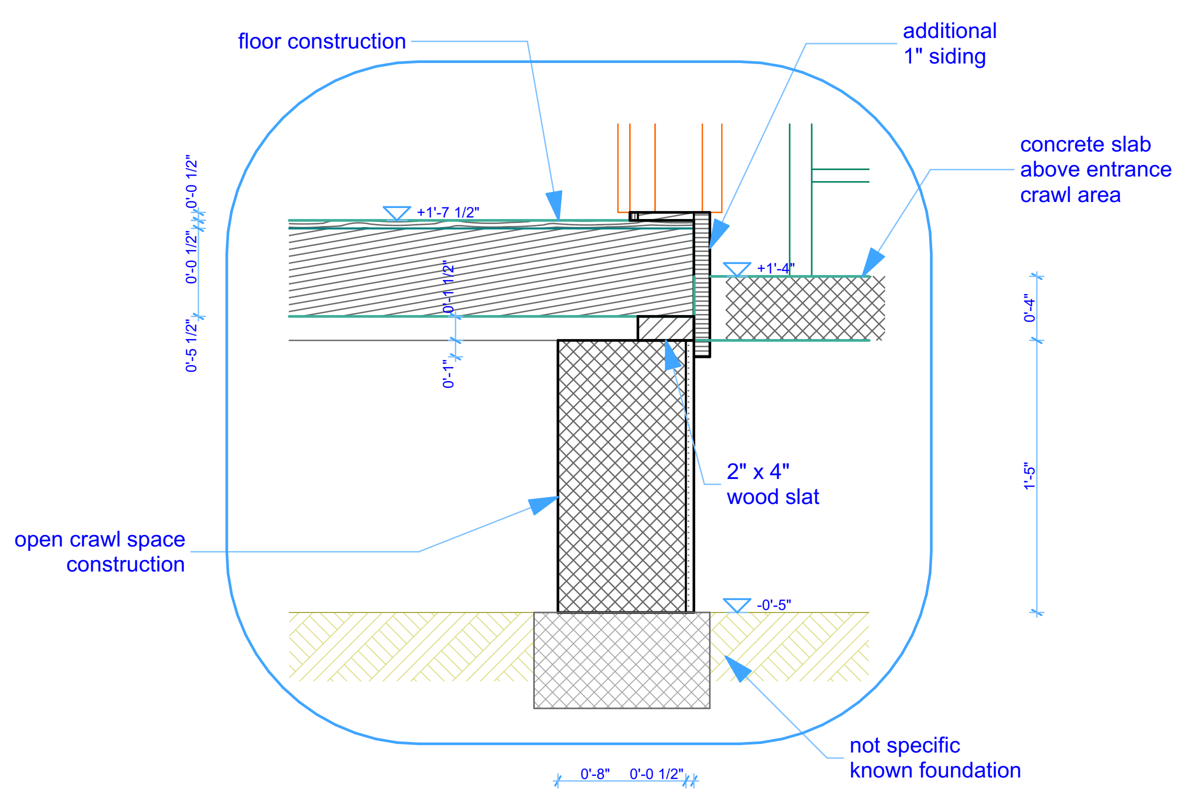
1/8" = 1'-0"

S-02 West-East Section (N to S)

Company Title	
Georgia Insititute of Technology 210 Technology Circle Savannah GA 31407	
Job Title	
Redesigning 1940's duplex **City of Savannah** 6 E Bay St Savannah GA 31401	
Drawing Name	
North-South Section (W to E), West-East Section (N to S)	
Drawing Status	
proposed plans	
Drawn by **Andreas Karl**	Date **04/10/2014**
Checked by **Andreas Karl**	Date
Drawing Scale	
ANSI B, 1/4" = 1'-0", 1/8" = 1'-0"	
Layout ID **A.02.1**	Status / Revision **1.0**

ARCHICAD EDUCATION VERSION
GRAPHISOFT.

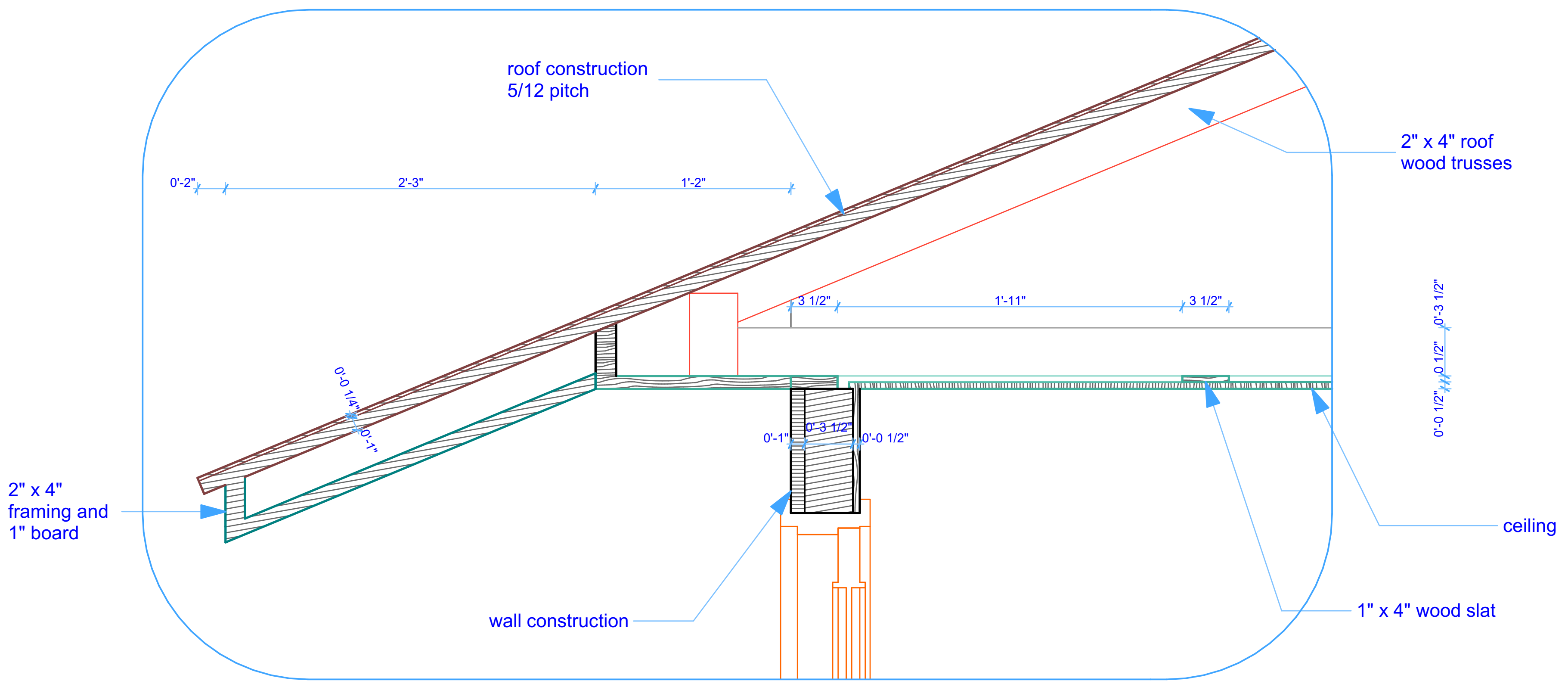
1" = 1'-0"



D-01

Detail:Floor to open crawl space connection

1" = 1'-0"



D-02

Detail:Roof to wall connection

Company Title

Georgia Institute of Technology

Georgia Insititute of Technology
2010 Technology Circle
Savannah,
GA 31407,
United States

Job Title

Redesigning 1940's duplex
City of Savannah
6 E Bay St
Savannah,
GA 31401,
United States

Drawing Name

Detail:Floor to open crawl space connection, Detail:Roof to wall connection

Drawing Status

As-built drawings

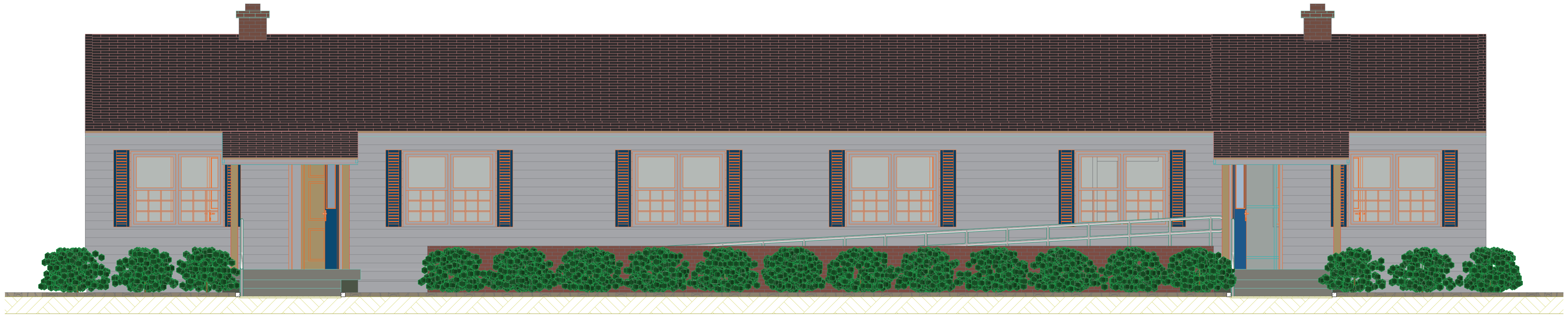
Drawn by	Date
Andreas Karl	**09/14/2014**
Checked by	Date

Drawing Scale

ISO A3, 1" = 1'-0"

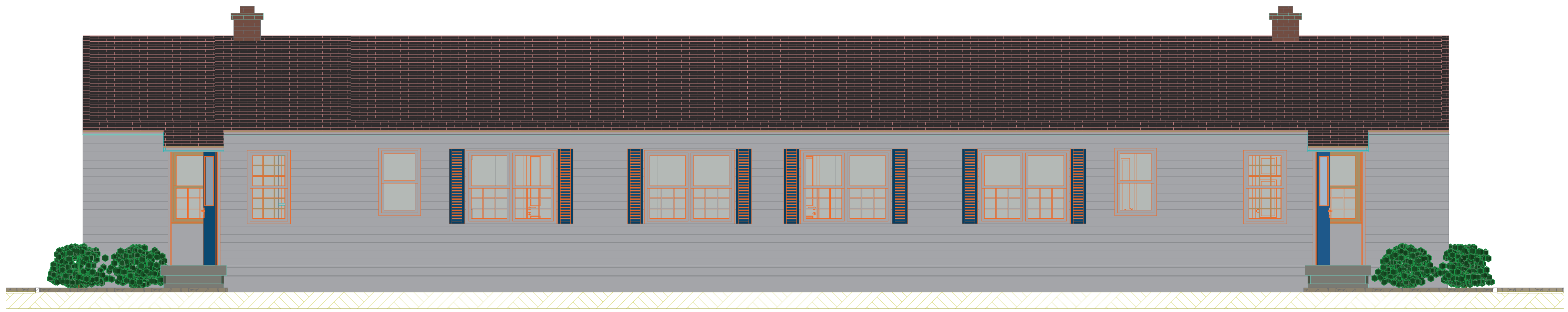
Layout ID	Status	Revision
A.03.2		**2.1**

1/8" = 1'-0"



West Elevation

1/8" = 1'-0"



East Elevation

Company Title

Georgia Insititute of Technology

210 Technology Circle
Savannah,
GA 31407,
United States

Job Title

Redesigning 1940's duplex
City of Savannah

6 E Bay St
Savannah,
GA 31401,
United States

Drawing Name

East Elevation, West Elevation

Drawing Status

Proposed plans

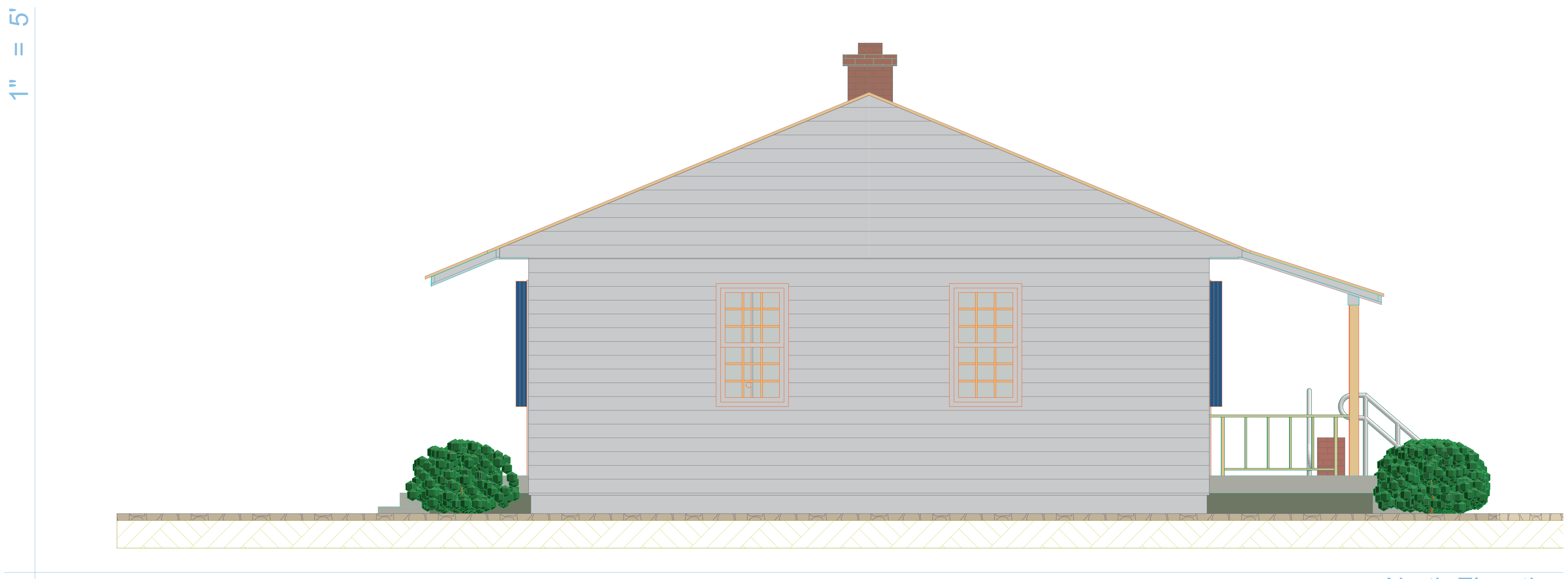
Drawn by	Date
Andreas Karl	04/10/2014
Checked by	Date

Drawing Scale

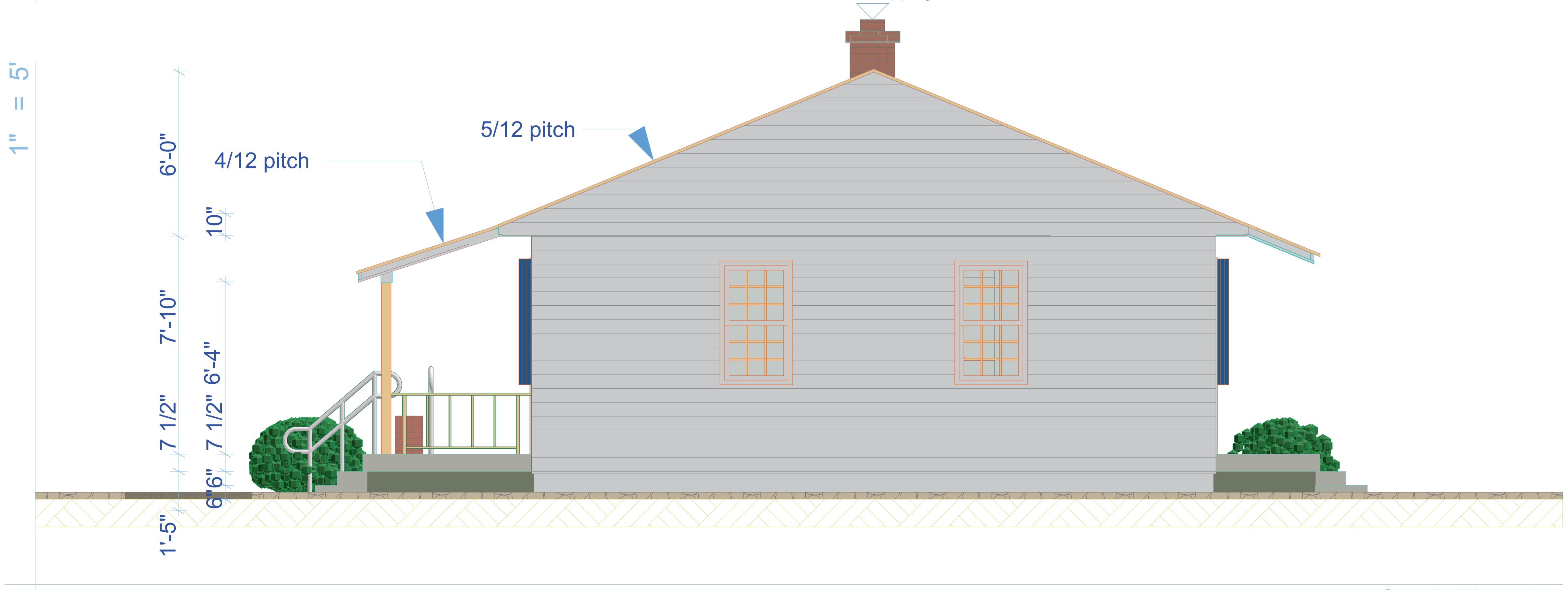
ISO A3, 1/8" = 1'-0"

Layout ID	Status	Revision
A.03.1		2.0

ARCHICAD EDUCATION VERSION
GRAPHISOFT



North Elevation



South Elevation

Company Title

Georgia Institute of Technology

Georgia Insititute of Technology
210 Technology Circle
Savannah,
GA 31407,
United States

Job Title

Redesigning 1940's duplex
City of Savannah
6 E Bay St
Savannah,
GA 31401,
United States

Drawing Name

North Elevation, South Elevation

Drawing Status

Proposed plans

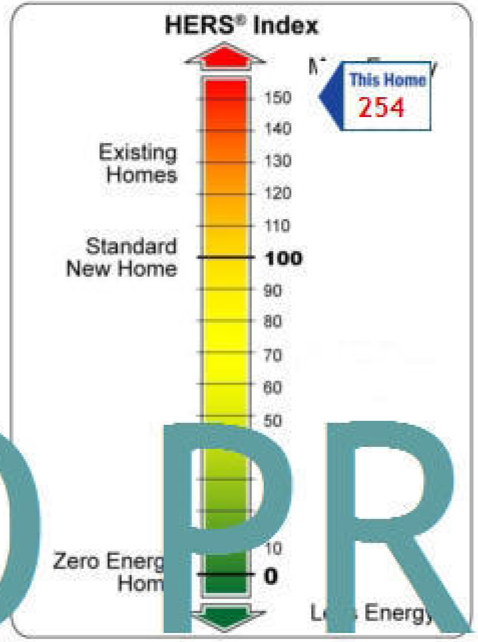
Drawn by	Date
Andreas Karl	**04/10/2014**
Checked by	Date

Drawing Scale

ISO A3, 1" = 5'

Layout ID	Status	Revision
A.03.2		**2.0**

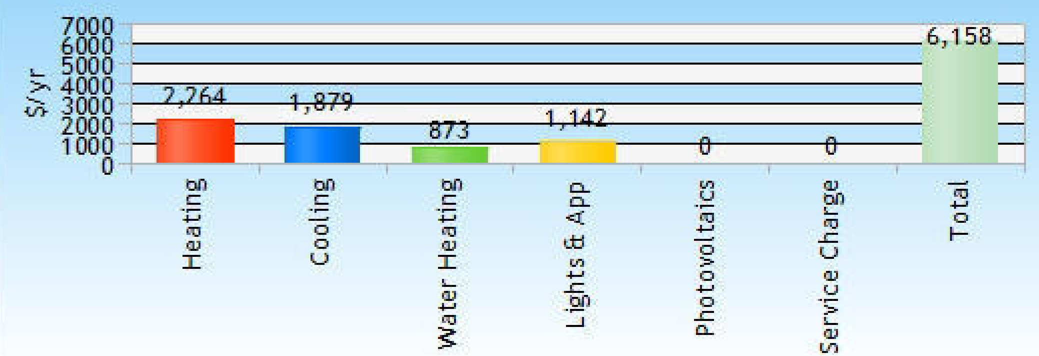
HOME PERFORMANCE WITH ENERGY STAR



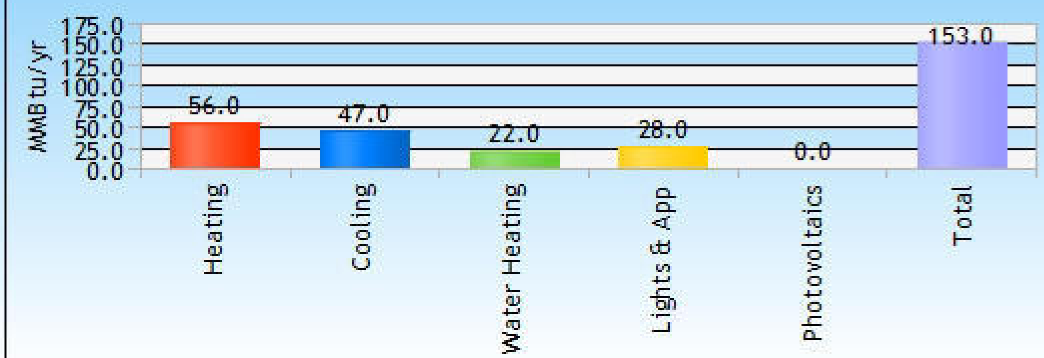
ENERGY RATING CERTIFICATE

Projected Rating: Based on Plans - Field Confirmation Required.

Estimated Annual Energy Cost



Estimated Annual Energy Consumption

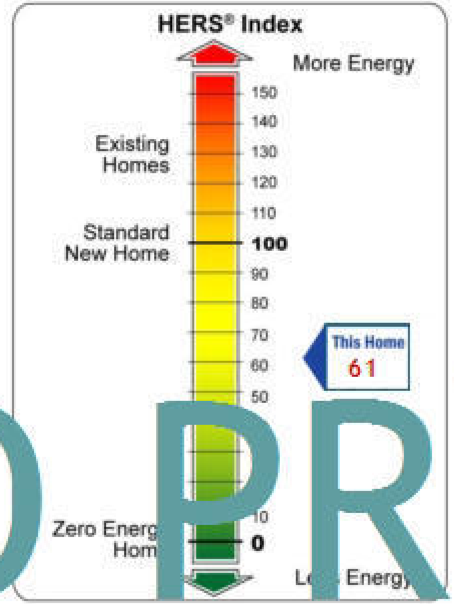


Address	Crescent Drive 520-522	Annual Estimates*		TITLE	
	Savannah, GA 31401	Electric(kWh):	44848	Company	
House Type	Single-family detached	C02 emissions(Tons):	29	Address	
Cond. Area	1880 sq. ft.	Annual Savings**:	$0	Certified Rater	Andreas Karl
Rating No.	1			Rater ID	
Issue Date	June 03, 2014	* Based on standard operating conditions		Registry ID	
Certification	Verified	** Based on a HERS 130 Index Home		Rating Date	03/28/14

REM/Rate - Residential Energy Analysis and Rating Software v14.4.1

The Home Energy Rating Standard Disclosure for this home is available from the rating provider.

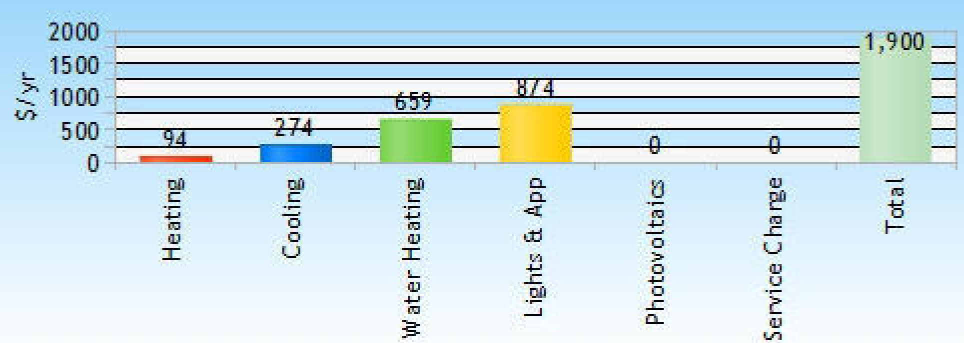
HOME PERFORMANCE WITH ENERGY STAR



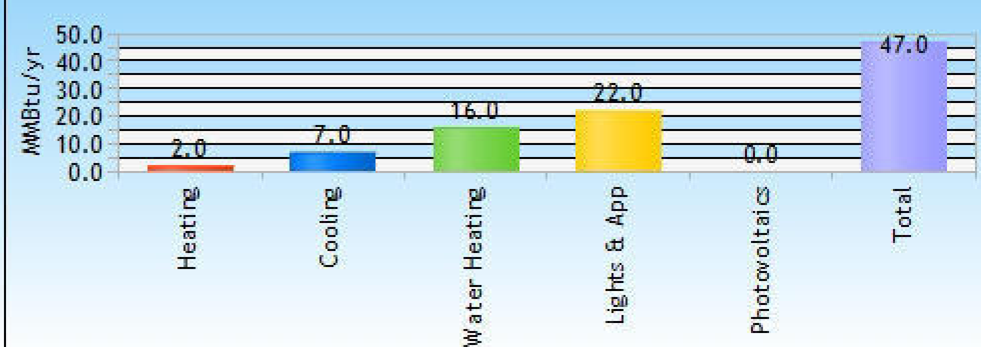
ENERGY RATING CERTIFICATE

Projected Rating: Based on Plans - Field Confirmation Required.

Estimated Annual Energy Cost



Estimated Annual Energy Consumption

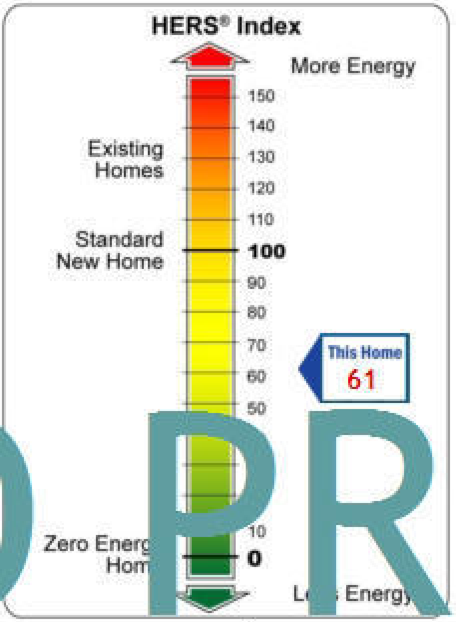


Address	Crescent Drive 520-522	Annual Estimates*	TITLE	
	Savannah, GA 31401	Electric(kWh): 13827	Company	
House Type	Single-family detached	C02 emissions(Tons): 9	Address	
Cond. Area	1880 sq. ft.	Annual Savings**: $1517	Certified Rater	Andreas Karl
Rating No.	1		Rater ID	
Issue Date	June 02, 2014	* Based on standard operating conditions	Registry ID	
Certification	Verified	** Based on a HERS 130 Index Home	Rating Date	03/28/14

REM/Rate - Residential Energy Analysis and Rating Software v14.4.1

The Home Energy Rating Standard Disclosure for this home is available from the rating provider.

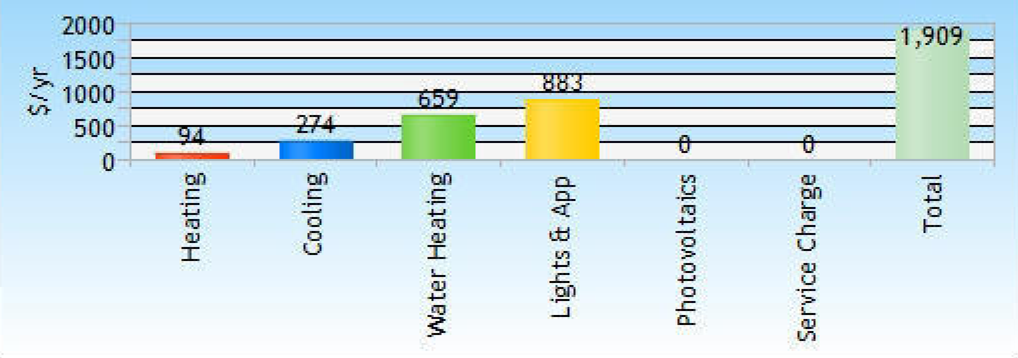
HOME PERFORMANCE WITH ENERGY STAR



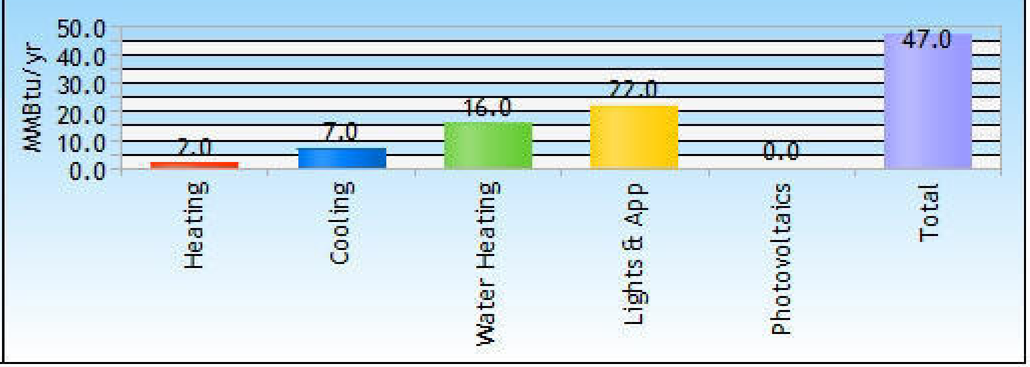
ENERGY RATING CERTIFICATE

Projected Rating: Based on Plans - Field Confirmation Required.

Estimated Annual Energy Cost



Estimated Annual Energy Consumption



Address	Crescent Drive 520-522
	Savannah, GA 31401
House Type	Single-family detached
Cond. Area	1880 sq. ft.
Rating No.	1
Issue Date	June 03, 2014
Certification	Verified

Annual Estimates*
Electric(kWh): 13892
C02 emissions(Tons): 9
Annual Savings**: $1508

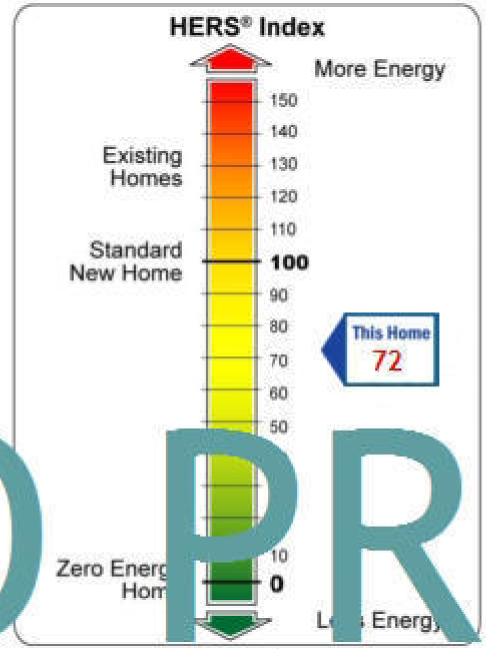
* Based on standard operating conditions
** Based on a HERS 130 Index Home

TITLE	
Company	
Address	
Certified Rater	Andreas Karl
Rater ID	
Registry ID	
Rating Date	03/28/14

REM/Rate - Residential Energy Analysis and Rating Software v14.4.1

The Home Energy Rating Standard Disclosure for this home is available from the rating provider.

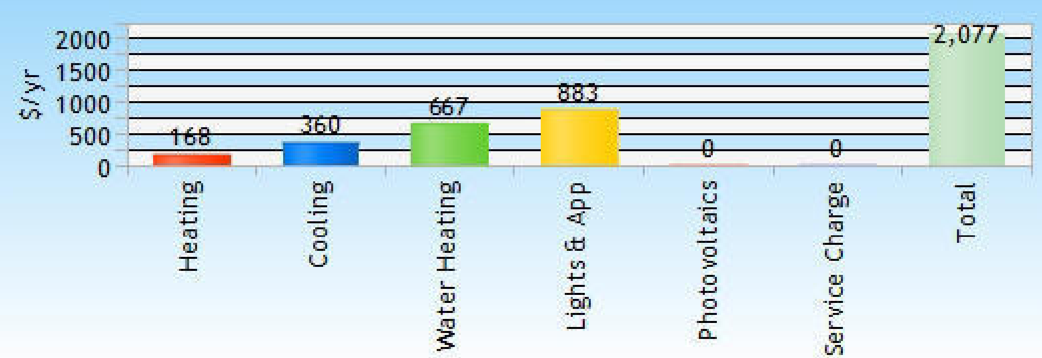
HOME PERFORMANCE WITH ENERGY STAR



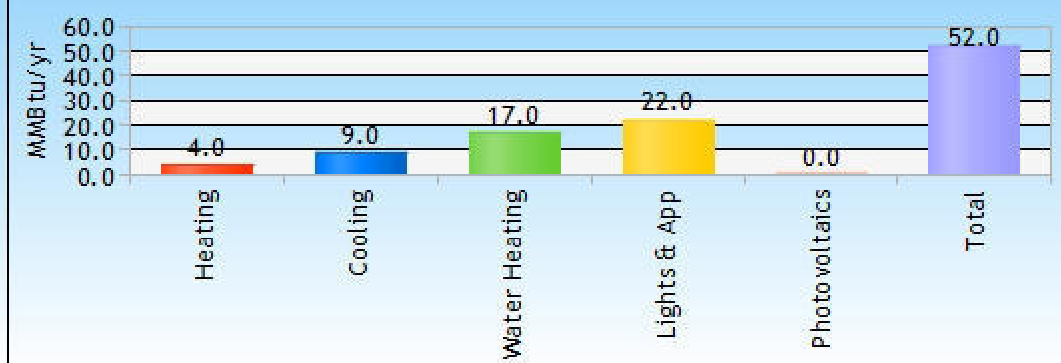
ENERGY RATING CERTIFICATE

Projected Rating: Based on Plans - Field Confirmation Required.

Estimated Annual Energy Cost



Estimated Annual Energy Consumption



Address	Crescent Drive 520-522	Annual Estimates*		TITLE	
	Savannah, GA 31401	Electric(kWh):	15113	Company	
House Type	Single-family detached	C02 emissions(Tons):	10	Address	
Cond. Area	1880 sq. ft.	Annual Savings**:	$1331	Certified Rater	Andreas Karl
Rating No.	1			Rater ID	
Issue Date	June 10, 2014	* Based on standard operating conditions		Registry ID	
Certification	Verified	** Based on a HERS 130 Index Home		Rating Date	03/28/14

REM/Rate - Residential Energy Analysis and Rating Software v14.4.1

The Home Energy Rating Standard Disclosure for this home is available from the rating provider.

DOE Based Sizing

PROJECT SUMMARY

Short Desc:	Duplex Savannah	**Description:**	Duplex Savannah
Owner:	City of Savannah		
Address1:	522 E Crescent Drive	**City:**	Savannah
Address2:		**State:**	GA
		Zip:	31401
Type:	Office	**Class:**	New Shell building
Weather File:	GA_SAVANNAH_INTL_AP.tm3		
Conditioned Area:	2048 SF	**Conditioned & UnConditioned Area:**	4096 SF
No of Stories:	1	**Area entered from Plans**	0 SF
Permit No:	0	**Max Tonnage**	3
		If different, write in:	______________________

CERTIFICATIONS

I hereby certify that the plans and specifications covered by this calculation are in compliance as required by the authority of jurisdiction

Prepared By: ___________________ Building Official: ___________________

Date: __________________ Date: ___________________

I certify that this building is in compliance as required by the authority of jurisdiction

Owner Agent: ___________________ Date: ___________________

If required by law, I hereby certify (*) that the system design is in compliance as required by the authority of jurisdiction

Architect: ___________________ Reg No: ___________________

Electrical Designer: ___________________ Reg No: ___________________

Lighting Designer: ___________________ Reg No: ___________________

Mechanical Designer: ___________________ Reg No: ___________________

Plumbing Designer: ___________________ Reg No: ___________________

(*) Signature may be required when law requires design to be performed by registered design professionals. Typed names and registration numbers may be used where all relevant information is contained on signed/sealed plans.

DOE 2.1 E Based Sized Parameters (Beta Feature)

IdSystem	System Name	System Type
1	**Heat Pump**	System 2

Component	Sized Value	Units
Cooling System	48810	BTU/HR
Heating System	38240	Btu/h
Handling System -Supply	1069	CFM
Distribution System (Sup)	0	
Distribution System (Ret)	0	

DOE Based Sizing

PROJECT SUMMARY

Short Desc:	Duplex Savannah	**Description:**	Duplex Savannah
Owner:	City of Savannah		
Address1:	522 E Crescent Drive	**City:**	Savannah
Address2:		**State:**	GA
		Zip:	31401
Type:	Office	**Class:**	New Shell building
Weather File:	GA_SAVANNAH_INTL_AP.tm3		
Conditioned Area:	2048 SF	**Conditioned & UnConditioned Area:**	4096 SF
No of Stories:	1	**Area entered from Plans**	0 SF
Permit No:	0	**Max Tonnage**	5
		If different, write in:	______________________

CERTIFICATIONS

I hereby certify that the plans and specifications covered by this calculation are in compliance as required by the authority of jurisdiction

Prepared By:	__________________	Building Official:	__________________
Date:	__________________	Date:	__________________

I certify that this building is in compliance as required by the authority of jurisdiction

Owner Agent:	__________________	Date:	__________________

If required by law, I hereby certify (*) that the system design is in compliance as required by the authority of jurisdiction

Architect:	__________________	Reg No:	__________________
Electrical Designer:	__________________	Reg No:	__________________
Lighting Designer:	__________________	Reg No:	__________________
Mechanical Designer:	__________________	Reg No:	__________________
Plumbing Designer:	__________________	Reg No:	__________________

(*) Signature may be required when law requires design to be performed by registered design professionals. Typed names and registration numbers may be used where all relevant information is contained on signed/sealed plans.

DOE 2.1 E Based Sized Parameters (Beta Feature)

IdSystem	System Name	System Type
1	**Heat Pump**	System 2

Component	Sized Value	Units
Cooling System	49230	BTU/HR
Heating System	27430	Btu/h
Handling System -Supply	1084	CFM
Distribution System (Sup)	0	
Distribution System (Ret)	0	

TRNSYS RESULTS *w/o passive cooling*		SALES	COMM	OFFICE A	OFFICE B	OFFICE C	OFFICE D	REST A	REST B	CONF	BREAK	CORR	BLDG
A useful	*[sqft]*	143	681	135	118	88	95	32	79	205	139	165	**1880**
V useful	*[cft]*	1108	5278	1046	915	682	736	248	612	1589	1077	1279	**14570**
A useful	*[m2]*	13.3	63.3	12.5	11.0	8.2	8.8	3.0	7.3	19.0	12.9	15.3	**174.7**
V useful	*[m3]*	103.0	490.3	97.2	85.0	63.4	68.4	23.0	56.9	147.6	100.1	118.8	**1353.6**
Qheat	*[kWh/a]*	176	1945	184	134	79	76	35	132	301	261	52	**3375**
Qheat,spec,sqft	*[kWh/a*sqft]*	1.23	2.86	1.36	1.14	0.90	0.80	1.09	1.67	1.47	1.88	0.32	**1.80**
Qheat,spec,sqm	*[kWh/a*m ^{2}]*	13.25	30.74	14.67	12.22	9.66	8.61	11.77	17.99	15.80	20.21	3.39	**19.32**
Qcool	*[kWh/a]*	572	4270	872	1144	1341	1256	288	491	1137	583	6	**11960**
Qcool,spec,sqft	*[kWh/a*sqft]*	4.00	6.27	6.46	9.69	15.24	13.22	9.00	6.22	5.55	4.19	0.04	**6.36**
Qcool,spec,sqm	*[kWh/a*m ^{2}]*	43.06	67.49	69.53	104.36	164.03	142.31	96.88	66.90	59.70	45.15	0.39	**68.48**
total demand	*[kWh/a]*	748	6215	1056	1278	1420	1332	323	623	1438	844	58	**15335**
	[mmBtu/a]	2.55	21.19	3.60	4.36	4.84	4.54	1.10	2.12	4.90	2.88	0.20	**52.28**
	*[kWh/a*sqft]*	5.23	9.13	7.82	10.83	16.14	14.02	10.09	7.89	7.01	6.07	0.35	**8.16**
	*[kWh/a*m ^{2}]*	56.30	98.23	84.20	116.58	173.69	150.92	108.65	84.89	75.50	65.36	3.78	**87.80**
total heat elec*	*[mmBtu/a]*	0.15	1.62	0.15	0.11	0.07	0.06	0.03	0.11	0.25	0.22	0.04	**2.81**
total cool heat*	*[mmBtu/a]*	0.34	2.52	0.51	0.68	0.79	0.74	0.17	0.29	0.67	0.34	0.00	**7.06**
energy cost*	*[$/a]*	19.53	166.92	26.94	31.74	34.59	32.46	8.03	16.12	37.17	22.64	1.89	**398.02**
	*[$/a*sqft]*	0.14	0.25	0.20	0.27	0.39	0.34	0.25	0.20	0.18	0.16	0.01	**0.21**

TRNSYS RESULTS													
with passive cooling													
		SALES	**COMM**	**OFFICE A**	**OFFICE B**	**OFFICE C**	**OFFICE D**	**REST A**	**REST B**	**CONF**	**BREAK**	**CORR**	**BLDG**
A useful	*[sqft]*	143	681	135	118	88	95	32	79	205	139	165	**1880**
V useful	*[cft]*	1108	5278	1046	915	682	736	248	612	1589	1077	1279	**14570**
A useful	*[m2]*	13.3	63.3	12.5	11.0	8.2	8.8	3.0	7.3	19.0	12.9	15.3	**174.7**
V useful	*[m3]*	31.38	149.45	29.63	25.90	19.31	20.85	7.02	17.34	44.99	30.50	36.21	**412.6**
Qheat	*[kWh/a]*	184	1995	206	193	107	87	36	137	317	277	53	**3592**
Qheat,spec,sqft	*[kWh/a*sqft]*	1.29	2.93	1.53	1.64	1.22	0.92	1.13	1.73	1.55	1.99	0.32	**1.91**
Qheat,spec,sqm	*[kWh/a*m ^{2}]*	13.85	31.53	16.42	17.61	13.09	9.86	12.11	18.67	16.64	21.45	3.46	**20.57**
Qcool	*[kWh/a]*	409	3495	672	828	1017	972	160	288	823	435	4	**9103**
Qcool,spec,sqft	*[kWh/a*sqft]*	2.86	5.13	4.98	7.02	11.56	10.23	5.00	3.65	4.01	3.13	0.02	**4.84**
Qcool,spec,sqm	*[kWh/a*m ^{2}]*	30.79	55.24	53.58	75.53	124.40	110.13	53.82	39.24	43.21	33.69	0.26	**52.12**
total demand	*[kWh/a]*	593	5490	878	1021	1124	1059	196	425	1140	712	57	**12695**
	[mmBtu/a]	2.02	18.72	2.99	3.48	3.83	3.61	0.67	1.45	3.89	2.43	0.19	**43.28**
	*[kWh/a*sqft]*	4.15	8.06	6.50	8.65	12.77	11.15	6.13	5.38	5.56	5.12	0.35	**6.75**
	*[kWh/a*m ^{2}]*	44.64	86.78	70.01	93.14	137.48	119.99	65.93	57.91	59.86	55.14	3.72	**72.69**
total heat elec*	*[mmBtu/a]*	0.15	1.66	0.17	0.16	0.09	0.07	0.03	0.11	0.26	0.23	0.04	**2.99**
total cool heat*	*[mmBtu/a]*	0.24	2.06	0.40	0.49	0.60	0.57	0.09	0.17	0.49	0.26	0.00	**5.38**
energy cost*	*[$/a]*	15.91	150.14	22.91	26.19	27.81	26.07	5.02	11.45	30.23	19.65	1.87	**337.26**
	*[$/a*sqft]*	0.11	0.22	0.17	0.22	0.32	0.27	0.16	0.14	0.15	0.14	0.01	**0.18**

COMPARING RESULTS													
with passive cooling													
		SALES	**COMM**	**OFFICE A**	**OFFICE B**	**OFFICE C**	**OFFICE D**	**REST A**	**REST B**	**CONF**	**BREAK**	**CORR**	**BLDG**
reduction cool	*[kWh/a]*	163	775	200	316	324	284	128	203	314	148	2	**2857**
reduction heat	*[kWh/a]*	-8	-50	-22	-59	-28	-11	-1	-5	-16	-16	-1	**-217**
reduction total	*[kWh/a]*	155	725	178	257	296	273	127	198	298	132	1	**2640**
reduction	*[%]*	26.1	13.2	20.3	25.2	26.3	25.8	64.8	46.6	26.1	18.5	1.8	**20.8**
reduction elec	*[kWhel/a]*	26.28	122.04	29.28	40.34	49.29	46.51	21.93	33.94	50.48	21.73	0.10	**441.92**
	[mmBtu/a]	0.09	0.42	0.10	0.14	0.17	0.16	0.07	0.12	0.17	0.07	0.00	**1.51**
reduction*	*[$/a]*	**3.61**	**16.78**	**4.03**	**5.55**	**6.78**	**6.39**	**3.01**	**4.67**	**6.94**	**2.99**	**0.01**	**60.76**

* considering SEER 19.7, HSPf 14.0, $ 0.1345 per kWh

Detailed Scope of Work

To:	Steven Adams Johnson-Laux Construction, Inc. 41 Park of Commerce Way Suite 103 Savannah, GA 31405 (912) 398-9976	**From:**	Liberto Chacon City of Savannah 912-651-6510

Date Printed: May 19, 2014

Work Order Number: 019967.00

Work Order Title: City Savannah Gardens Renovations Project

Brief Scope: The project consists of specific activities associated with the Savannah Gardens Duplex Renovations for the City of Savannah located at 515 Pennsylvania Avenue, Savannah, Georgia 31404.

☐ **Preliminary** ☐ **Revised** ☒ **Final**

The following items detail the scope of work as discussed at the site. All requirements necessary to accomplish the items set forth below shall be considered part of this scope of work.

SCOPE OF WORK
City of Savannah
Savannah Gardens Duplex Renovation
515 Pennsylvania Avenue
Savannah, Georgia 31404

Summary Scope

The project consists of specific activities associated with the Savannah Gardens Duplex Renovations for the City of Savannah located at 515 Pennsylvania Avenue, Savannah, Georgia 31404.

Drawings and Specifications

Referenced and attached hereto:

Please reference pages noted below in notes specified in the Detailed Scope of Work:

- City Supplied Savannah Gardens Duplex Site Plan
- City Supplied Savannah Gardens Duplex Existing Floor Plan
- City Supplied Savannah Gardens Duplex New Floor Plan

Detailed Scope of Work

The Contractor shall provide all materials, labor, and equipment and perform all work as described below and per any attached specifications and drawings along with the items below.

Please see attached PDF Documents Labled Savannah Gardens Duplex Renovations 5-19-14 & Savannah gardens ECLC Certification Worksheet, referenced hereto and made part of this Work Order Package.

Contractor's Price Proposal - Summary

Date: May 19, 2014

IQC Master Contract #: GA12-062911-JLC
Work Order Number: 019967.00
Owner PO #:
Work Order Title: City Savannah Gardens Renovations Project
Contractor: Johnson-Laux Construction, Inc.
Proposal Name: Savannah Gardens Office Space
Proposal Value: $562,101.97

01 - General Requirements	**$96,862.87**
02 - Site Work	**$36,990.32**
03 - Concrete	**$11,533.70**
04 - Masonry	**$17,372.39**
05 - Metals	**$4,406.21**
06 - Wood, Plastic, and Composites	**$41,537.93**
07 - Thermal & Moisture Protection	**$52,748.91**
08 - Openings	**$52,822.96**
09 - Finishes	**$38,893.18**
10 - Specialties	**$2,971.53**
11 - Equipment	**$230.59**
12 - Furnishings	**$982.82**
22 - Plumbing	**$14,108.14**
23 - Heating, Ventilating, And Air-Conditioning (HVAC)	**$38,353.95**
26 - Electrical	**$55,774.57**
27 - Communications	**$38.34**
31 - Earthwork	**$8,770.00**
32 - Exterior Improvements	**$87,544.06**
33 - Utilities	**$159.50**
Proposal Total	**$562,101.97**

This total represents the correct total for the proposal. Any discrepancy between line totals, sub-totals and the proposal total is due to rounding.

NET PRESENT VALUE, PAYBACK TIME FOR WINDOW, WALL AND HVAC SYSTEM IMPROVEMENT

Inflation	2.02	*[%/a]*
Electricity rate	0.1452	*[$/kWh]*
Electricity rate growth	2.49	*[%/a]*

Year	Investment	Energy Savings		CF	DCF	NPV
	[$]	*[mmBtu/a]*	*[kWh/a]*	*[$]*	*[$]*	*[$]*
0	94,587.06	108.7	31879.43	4628.89	4628.89	-89,958.17
1		108.7	31879.43	4744.15	4650.22	-85,307.95
2		108.7	31879.43	4862.28	4671.64	-80,636.31
3		108.7	31879.43	4983.35	4693.16	-75,943.15
4		108.7	31879.43	5107.44	4714.78	-71,228.36
5		108.7	31879.43	5234.61	4736.50	-66,491.86
6		108.7	31879.43	5364.96	4758.33	-61,733.53
7		108.7	31879.43	5498.54	4780.25	-56,953.28
8		108.7	31879.43	5635.46	4802.27	-52,151.01
9		108.7	31879.43	5775.78	4824.39	-47,326.62
10		108.7	31879.43	5919.60	4846.62	-42,480.00
11		108.7	31879.43	6066.99	4868.95	-37,611.05
12		108.7	31879.43	6218.06	4891.38	-32,719.68
13		108.7	31879.43	6372.89	4913.91	-27,805.76
14		108.7	31879.43	6531.58	4936.55	-22,869.21
15		108.7	31879.43	6694.21	4959.29	-17,909.92
16		108.7	31879.43	6860.90	4982.14	-12,927.78
17		108.7	31879.43	7031.74	5005.09	-7,922.69
18		108.7	31879.43	7206.83	5028.15	-2,894.54
19		**108.7**	**31879.43**	**7386.28**	**5051.31**	**2,156.78**
20		108.7	31879.43	7570.19	5074.59	7,231.36
21		108.7	31879.43	7758.69	5097.96	12,329.33
22		108.7	31879.43	7951.88	5121.45	17,450.78
23		108.7	31879.43	8149.88	5145.04	22,595.82
24		108.7	31879.43	8352.82	5168.75	27,764.57
25		108.7	31879.43	8560.80	5192.56	32,957.13
26		108.7	31879.43	8773.97	5216.48	38,173.61
27		108.7	31879.43	8992.44	5240.51	43,414.12
28		108.7	31879.43	9216.35	5264.66	48,678.78
29		108.7	31879.43	9445.84	5288.91	53,967.69
30		108.7	31879.43	9681.04	5313.28	59,280.96