MASTER'S DEGREE PROGRAMME

UNIVERSITY OF APPLIED SCIENCES UPPER AUSTRIA

Eco-Energy Engineering

Development of a detailed cost-benefit analysis to evaluate and compare several sustainable building services systems for the implementation in public buildings in the City of Savannah.

SUBMITTED AS MASTER THESIS

to obtain the academic degree of

Master of Science in Engineering (MSc)

by

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Thesis supervisor

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SWORN DECLARATION

I hereby declare, in lieu of an oath, that I prepared the present work independently and without help from third parties, that I did not use sources other than the ones referenced, and that I indicated passages adopted from said sources as such.

This thesis was not submitted in identical or similar form to another examination board and was not published.

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Paul-Johannes Deinhofer

Aschbach-Markt, September 2015

ABSTRACT

The reduction of energy consumption is a big goal for the state of Georgia and therefore also for the City of Savannah. To reach the scheduled objectives, Savannah implements energy efficiency measures in numerous areas to reduce the city's energy consumption. One of these areas is the building services sector whereat retrofits for commercial and residential buildings are done, which belong to the city, or the planning for residential affordable housing projects is done, which are supported by the city. To enable this projects and reach the goal, the energy consumption but also the costs should be kept at a minimum.

Therefore, there is an urgent need for an assessment approach and a tool to determine the most cost- and energy-efficient solution for the used sustainable building services systems. To develop such a tool and the associated approach, also a general research and the fundamental model needs to be developed.

First of all, a background analysis of the energy sector, the prevailing local frame conditions, the building market, the consumer structure and the energy demand is done to obtain the required basis. The next step includes the elaboration of the necessary climate data for the simulation and the cost data for the economic evaluation. In addition, all needed theoretical approaches and models for the economics calculation and the thermal building simulation are prepared.

Based on the generated basis and the collected information and data, a building simulation program with a system- and measure-selection feature and an embedded component cost database is developed. The so called cost-benefit tool is validated and compared with the building simulation software REM/Rate™.

The provided results of the cost-benefit tool enable a direct comparison of different building services systems and can also be used for further evaluations. Among other things, the results provide parameters such as energy demand for heating and cooling, but also economic figures like annuity and simple payback time. The tool is well-suited for first assessments and approaches for the right system selection but also for the revelation of cost- and energy-saving potentials.

KURZFASSUNG

Die Verminderung des Energieverbrauchs ist ein wichtiges Ziel im U.S.-Bundesstaat Georgia und somit auch in der Stadt Savannah. Um die festgesetzten Vorgaben zu erreichen, werden in Savannah Energieeffizienzmaßnahmen in vielen verschieden Bereichen umgesetzt. Einer dieser Bereiche ist der Gebäudetechniksektor wobei die Sanierung von städtischen Geschäfts- und Wohngebäuden durchgeführt wird aber auch die Planung von Bauprojekten für leistbares Wohnen von der Stadt unterstützt wird. Um die Ziele und Projekte zu ermöglichen, müssen sowohl Kosten als auch Energieverbrauch auf ein Minimum gehalten werden. Es besteht daher ein großer Bedarf an einer Bewertungsmethode und einem Hilfsmittel zur Bestimmung der kosten- und energie-effizientesten Lösung für die verwendeten nachhaltigen Gebäudetechniksysteme. Um solch ein Hilfsprogramm zu entwickeln, ist auch eine umfassende Recherche nötig und das zugrundeliegende Modell muss entwickelt werden.

Der erste Schritt ist die Analyse des Energiesektors, der lokalen Rahmenbedingungen, der Verbraucherstruktur und des Energieverbrauchs. Die Aufbereitung der erforderlichen Klimadaten für die Simulation und der Kostendaten für die Wirtschaftlichkeitsrechnung ist der nächste Schritt. Zusätzlich werden die nötigen theoretischen Modelle für die Berechnung und Simulation konkretisiert.

Basierend auf der erstellten Grundlage und den Informationen wird ein Gebäudesimulationsprogramm, welches eine System- und Maßnahmenauswahl und eine Kostendatenbank inkludiert, entwickelt. Dieses so genannte Kosten-Nutzen Tool wird mit dem Gebäudesimulationsprogramm REM/Rate™ validiert und verglichen. Die erhaltenen Ergebnisse des Tools ermöglichen den direkten Vergleich von unterschiedlichen Gebäudetechniksystemen. Neben Parametern wie dem Heiz- und Kühlenergiebedarf liefern die Ergebnisse auch wirtschaftliche Kennzahlen wie die Annuität und die einfache Amortisationsdauer. Das Tool ist sehr gut für erste Bewertungen und Ansätze für die richtige Systemwahl geeignet, aber auch um Kosten- und Energie-einsparungspotential aufzudecken.

CONVERSION TABLE

Unless specified differently, basically the in the United States of America most commonly used units are also applied in this thesis. Apart from that, most of the included calculations are executed with metric units. The used conversion table can be found in (Porges, 2001 p. 5 to 7)

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INTRODUCTION

The world energy consumption is constantly rising and it is not expected that this fact will change in the near future. Hence, the concern to safe energy gets worldwide more and more important. There are several reasons for this rise which obtain increasingly public awareness and run into political issues. Facts such as increasing energy demand, intense environmental pollution, diminution of fossil energy sources, rising living standards, growing population and also constantly rising energy prices are only a few influencing factors for this issue. (cf. International Energy Agency, 2014)

The state of Georgia is aware of this upcoming challenge and thus, the state agencies and consequently also the City of Savannah, Georgia have set themselves the goal to tackle this problem and therefore they want to reduce the state's energy consumption by 15% below 2007 levels by the year 2020. (cf. GEFA Energy - Land - Water, 2012 p. 14) To achieve this goal, Savannah makes great efforts by implementing energy efficiency measures in different areas and therefore reducing the energy consumption. One focus is on retrofits of commercial and residential buildings which can be public buildings that belong to the city itself or residential housing projects which are supported by the city. In addition, Savannah also performs and funds affordable housing projects for new-built single and multifamily houses for low income family households.

As a result, cooperation between the City of Savannah, the University of Applied Sciences Upper Austria (UASUA) and the Georgia Institute of Technology (GT) Savannah has been established. Students from UASUA have the chance to write their master's thesis by working on research projects related to this target.

There is a large number of buildings which belong to the properties of the City of Savannah. Due to a continuous improvement in the field of sustainable building services, the efficiency increases and especially the energy demand of the systems decreases. Consequently, there is the possibility of saving a

considerable amount of energy and energy costs by exchanging the out-of-date building services systems with sustainable state-of-the-art systems in public buildings in Savannah.

Furthermore, affordable housing is a big issue in Savannah due to relatively high housing costs respectively rental costs and a high population growth rate (see also chapter 1.1.1 and 1.1.2). In 2011, the Mayor and the Alderman of the City of Savannah established a resolution for the Savannah Affordable Housing Fund which is a complementary finance tool leverage investment for housing projects and provide technical assistance to local developers (see also 1.1.3).

The main focus of the thesis is to develop a guideline and a cost-benefit tool as assistance to find, develop and implement possible energy saving building services system projects and prior to support the city within the planning process for the affordable housing projects.

In general, the thesis is based on the following energy-relevant topics of building services:

- Heating system,
- Cooling system and
- Air supply system.

Especially in warmer climate zones such as in the south-eastern United States of America, therefore also in Georgia and Savannah, these different system types are often combined in one system which provides heating, cooling and also the air supply (e.g. Air Source Heat Pump with duct system). That means, that such combined building services systems are the most common devices for the purpose of heating, cooling and ventilation in this area. (Brainerd (a), 2015)

This circumstances were special considered during the development of the tool to gain a practical use for the city and its project environment.

Seo et al. (Seo, et al., 2014), Teke and Timur (Teke, et al., 2014), Vakiloroaya et al. (Vakiloroaya, et al., 2013) and Watzak-Helmer (Watzak-Helmer, 2013) already processed and discussed the energy saving potentials of some of the system types mentioned above. Despite the comprehensive research in this field, there is no free accessible general approach and a general model in order to assess and compare sustainable building services systems with respect to cost-benefit and energy-saving criteria. Therefore, this area has great research potential and by preparing this project, the City of Savannah is able to support further steps in achieving their energy saving goals.

The expected result of this research is a "Cost-Benefit Assessment Guide in combination with an EXCEL-Tool" which provides parameters to compare existing building services systems with alternative sustainable variants in reference to energy- and cost-efficiency. In addition, the tool enables to compare building services systems for the planned implementation in future building projects. The tool is easy to operate by using universal input-parameters which can be determined for a wide range of building types. Its main purpose is the application in the building services sector to further projects and housing designs in Savannah. It can be seen as a reusable checklist for continuous improving of the energy cost situation for buildings.

1 GENERAL INFORMATION – PROJECT SCOPE

This chapter has the task to present and explain the used theoretical foundation of the thesis. It gives basic information about the main purpose and therefore it should also show the importance of the work in the specific project field. Thus, the chapter reveals the consumer structure and the energy demand in different sectors of the whole United States and the state of Georgia. It provides knowledge about the geographical frame conditions of the calculation tool and also demographic facts about the City of Savannah. It should be clarified on which ideas the thesis is based on and which solutions are expected.

1.1 GEORGIA AND THE CITY OF SAVANNAH

The targeted simulation tool is preliminary intended for the use within the municipal government of the City of Savannah. Accordingly, all used data sources refer to this circumstance. This chapter should summarize some of the most important basic data for the city and the state of Georgia.

The state of Georgia has experienced a strong economic and population growth for many years now. This economic development provided great benefit for the whole society and businesses. This progress also brings new challenges especially in the energy and environmental requirements, which are one key factor to remain an economically competitive market in Georgia. As mentioned above, the state was one of the fastest growing states during the 20th century within the United States of America. This trend continued also into the first decade of the 21st century whereat Georgia was the seventh fastest-growing state in the U.S. between 2000 and 2010. During this period, the state added 18.3% more people than the previous decade and the trends still suggest that it will remain a high-growth rate. Thus, there is also the increasing need to plan now for the future energy need of Georgia. Due to the estimation of the Georgia Office of Planning and Budget (OPB), the state's population will increase to nearly almost 12.2 million people. (cf. GEFA Energy - Land - Water, 2012 p. 3) Table 1 indicates an estimated population of 10,097,343 for the state of Georgia in 2014.

Figure 1: Location of Savannah in the USA (Google-INEGI, 2015)

Figure 1 shows the location of Savannah and the state of Georgia to obtain an idea of where they are sited in the United States.

The city is located in the southeast of the United States of America. It is one of the largest cities in Georgia and it belongs to Chatham County which is directly located on the Atlantic coast. Furthermore, Savannah has the fourth busiest and fastest growing port in the United States and therefore plays an important role for the economy of the country. (cf. City of Savannah, 2015)

1.1.1 POPULATION

As shown in Table 1, Savannah has an estimated population of 142,772 inhabitants based on the year 2013. The table also provides several population data concerning the change rate, age and gender. Additionally it indicates all data compared to Georgia and the United States. Consequently, it can be seen that Savannah has clearly higher population growth rate than the state and the country which also means, that there is a constant increase of housing demand in the city. (cf. U.S. Census Bureau (b), 2015)

Table 1: People Quck Facts about Savannah, Georgia and USA (U.S. Census Bureau (b), 2015)

People QuickFacts - Savannah, Georgia, USA	Savannah	Georgia	USA
Population, 2014 estimate	-	10,097,343	318,857,056
Population, 2013 estimate	142,772	9,994,759	316,497,531
Population, 2010 (April 1) estimates base	136,341	9,688,681	308,758,105
Population, percent change - April 1, 2010 to July 1, 2014	-	4.20%	3.30%
Population, percent change - April 1, 2010 to July 1, 2013	4.70%	3.20%	2.50%
Population, 2010	136,286	9,687,653	308,745,538
Persons under 5 years, percent, 2013	7.10%	6.70%	6.30%
Persons under 18 years, percent, 2013	22.40%	24.90%	23.30%
Persons 65 years and over, percent, 2013	11.70%	12.00%	14.10%
Female persons, percent, 2013	52.10%	51.10%	50.80%

1.1.2 BUILDING STRUCTURE

The actual situation in the housing structure of the City of Savannah is presented in this chapter. This brief assessment provides an overview about the occupancy, number of units and year of construction of housings in Savannah. In addition, it informs about the housing tenure, the average household size and the gross rent rates.

Table 2 displays in its first part the total housing units of Georgia and Savannah which has an estimated number of 62,122 units. The occupancy rate for these housings is 84% which in return means, that over 9,900 housing units (about 16%) are vacant. (cf. U.S. Census Bureau (a), 2013) The table also provides that the rental vacancy rate is several times the homeowner vacancy rate. There are only small differences between the percentage values of Georgia and Savannah.

Table 2: Housing Occupancy in Savannah and Georgia (U.S. Census Bureau (a), 2013)

Subject	Georgia		Savannah city, Georgia	
	Estimate	Percent	Estimate	Percent
HOUSING OCCUPANCY				
Total housing units	4,094,812	4,094,812	62,122	62,122
Occupied housing units	3,518,097	85.90%	52,164	84.00%
Vacant housing units	576,715	14.10%	9,958	16.00%
Homeowner vacancy rate	3.2	(X)	3.7	(X)
Rental vacancy rate	10.5	(X)	9.3	(X)

A high housing vacancy rate always increases the chance of building deterioration which has a bad impact on the building environment and neighborhood. In general, this rate should be kept as low as possible. One potential cause of high vacancy rates can be a too high building price.

The different housing structures in Savannah and Georgia respectively the number of units in building structures is summarized in Table 3. Over 55% of the housing units in Savannah consists of "1-unit, detached" buildings. In the state of Georgia, this type of housing units has a larger share with over 66%. In contrast, 10.1% of the houses in Savannah has 5 to 9 units whereas the state only has 5.1%. Also the percentage of all other housing types with more than one unit and "1-unit, attached" is higher in Savannah compared to the state, except buildings with 10 to 19 housing units, mobile homes and boats, RVs, vans, etc. (cf. U.S. Census Bureau (a), 2013)

Table 3: Housing units in Structure in Savannah and Georgia (U.S. Census Bureau (a), 2013)

Subject	Georgia		Savannah city, Georgia	
	Estimate	Percent	Estimate	Percent
UNITS IN STRUCTURE				
Total housing units	4,094,812	4,094,812	62,122	62,122
1-unit, detached	2,721,525	66.50%	34,291	55.20%
1-unit, attached	149,083	3.60%	4,715	7.60%
2 units	93,256	2.30%	4,191	6.70%
3 or 4 units	124,553	3.00%	5,293	8.50%
5 to 9 units	210,326	5.10%	6,293	10.10%
10 to 19 units	192,636	4.70%	2,873	4.60%
20 or more units	218,333	5.30%	3,365	5.40%
Mobile home	382,770	9.30%	1,088	1.80%
Boat, RV, van, etc.	2,330	0.10%	13	0.00%

Table 4 summarizes the year of construction-data for the housing stock in Savannah and Georgia. It is striking that the city, compared to the state, has a fairly high percentage of buildings which has been built in the year 1939 or earlier. Furthermore, also Savannah's rates of housing units built from 1940 to 1979 are significant higher than the state's. In general, the average age of Savannah's building stock is higher than the age of the state's buildings. (cf. U.S. Census Bureau (a), 2013)

Table 4: Year of Construction of Housings in Savannah and Georgia (U.S. Census Bureau (a), 2013)

Subject	Georgia		Savannah city, Georgia	
	Estimate	Percent	Estimate	Percent
YEAR STRUCTURE BUILT				
Total housing units	4,094,812	4,094,812	62,122	62,122
Built 2010 or later	25,355	0.60%	734	1.20%
Built 2000 to 2009	937,248	22.90%	6,907	11.10%
Built 1990 to 1999	862,395	21.10%	4,721	7.60%
Built 1980 to 1989	721,018	17.60%	6,273	10.10%
Built 1970 to 1979	592,895	14.50%	10,079	16.20%
Built 1960 to 1969	377,034	9.20%	8,772	14.10%
Built 1950 to 1959	264,474	6.50%	9,440	15.20%
Built 1940 to 1949	124,120	3.00%	4,866	7.80%
Built 1939 or earlier	190,273	4.60%	10,330	16.60%

The distribution between owner-occupied and renter-occupied housings in Savannah and Georgia are given in Table 5. With 54.20% compared to 34.90%, the city has a distinct higher renter-occupied rate than the state of Georgia. The average household sizes do not vary widely between the city and the state which are about 2.6 people per household. (cf. U.S. Census Bureau (a), 2013)

Table 5: Housing Tenure and Average Household Size in Savannah and Georgia (U.S. Census Bureau (a), 2013)

Subject	Georgia		Savannah city, Georgia	
	Estimate	Percent	Estimate	Percent
HOUSING TENURE				
Occupied housing units	3,518,097	3,518,097	52,164	52,164
Owner-occupied	2,292,030	65.10%	23,917	45.80%
Renter-occupied	1,226,067	34.90%	28,247	54.20%
Average household size of owner-occupied unit	2.74	(X)	2.58	(X)
Average household size of renter-occupied unit	2.67	(X)	2.49	(X)

Details of the housing gross rent in the city and the state are provided in Table 6. The table shows that the percentage of gross rent in the range of $750 to $1,499 is higher in Savannah than in Georgia. Contrary, the gross rent fraction from $200 to $749 is higher in Georgia than in Savannah. Subsequently, compared to the state, the gross rent in the City of Savannah is higher which also means that it is harder to afford a rented accommodation for low income households. (cf. U.S. Census Bureau (a), 2013)

Table 6: Gross Rent in Savannah and Georgia (U.S. Census Bureau (a), 2013)

Subject	Georgia		Savannah city, Georgia	
	Estimate	Percent	Estimate	Percent
GROSS RENT				
Occupied units paying rent	1,149,048	1,149,048	27,036	27,036
Less than $200	18,200	1.60%	690	2.60%
$200 to $299	32,006	2.80%	698	2.60%
$300 to $499	90,465	7.90%	1,566	5.80%
$500 to $749	276,173	24.00%	5,217	19.30%
$750 to $999	344,219	30.00%	9,461	35.00%
$1,000 to $1,499	306,433	26.70%	7,568	28.00%
$1,500 or more	81,552	7.10%	1,836	6.80%
Median (dollars)	860	(X)	883	(X)
No rent paid	77,019	(X)	1,211	(X)

1.1.3   SAVANNAH AFFORDABLE HOUSING FUND

This chapter represents the affordable housing program in Savannah and one of the possible application areas of the developed cost-benefit simulation tool within this project.

The Mayor and the Alderman of the City of Savannah established a resolution for the Savannah Affordable Housing Fund (SAHF) on November 17, 2011. (.cf Advisory Committee, 2013 p. 1)

"The fund was established to serve as a : 'Complementary finance tool allowing for maximum flexibility and local control, leveraging private and other investment, attract investors, fund construction and rehabilitation of housing, provide technical assistance to and provide capacity building for local developers, and provide a revolving loan fund'" (Advisory Committee, 2013 p. 1)

The Savannah Affordable Housing Fund Policy Guidelines consist of three ground rules which are not explained in detail here. Basically the guidelines regulate the circumstances to gain the best results out of the Savannah Affordable Housing Fund.

Leverage resources to create, rehabilitate or retain affordable housing in Savannah is the main purpose of the Savannah Affordable Housing Fund. (cf. Advisory Committee, 2013 p. 2)

The City of Savannah Affordable Housing Study, completed by the University of Georgia in 2008, is one of the several community reports and stakeholder convening over the last twenty years. The recommendation for the locally controlled Affordable Housing Fund are based on the results of this studies and reports. The Study determined the existing population of cost-burdened households in the City of Savannah which accounted in a total number of 23,696 respectively 41% of all households. Out of these data, a model was created which projects the growth rate of the cost-burdened population over a 10-year period. These results on this are shown in Figure 2. (cf. Advisory Committee, 2013 p. 2)

Cost-Burdened Households in Savannah

	2000	2008	2018	2023
Cost-Burdened households	20,425	23,696	24,513	25,208
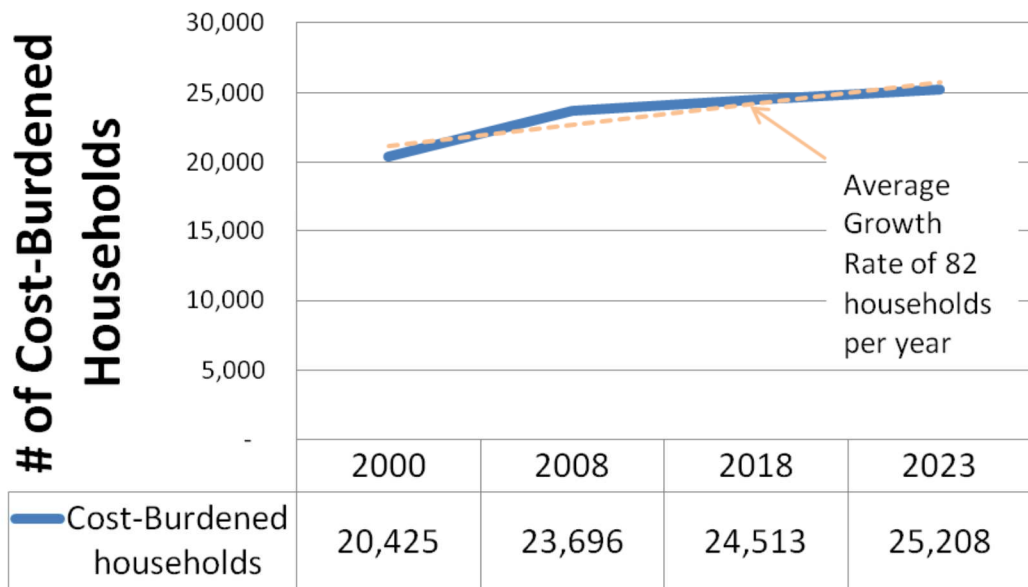
Figure 2: Cost-Burdened Households in Savannah (Advisory Committee, 2013 p. 2)

The outcomes of the study indicates that the Savannah Affordable Housing Fund has to address the cost-burdened household growth rate of 82 households per year to be successful. This number is the essential point towards reducing the total population of cost-burdened households which only can be reached by a more substantial fund volume. Based on diverse housing mix interventions and a revolving fund, historic data from the City of Savannah Housing Department suggest that $5,000 of new fund allocations has produced one new affordable housing unit in the past. Based on this data, an estimated annual fund capitalization of $410,000 is required to address the growth rate of cost-burdened households in the City of Savannah. (cf. Advisory Committee, 2013 p. 2)

The investment decisions for the Savannah Affordable Housing Fund are based on four basic investment requirements that must be fulfilled for all SAHF funded projects. Those four requirements are:

● "**Leveraging.** All invested projects must substantially leverage outside funds.

● **Affordability.** Investments will seek the maximum secured affordability period appropriate for the development type and funding volume.

● **Beneficiaries.** Housing will be priced, available, and affordable to qualified households with incomes at or below area median income.

● **Neighborhood Benefits.** Invested projects will have demonstrated consideration of the neighborhood benefit of the investment. " (Advisory Committee, 2013 p. 2)

The use of the SAHF funds is scheduled for affordable housing that may not otherwise be created or retained by the conventional local housing market. (cf. Advisory Committee, 2013 p. 3)

Due to the Savannah Affordable Housing Fund program, numerous affordable housing projects are carried out in the City of Savannah. These projects are suitable to apply the aspired cost-benefit tool and guideline of the master's thesis. Applied to such projects, the tool can provide recommendations which building services systems would be the best solution for the SAHF assisted housing investments.

1.2 ENERGY DEMAND AND CONSUMER STRUCTURE

This chapter represents an introduction and overview of the overall energy demand and consumer structure of the whole world, the United States of America and the State of Georgia. Additionally it contains the distribution of the different house heating fuel types in Georgia and Savannah. The aim is to highlight the most energy intense load areas and consequently to reveal the highest energy and cost saving potential. In short, the importance of this thesis and therefore of sustainable energy saving measures is underlined.

1.2.1 WORLD

Due to worldwide increasing population, living standards, economy and many other different influencing factors, the worldwide energy demand is constantly rising for decades. The rising demand can also be presented by the primary energy supply in Figure 3.

Figure 3: World total primary energy supply from 1971 to 2012 by fuel (Mtoe) (International Energy Agency, 2014 p. 6)

The figure above illustrates the worldwide total primary energy supply from 1971 to 2012 and also which fuel types are used to produce this energy. Besides the continuous rise of the total amount, it can be easily seen that Coal, Oil and Natural gas have the biggest share in the needed energy supply. Figure 4 displays, that all three sources together have a percentage of more than 80% which also means that most of the world's energy supply is based on non-sustainable fossil fuel sources. However, the availability of some fossil fuels is on the peak or already retrogressive.

1973 and 2012 fuel shares of TPES

1973

Hydro 1.8%
Biofuels and waste 10.5%
Other*** 0.1%
Coal** 24.6%
Nuclear 0.9%
Natural gas 16.0%
Oil 46.1%

6 106 Mtoe

2012

Hydro 2.4%
Biofuels and waste 10.0%
Other*** 1.1%
Coal** 29.0%
Nuclear 4.8%
Natural gas 21.3%
Oil 31.4%

13 371 Mtoe
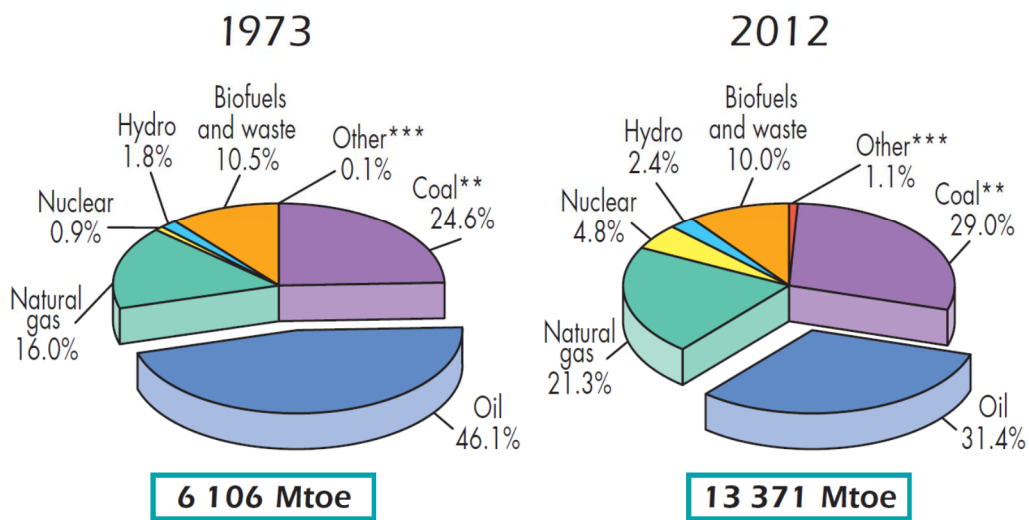
**In these graphs, peat and oil shale are aggregated with coal.
***Includes geothermal, solar, wind, heat, etc.*

Figure 4: 1973 and 2012 fuel shares of total primary energy supply (International Energy Agency, 2014)

Sustainable sources such as Hydro, Geothermal, Solar and Wind play only a minor role so far which has to be changed to meet the worlds energy needs also in the future. Compared to the 13,371 Mtoe (Million tons of oil equivalent) of total primary energy supply in Figure 4, only 8,979 Mtoe were used in the total final consumption in 2012 (International Energy Agency, 2014 p. 28). Subsequently, it is necessary to introduce energy efficiency measures in all energy consuming

procedures and activities to attenuate the rise or even to decrease the future energy demand.

1.2.2 UNITED STATES OF AMERICA

This chapter gives a short outline of the energy consumption, production, imports and exports in the United States of America. Moreover, the total electricity generation, particularly the renewable electricity generation and the energy consumption in the residential sector are viewed.

To get an basic understanding from which fuel types and sectors the U.S. sources, produces and consumes its energy, Figure 5 shows the main energy flows and its amounts. As can be seen, the U.S. is mostly dependent on fossil fuels with 69.03 quadrillion Btu which represent about 79% of the domestic production and over 62% of the total supply. With 21.53 quadrillion Btu and nearly 22% of the whole energy consumption, the residential sector has an essential share and also a high potential for energy saving measures.
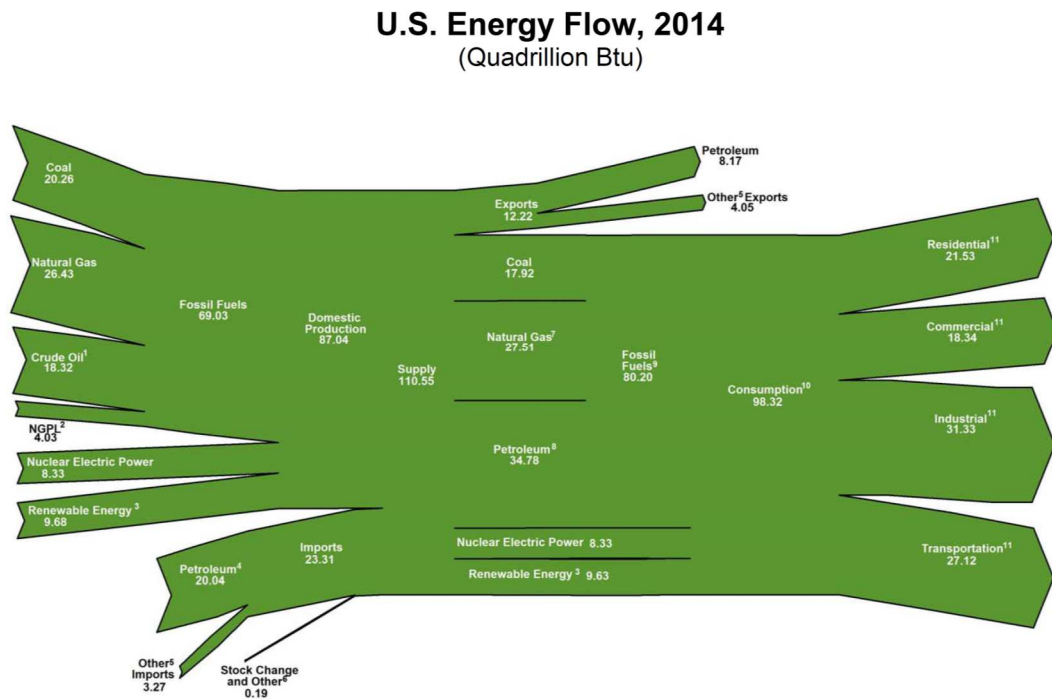
Figure 5: U.S. Energy Flow, 2014 (U.S. Energy Information Administration (EIA) (a), 2015)

1.2.2.1 U.S. - ENERGY CONSUMPTION BY PRIMARY FUEL AND PRODUCTION, IMPORTS AND EXPORTS

As provided in Figure 6, the U.S. Energy Information Administration expects a further total primary energy consumption growth from 2013 to 2040 in their Annual Energy Outlook 2015 (AEO2015) Reference case for the United States of America.

Figure 6: Primary energy consumption by fuel in the Reference case, 1980-2040 (quadrillion Btu) (U.S. Energy Information Administration (EIA) (b), 2015 p. 15)

It is assumed, that the consumption rises from 97.1 quadrillion Btu in 2013 to 105.7 quadrillion Btu in 2040 which corresponds an increase of 8.9%. Most of the growth is expected to come from consumption of natural gas and renewable energy. Across all sectors, the petroleum products consumption in 2040 is unchanged from 2013 levels. This is caused by the decline of motor gasoline consumption in the transportation sector as a result of 70% more efficient on-road light-duty vehicle. The consumption of petroleum and other liquids in the U.S.,

which is totaled 35.9 quadrillion Btu in 2013, increases to 36.2 quadrillion Btu in 2040.

Figure 6 also reveals, that the natural gas consumption in the AEO2015 Reference case increases from 26.9 quadrillion Btu in 2013 to 30.5 quadrillion Btu in 2040 and the coal use grows from 18.0 quadrillion Btu in 2013 to 19.0 quadrillion Btu in 2040. Seen from a sustainable point of view, the most important increase in the Reference case happens in the consumption of marketed renewable energy from 9.0 quadrillion Btu in 2013 to 12.5 quadrillion Btu in 2040, with most of the growth in the electric power sector.

Due to uncertainties about the future economic growth, the AEO2015 also presents to cases with different economic growth rates. Consequently, the widest variation in the projections for total primary energy consumption in 2040, ranges from 98.0 quadrillion Btu in the Low Economic Growth case to 116.2 quadrillion Btu in the High Economic Growth case. (cf. U.S. Energy Information Administration (EIA) (b), 2015 p. 15f.)

However, these consumption forecasts illustrate again the need of energy efficiency measures to maybe guide the future consumption rate toward the lower increase prediction.

The proportion of total energy production and consumption in the U.S. for the AEO2015 Reference case is illustrated by Figure 7.
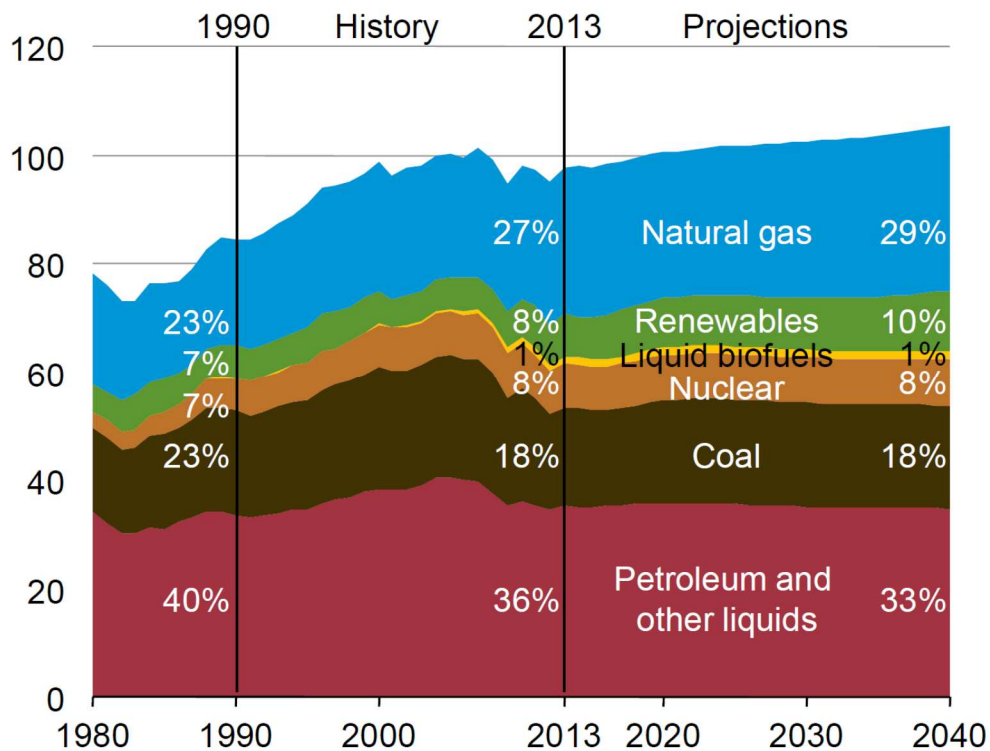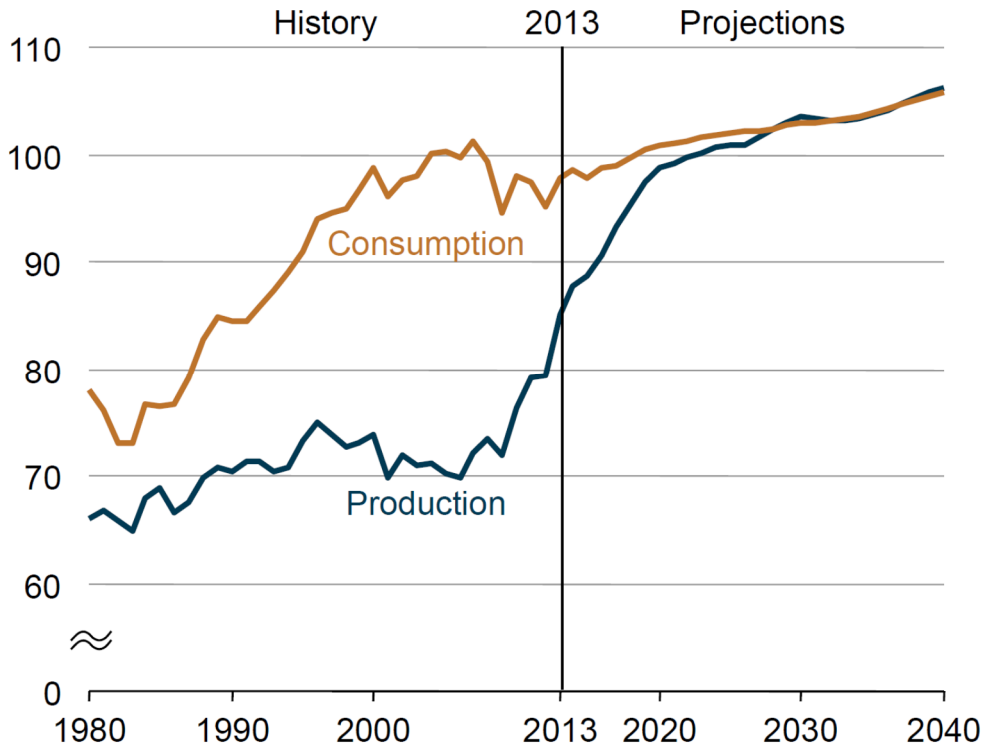

Figure 7: Total energy production and consumption in the Reference case, 1980-2040 (quadrillion Btu) (U.S. Energy Information Administration (EIA) (b), 2015 p. 17)

The figure above shows, that in general the U.S. currently consumes more energy than it produces although the net imports of energy declined form 30% of total energy consumption in 2005 to 13% in 2013. The reason is a strong growth in domestic oil and dry natural gas production from tight formations and slow growth of total energy consumption. The energy imports decline is projected to continue at a slower rate in the AOE2015 Reference case. Hence, the energy imports and exports coming into balance around 2028 and from 2025 to 2040, energy exports account for about 23% of total annual U.S. energy production. (cf. U.S. Energy Information Administration (EIA) (b), 2015 p. 17)

1.2.2.2 U.S. - ELECTRICITY GENERATION

Due to the fact that renewable energies have a significant percentage in the total electricity generation and also sustainable building services systems, such as heat pumps, preliminary use electricity to condition buildings, Figure 8 reveals the U.S. electricity generation by fuel in the Reference case of the AEO2015.
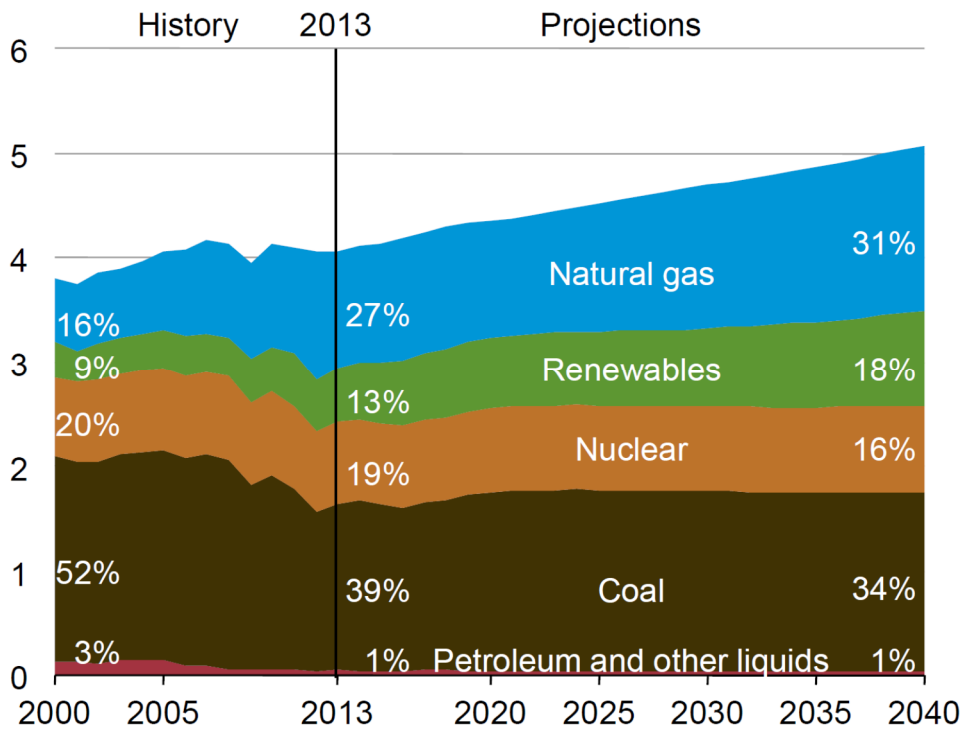
Figure 8: Electricity generation by fuel in the Reference case, 2000-2040 (trillion kilowatthours) (U.S. Energy Information Administration (EIA) (b), 2015 p. 24)

The total electricity use grows by an average of 0.8 %/year, from 3,836 billion kilowatthours (kWh) in 2013 to 4,797 billion kWh in 2040. The fuels used for electricity generation changes due to a relatively slow growth in demand, combined with rising natural gas prices, environmental regulations and a steady growth in renewable generation. Natural gas-fired electricity generation more than doubled from 2000 to 2012 as natural gas prices fell to relatively low levels. In the longer term, natural gas and renewable energy supplies most of the new electricity generation needed. From 2013 to 2040, the total electricity generation increases by 24% in the Reference case but varies highly with different economic

assumptions. As presented by the graph, generation from coal and nuclear energy remains fairly flat of even decrease from 2013 to 2040 in the Reference case but still account for about 50% of total generation. (cf. U.S. Energy Information Administration (EIA) (b), 2015 p. 24)

As shown in Figure 9, the U.S. electricity generation by renewable fuel types is expected to experience an enormous growth in the future.
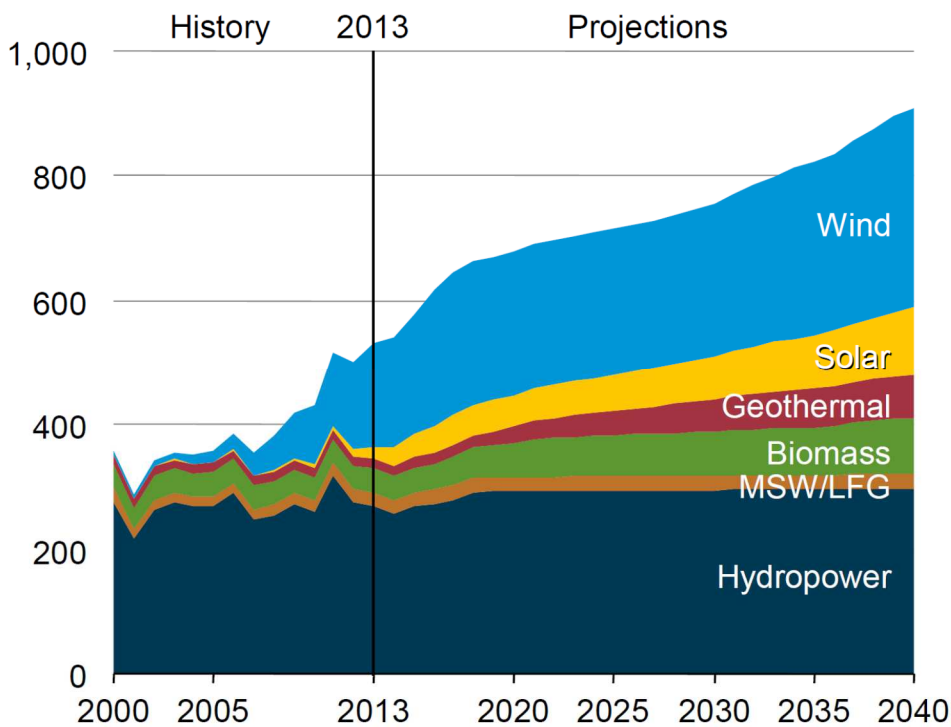
Figure 9: Renewable electricity generation by fuel type in the Reference case, 2000-2040 (billion kilowatthours) (U.S. Energy Information Administration (EIA) (b), 2015)

In the Reference case, the highest growth rate in expected for wind and solar generation. Total nonhydropower renewable electricity generation was almost equal to hydroelectric generation within the U.S. in 2013 for the first time. This is attributed by increases in wind and solar generation. Nonhydropower renewable energy sources account for more than two-thirds of the total renewable generation in 2040. As can be seen in Figure 8, in the Reference case the total renewable percentage of all electricity generation increases form 13% in 2013 to 18% in 2040 (cf. U.S. Energy Information Administration (EIA) (b), 2015 p. 25).

1.2.2.3 U.S. - DELIVERED ENERGY CONSUMPTION FOR RESIDENTIAL SECTOR

Due to the fact that this master thesis contains a residential building as sample application for the programmed tool, also the energy related part for this building type in the U.S. is explained in the following.

Figure 10 shows delivered energy consumption by fuel type for the U.S. residential sector in the Reference case of the AEO2015.
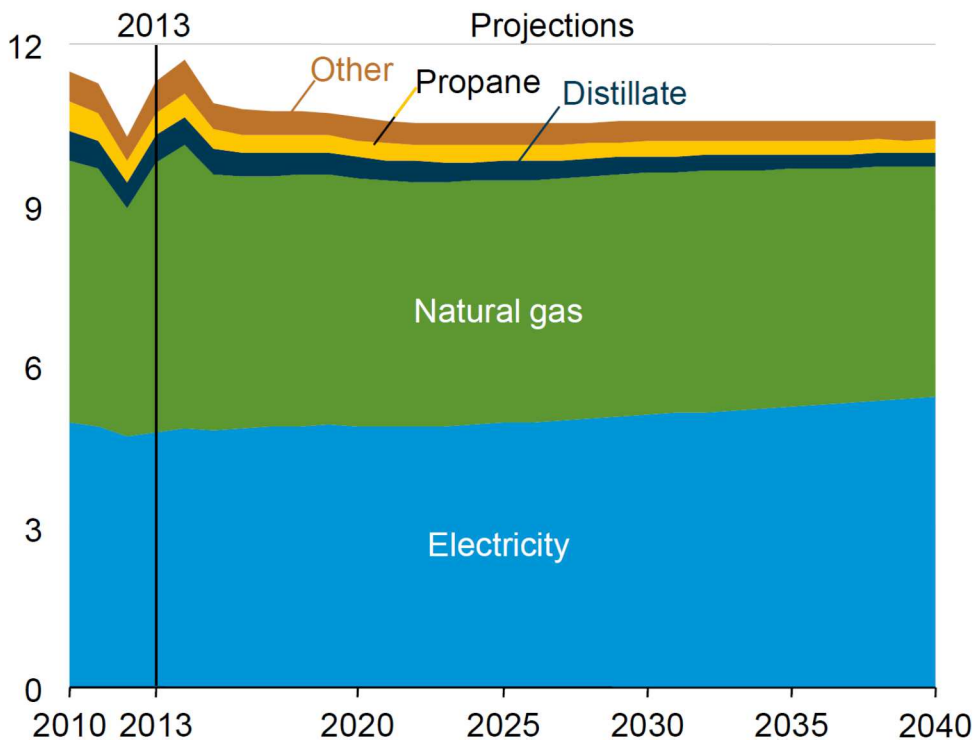
Figure 10: Residential sector delivered energy consumption by fuel in the Reference case, 2010-40 (quadrillion Btu) (U.S. Energy Information Administration (EIA) (b), 2015 p. 13)

Despite an expected 0.8 %/year growth rate for the total number of households from 2013 to 2040, the delivered energy consumption decreases at an average rate of 0.3 %/year in the residential sector over the same period in the AOE2015 Reference case. During the same time span, the electricity consumption in the residential sectors increases by 0.5 %/year in the Reference case. Furthermore, the energy demand shifts from space heating to space cooling as a growing share of population moves to warmer regions in the U.S. Besides that, electric loads

caused by miscellaneous, which comes from a variety of devices and appliances that range from microwaves ovens to medical imaging equipment, continue to grow in the residential sector. The residential natural gas use declines with improvements in equipment and building shell efficiencies, price increases over time and reduced heating needs. Also the distillate and propane consumption, primarily for space heating, decline by 2.7 %/year and 2.0 %/year in the Reference case from 2013 to 2040. (cf. U.S. Energy Information Administration (EIA) (b), 2015 p. 13f.)

Figure 11 gives an overview of the delivered energy Intensity for selected end uses in the AEO2015 Reference case in the residential sector.
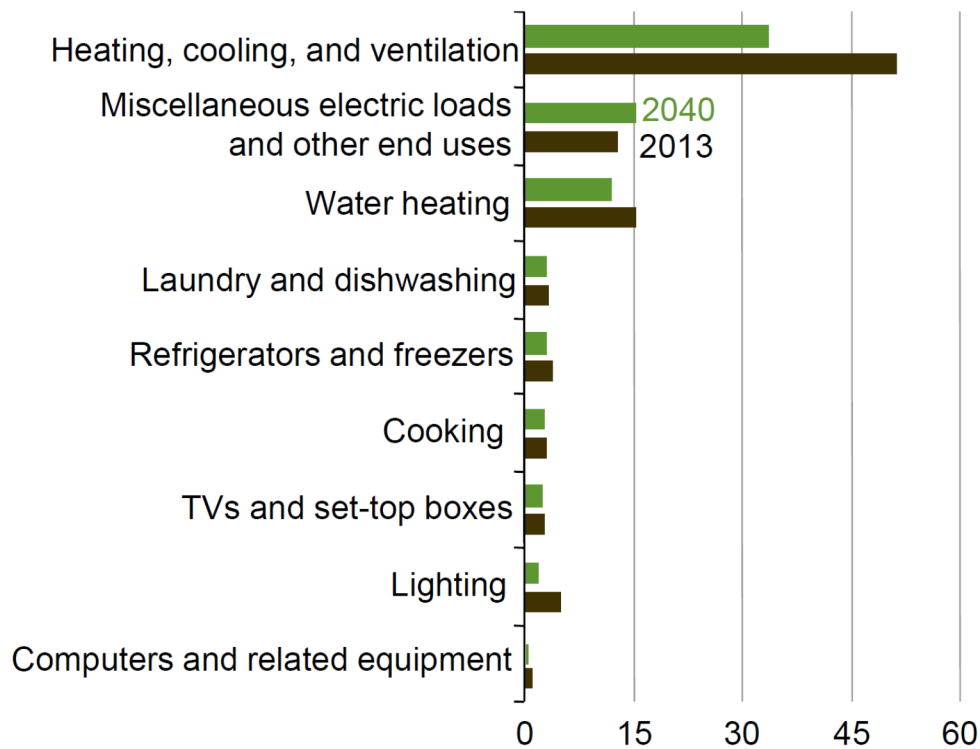
Figure 11: Residential sector delivered energy intensity for selected end uses in the Reference case, 2013 and 2040 (million Btu per household per year) (U.S. Energy Information Administration (EIA) (b), 2015 p. 15)

The end-use energy intensity, as can be seen in the figure above, is measured by consumption per residential household. It decreases in the Reference case as a result of increases in the efficiency of equipment for many end uses such as

heating, cooling and ventilation, Lighting etc. Voluntary market transformation programs and federal standards (e.g. Energy Star) target uses such as space heating and cooling, water heating, lighting, refrigeration and rapidly proliferating devices, such as set-boxes and external power supplies. The future energy use for heating and cooling in the residential and the commercial sectors will reduce as more states adopt new building codes and so shell efficiencies of newly constructed buildings are improving (cf. U.S. Energy Information Administration (EIA) (b), 2015 p. 14).

The developed cost-benefit building simulation tool in connection with this thesis can help to improve the shell efficiencies of old and new buildings and consequently to reduce the future energy use.

1.2.3 GEORGIA

The energy market in the state of Georgia and especially the household energy use is summarized in this chapter. Figure 12 shows the total energy consumption by sector for Georgia. In 2009, the residential sector was the second biggest energy consumer with 723,200 billion Btu only topped by the transportation sector with 952,000 billion Btu. After the residential sector follows the industrial sector with 720,000 billion Btu and finally the commercial sector with 553,300 billion Btu. The decreases from the industrial and transportation sector after 2005 are both partly related to increases in automobile efficiency and the beginning of the economic downturn in 2008. (GEFA Energy - Land - Water, 2012 p. 4)
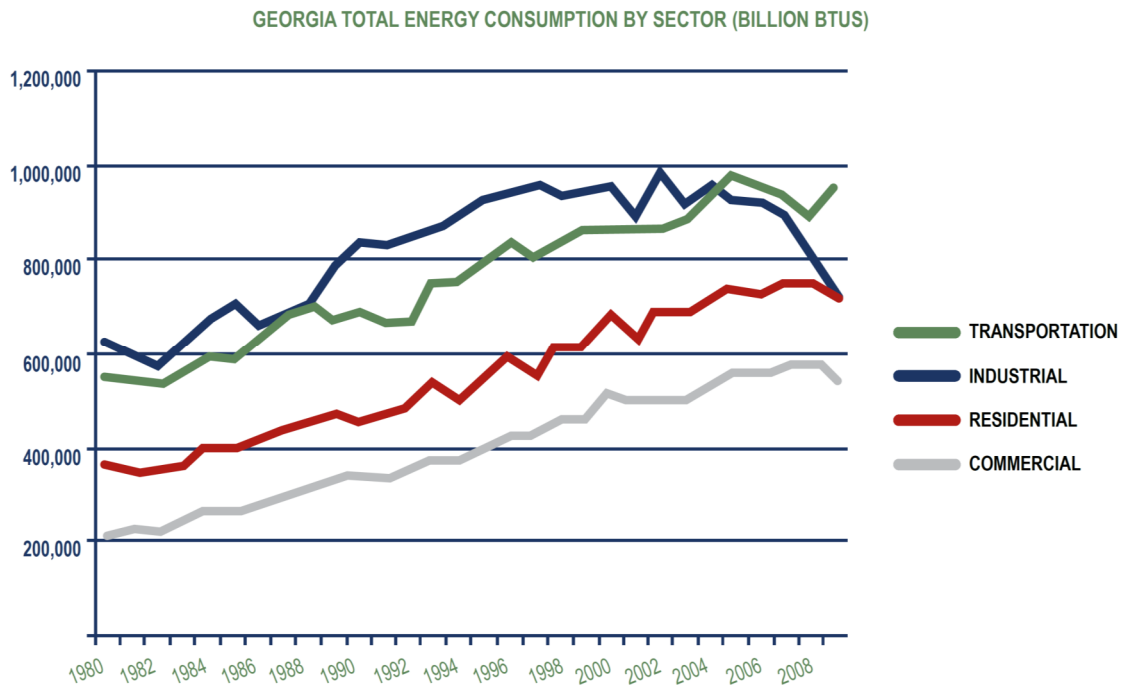
Figure 12: Georgia total energy consumption by sector (billion Btus) (GEFA Energy - Land - Water, 2012 p. 4)

1.2.3.1 RENEWABLE ENERGY IN GEORGIA

Georgia's demand for renewable energy is increasing, at which this type of energy is mostly used for electricity production and transportation fuels. Conventional hydroelectric, wood and wood waste biomass hold the majority of renewable electricity production in Georgia. Nevertheless, solar, landfill gas and

offshore wind are expanding sources in the state. Georgia generated 6.1 million MWh of renewable electricity in 2009, which represent about 4.7% of the whole electric power generation which also can be seen in Figure 13. 54% of the renewable electricity was generated by conventional hydroelectric and 45% was generated by wood and wood waste biomass. (cf. GEFA Energy - Land - Water, 2012 p. 6)

ELECTRIC GENERATION BY FUEL TYPE, 2009

- COAL (54.0%)
- NUCLEAR (24.6%)
- NATURAL GAS (15.9%)
- PETROLEUM (.5%)
- OTHER RENEWABLES (2.2%)
- HYDROELECTRIC (2.5%)
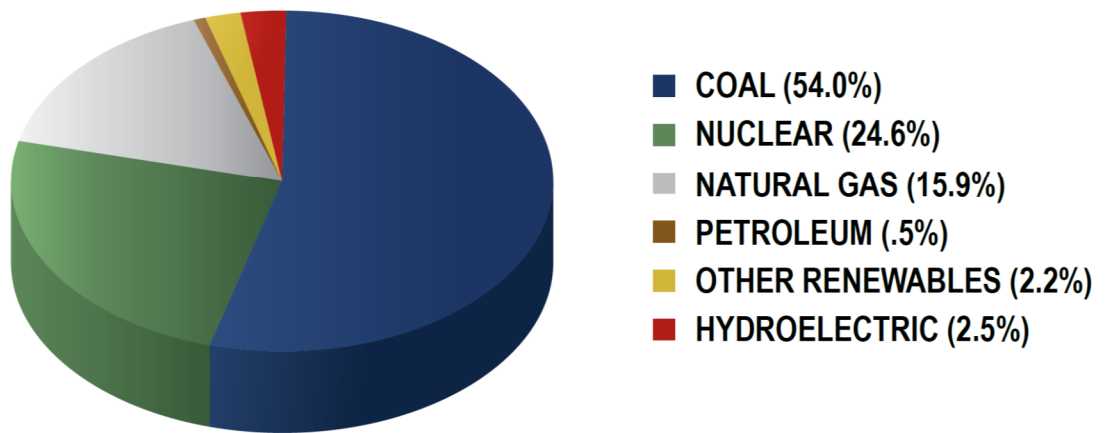
Figure 13: Georgia - Electric generation by fuel type, 2009 (GEFA Energy - Land - Water, 2012 p. 10)

However, the figure above shows that Georgia's electricity generation is mainly based on fossil fuels with a share of nearly 70% in 2009. To decrease the dependence on this diminishing resources, renewable energy need to be supported and increased. Especially since Georgia's position predestines the state to be a leader in advanced technology renewables such as solar power and wind power. Besides a very high solar energy potential, results of several studies are showing greater potential for Georgia's wind power than originally thought (cf. GEFA Energy - Land - Water, 2012 p. 10).

1.2.3.2 HOUSEHOLD ENERGY USE IN GEORGIA

The following chapter displays diverse data from the Energy Information Administration's 2009 Residential Energy Consumption Survey (RECS).

The RECS are administered by Energy Information Agency (EIA) and show a nationally representative sample of housing units. The energy characteristics on the housing unit, usage patterns and household demographics within the RECS are collected by specially trained interviewers. Combined with data from energy suppliers to these homes, this information is used to estimate energy costs und usage for heating, cooling, appliances and other end uses. These data are critical to meeting future energy demand to improve system and building efficiencies and building design.

The here presented survey from 2009 collected data from 12,083 households. This housing units are statistically selected to represent the 113.6 million housing units that are occupied as a primary residence. The RECS data from 2009 are tabulated for the four Census regions, the nine Census divisions, and 16 States. These states also vary in their geography, climate and population size (cf. U.S. Energy Information Administration (EIA) (c), 2015).

Figure 14 demonstrates the subdivision in the above mentioned regions, divisions and states. For all highlighted states in the figure also a fact sheet exists with detailed information on the household energy use respectively the residential energy consumption. As can be seen, the state of Georgia is also one of the marked states and is located in the South region and the South Atlantic (SoAtl) division. (cf. U.S. Energy Information Administration (EIA) (d), 2013)
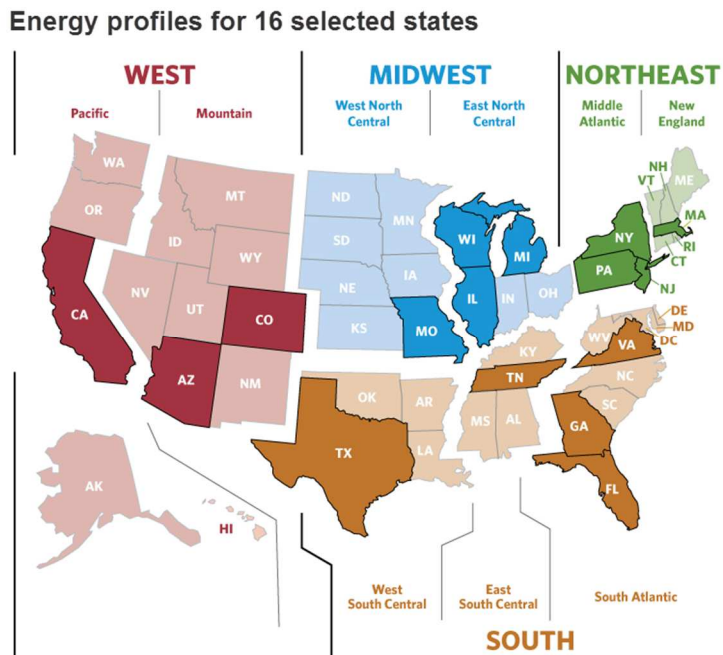
Figure 14: RECS Census regions, divisions and states (U.S. Energy Information Administration (EIA) (d), 2013)

All of the subsequent information are based on the Georgia fact sheet which also includes comparisons with the whole United States of America and the South Atlantic division.

The site energy consumption and the energy expenditures per household are faced in Figure 15 for the three above mentioned areas.

Figure 15: All Energy Use - average per household (excl. transportation) (U.S. Energy Information Administration (EIA) (e), 2013)

Georgia's energy consumption of 89.5 million Btu is slightly higher than the U.S. household average and the consumption of the South Atlantic region is clearly less compared to both. The household energy expenditures of Georgia amounts $2,067 and is similar to the U.S. and the South Atlantic region's value. (cf. U.S. Energy Information Administration (EIA) (e), 2013)

The electricity consumption per household for the same three areas is indicated in Figure 16. Georgia has among the highest value in the whole country, but similar to other states in the same region. Georgia has a relatively young housing structure whereat 45% of the state's homes were built since 1990. This characteristic is typically associated with lower per household consumption. However, Georgia homes are larger than the U.S. average which is a feature that can offset some of the efficiencies associated with living in a newer home.

The expenditures on electricity in Georgia is on the one hand higher than U.S. average per household but lower than the average in the South Atlantic region. (cf. U.S. Energy Information Administration (EIA) (e), 2013)

ELECTRICITY ONLY *average per household*

Site Consumption
kilowatthours

Expenditures
dollars
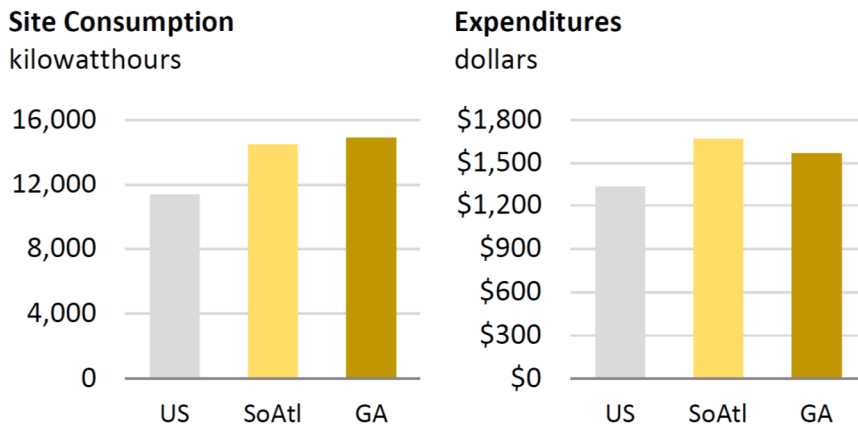
Figure 16: Electricity Only Use - average per household (U.S. Energy Information Administration (EIA) (e), 2013)

The split of the energy consumption by the end use in the building is one first step to reveal the energy saving potential in the different energy consuming sectors. This breakdown to the end use sectors is illustrated in Figure 17. Compared to other states in the U.S., Georgia is one of the few states where at least 30% of the household energy consumption is used for space heating and as well at least 10% of the energy consumed in homes is used for the air conditioning system. (cf. U.S. Energy Information Administration (EIA) (e), 2013)
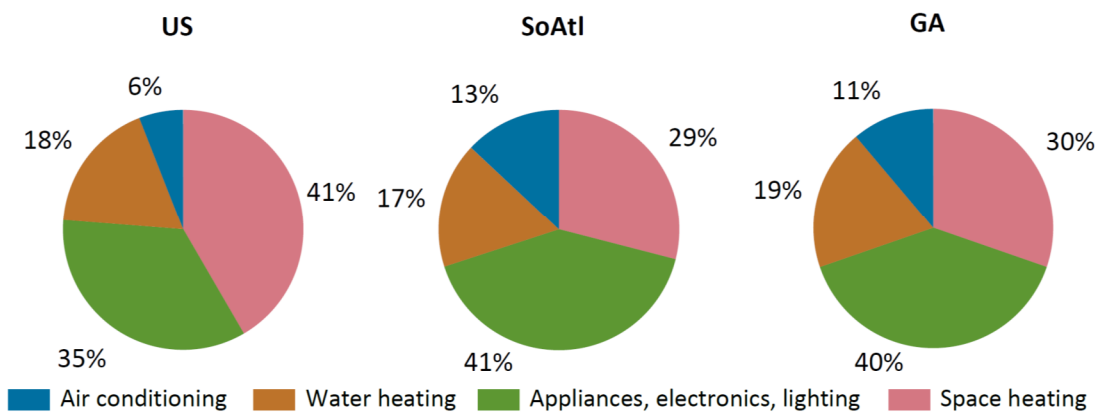
Figure 17: Georgia - Residential energy consumption by end use (U.S. Energy Information Administration (EIA) (e), 2013)

Very important information to demonstrate the significance of this thesis is presented in Figure 18.
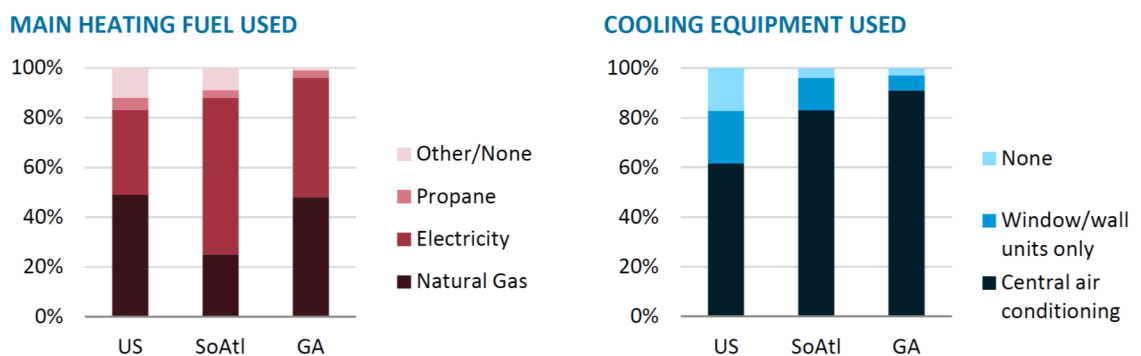
Figure 18: Georgia - Residential - main heating fuel used and cooling equipment used (U.S. Energy Information Administration (EIA) (e), 2013)

The left side of the image shows the main heating fuel type used in Georgia compared to the South Atlantic region and the U.S. The right side illustrates the partition of the used cooling equipment again as comparison between all three areas.

It becomes apparent that residential buildings in Georgia are mainly heated by natural gas and electricity. Both fuel types have a share of 48% and dominate together with about 96% the main heating fuel choices in Georgia homes. For the other two areas, the total share of these fuel types is not as big as for the state. The illustration on the right side of Figure 18 reveals that over 90% of Georgia residents use a central air conditioning system to cool their buildings. (cf. U.S. Energy Information Administration (EIA) (e), 2013)

The developed simulation tool comprises electricity and natural gas powered heating systems and also central air conditioning cooling systems. Therefore, it is perfectly adapted to Georgia's heating characteristics.

1.2.3.3 ELECTRICITY AND NATURAL GAS PRICE IN GEORGIA

This chapter is used to provide an overview on the current electricity and natural gas prices in Georgia and their expected future trend.

Figure 19 gives the average up-to-date retail price of electricity to ultimate customers by end use sector for the state of Georgia. It compares the prices in cents per kilowatt-hour from January 2014 to January 2015 at which can be seen that the price decreased for every sector during this period. The electricity price for Georgia's residential sector in January 2015 was about 10.5 cents/kWh.
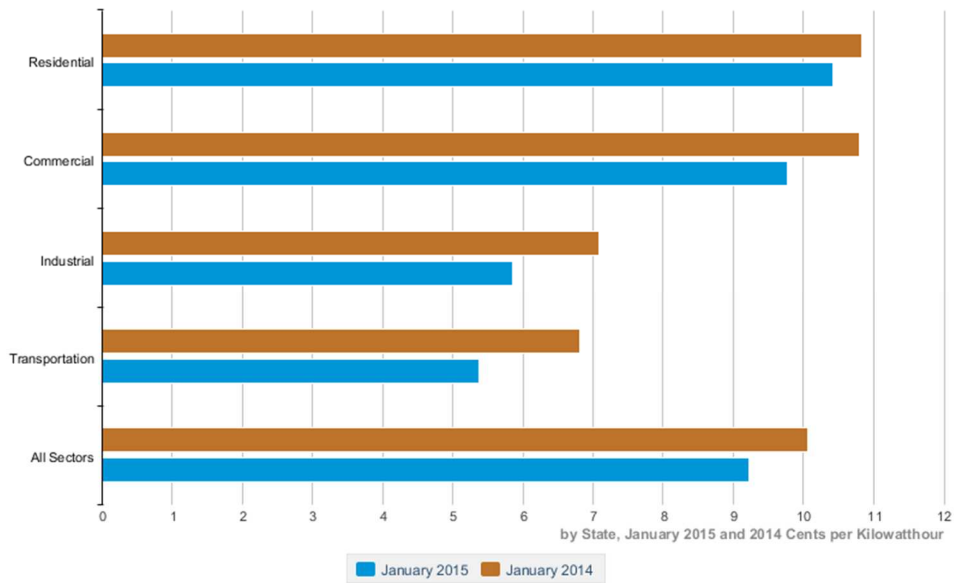
Figure 19: Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, Georgia (U.S. Energy Information Administration (EIA) (g), 2015)

As shown in Figure 20, the price for natural gas delivered to residential consumers in Georgia experienced an intense increase since 1970 to 2014. On the contrary, the price dropped from over 18 dollars per thousand cubic feet ($/Mcf) to the most recent value of slightly below 15 $/Mcf in 2014.
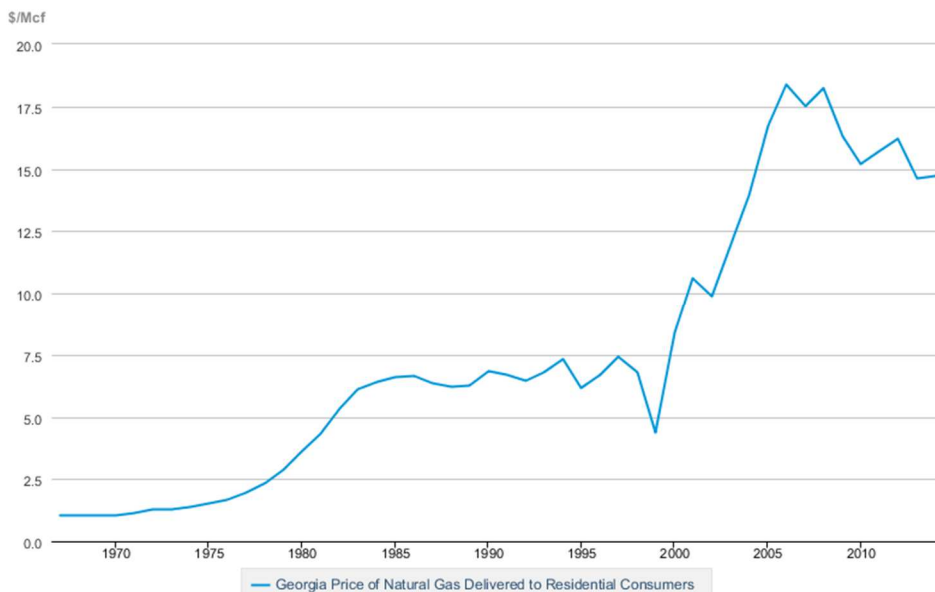
Figure 20: Georgia - Residential - Natural Gas Prices (Dollars per Thousand Cubic Feet) (U.S. Energy Information Administration (EIA) (h), 2015)

In addition to the current prices of different types of energy and of course also the future price development has great importance for the economical evaluation of an energy saving measure. The expected future energy price trend for electricity and natural gas in the South Atlantic region is demonstrated in Figure 21. The two curves are based on the prices from 2013 in $/mill Btu which are also indexed to the 2012 value. That means for example that the natural gas price decreased by about 6% from 2012 to 2013. However, as revealed by the graph, in the long run the electricity price is expected to increase up to about 25% in 2040 and the natural gas price up to almost 50% in the same period in the AEO2015 Reference case.
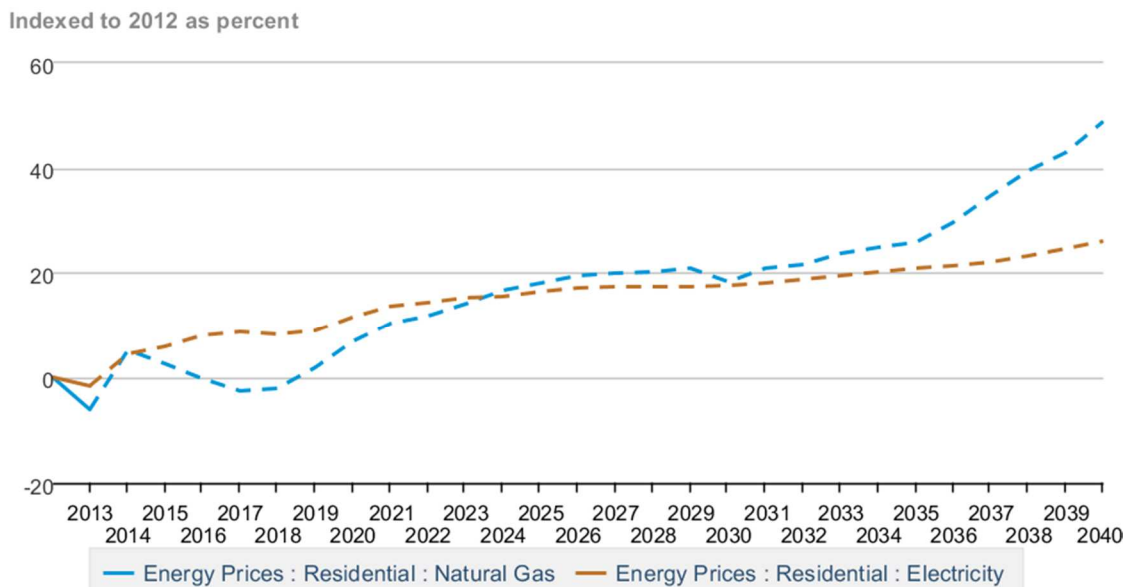
Figure 21: South Atlantic region - Residential - Energy Prices Electricity and Natural Gas (U.S. Energy Information Administration (EIA) (f), 2015)

1.2.3.4 GEORGIA ENERGY CHALLENGE

As mentioned before, the state of Georgia tries to tackle upcoming energy related issues by reducing its energy demand and therefore, the Georgia Energy Challenge was set up. State agencies were committed to reduce their consumption 15% below the level of 2007 by the year 2020. The responsible former governor of Georgia also challenged citizens, businesses and local

government to participate in the initiative. By reaching this goal, Georgia will be more independent from traditional energy sources, decrease environmental impact, protect Georgia's natural resources and support the local economy. The Georgia Energy Challenge also includes the State Energy Leadership Initiative. It includes a baseline energy usage and energy data tracking established by the state agencies in collaboration with the Georgia Environmental Finance Authority. Moreover, energy management plans has been developed to meeting the challenge. By meeting this energy goals, the state could save more than $30 million per year. (cf. GEFA Energy - Land - Water, 2012 p. 14)

1.2.4 SAVANNAH

Similar to Georgia's proportions in Figure 18, also the main house heating fuel types in the City of Savannah are dominated by utility gas and electricity which can be seen in Table 7. The percent values for the state in the table are slightly different to the above mentioned numbers due to a different information source. Furthermore, the table reveals that about 70% of Savannah's household heating is provided by electricity. Together with the utility gas portion, the two heating fuel types amount more than 98% of the city's house heating.

Table 7: House Heating Fuel in Savannah and Georgia (U.S. Census Bureau (a), 2013)

Subject	Georgia		Savannah city, Georgia	
	Estimate	Percent	Estimate	Percent
HOUSE HEATING FUEL				
Occupied housing units	3,518,097	3,518,097	52,164	52,164
Utility gas	1,450,088	41.20%	14,709	28.20%
Bottled, tank, or LP gas	194,959	5.50%	460	0.90%
Electricity	1,816,562	51.60%	36,696	70.30%
Fuel oil, kerosene, etc.	8,543	0.20%	74	0.10%
Coal or coke	162	0.00%	5	0.00%
Wood	34,335	1.00%	41	0.10%
Solar energy	448	0.00%	5	0.00%
Other fuel	2,782	0.10%	14	0.00%
No fuel used	10,218	0.30%	160	0.30%

2 SCIENTIFIC QUESTION

As already mentioned in the Introduction, there is no general approach for the determination of parameters which can help to decide if a refurbishment of old building services systems is economically and ecologically worthwhile or not.

The same issue applies to the identification of the best application of these systems for new built single and multi-family houses such as those which are planned and constructed with the aid of the Savannah Affordable Housing Fund. By comparing several systems of an energy-saving and cost-saving point of view, the best solution for the new built homes should emerge.

Thus, the question arises for a general tool and planning assistance guideline which determines the perfect solution for a sustainable building services system in the relevant buildings. It is very important that the proposed findings are adapted to local conditions in relation to the existing building structure, consumer habits, commonly used systems and the climatic conditions in Georgia and particularly in Savannah.

To get a satisfactory answer to the specific needs, with the work proposed,

- an analysis on the background of the energy sector, local frame conditions, building and consumer structure and energy demand,
- a general model
- the essential model parameter,
- an assessment approach, and
- a calculation tool

should be identified and developed in order to enable the assessment of possible energy cost saving projects.

3 THEORETICAL BACKGROUND – LITERATURE RESEARCH

Within this chapter, a brief presentation of the used theoretical foundations, the acknowledged methods for the performed calculations and processes, the methodological regulations to be applied and the economic methods, is done. Furthermore, a short summary of the used climatic boundary conditions in Savannah is presented. This is important because the building simulation part of the cost-benefit tool is based on this data which has a vast impact on the simulation results.

3.1 CLIMATE DATA – CITY OF SAVANNAH

The following chapter gives a summary of the most important climate data for the City of Savannah. These data present amongst others the basis for the simulation of the specific building calculations. Accordingly, information on the different U.S. climate zones, the hourly outdoor temperatures in Savannah and the available solar irradiation in the area of Savannah is provided.

3.1.1 CLIMATE ZONES

As can be seen in Figure 22, according to the International Energy Conservation Code (IECC), the land area of the United States of America is subdivided in seven different climate zones. This code is developed and released by the International Code Council (ICC) in collaboration with the U.S. Department of Energy (DOE). Its purpose is the establishment of a baseline for energy efficiency by setting performance standards for building envelope, mechanical systems, etc. (cf. U.S. Department of Energy (a), 2012). Each climate zone has different values for specific building and performance parameter in order to meet the energy conservation standard (cf. International Code Council, 2012). In the case of Savannah, Georgia, the figure below reveals that this area is located in climate

zone 2. Basically, this area's climate is mostly warm and humid and subsequently the energy conservation code standards for this zone are adapted to this circumstances.
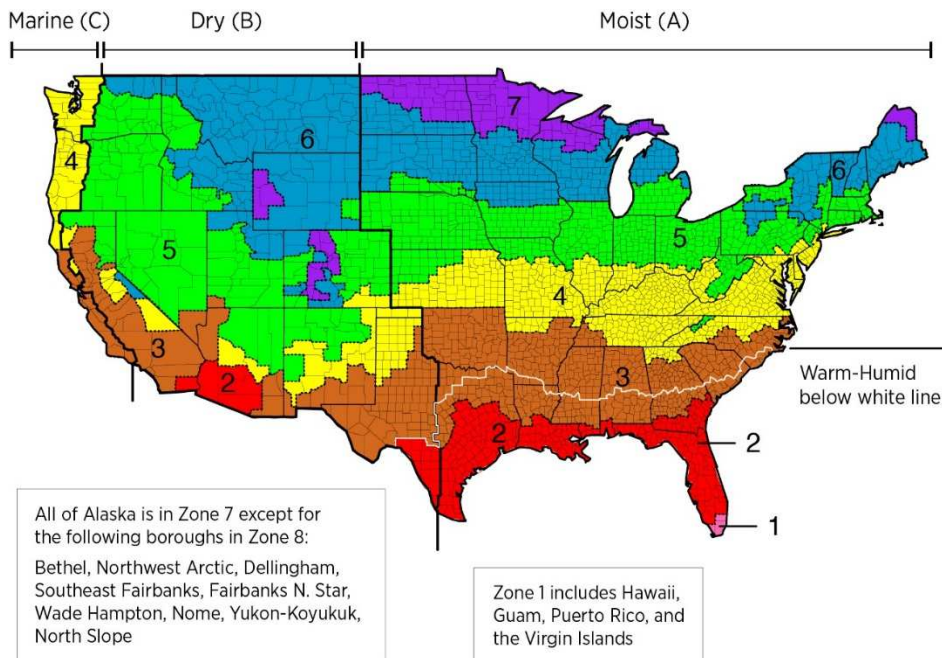
Figure 22: Climate Zones – USA (U.S. Department of Energy (a), 2012)

3.1.2 TEMPERATURE

For the simulation of the thermal behavior of a building and as a result also for the heating and cooling demand, the temperatures of the building environment are playing a major role. Therefore the outside temperature values for the building simulation within the cost-benefit tool are based on a data set which is provided by the program "Meteonorm 7" (Remund (a), et al., 2014). This set is a series of hourly measured ambient temperatures over a one year period at the Airport Savannah Weather Station. This data series is generated from the yearly values which are measured every year from 2000 to 2009. (Remund (a), et al., 2014) The diagram in Figure 23 shows the hourly values in two temperature trend lines. The blue line shows the values in °C and the orange line in °F. It can be seen that the temperature peak values in the summer month reach up to almost 100 °F (about 38 °C) and coldest temperatures in the winter time is nearly 22 °F (about

-5.5 °C). The diagram also reveals that the temperature fluctuation range in the winter months is much higher compared to the summer time.
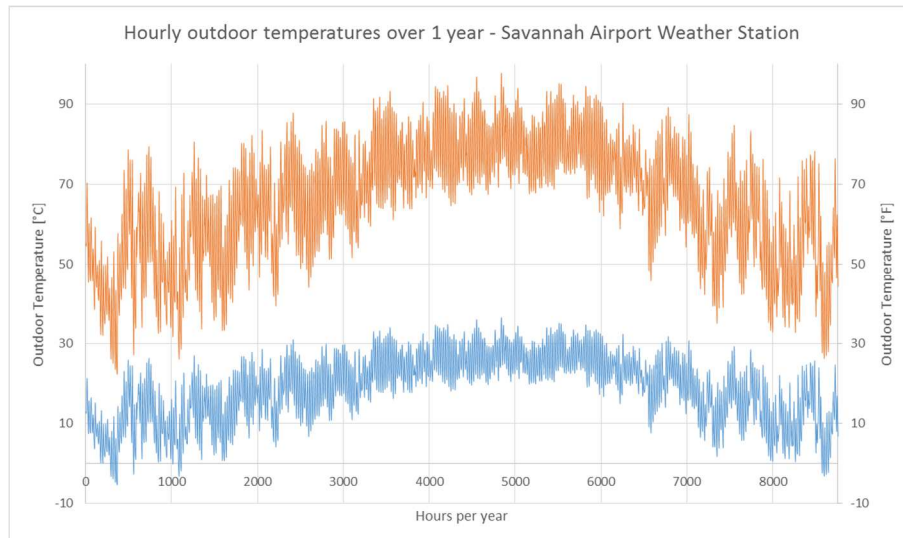
Figure 23: Hourly outdoor temperatures over 1 year - Savannah [Source: own Figure, data based on Meteonorm 7]

3.1.3 IRRADIATION

The irradiation data which are used in the cost-benefit tool also refer to the program "Metenorm 7" (Remund (a), et al., 2014). According to this software, the used irradiation data are TMY3 (Typical Meteorological Year) datasets from NREL (National Renewable Energy Laboratory). TMY3s are datasets of hourly values of solar radiation for a 1-year period which are based on data from 1991 to 2005 (cf. Remund (b), et al., 2014 p. 44). The data which are used for the tool comprise hourly data for global irradiance, direct radiation and scattered radiation for the City of Savannah. In addition, the appendant hourly values for the solar azimuth angle and the solar altitude angle are implemented to simulate the influence of solar energy input on each side of the building over the whole year.

Figure 24 shows the visualized irradiation data over one year. As can be seen, compared to the winter time, in the spring and summer month the available irradiation is much higher and goes up to about 1000 W/m². These data are the basis for the calculation of the solar heat gains within the cost-benefit tool.
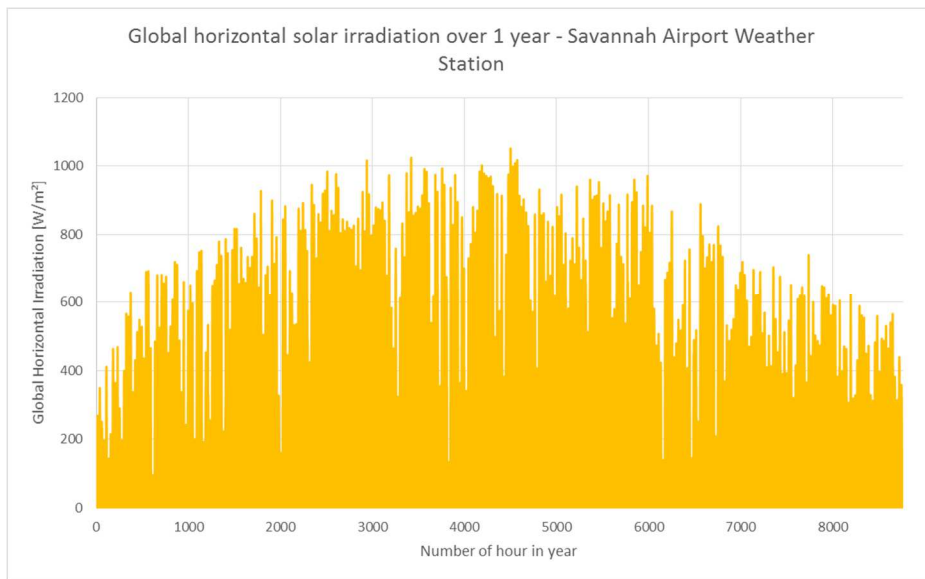
Figure 24: Global horizontal irradiation over 1 year - Savannah [Source: own Figure, data based on Meteonorm 7]

Figure 25 provides an example of a small timeframe of the data for one year. It shows the available irradiation for the first week of Mai at which can be seen that values have a strong hourly fluctuation.
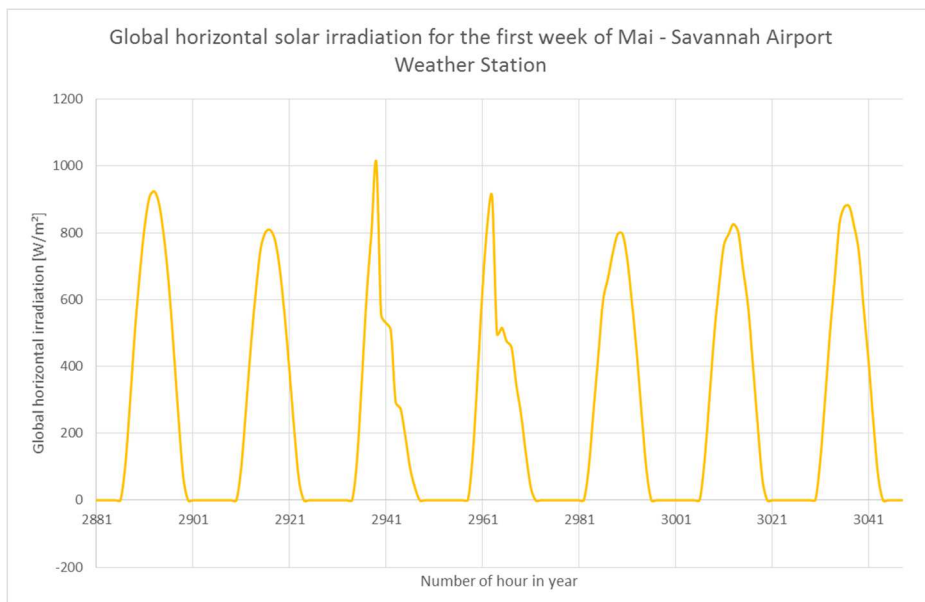
Figure 25: Global horizontal irradiation for the first week of Mai - Savannah [Source: own Figure, data based on Meteonorm 7]

3.2 ECONOMICS CALCULATION MODEL

To enable a comprehensive and reasonable comparison of the calculation results from different building services systems, three different economics calculation methods respectively parameters are determined in every calculation. With the annuity method, the results can be compared by means of one economic parameter, the annuity. The discounted accumulated cash flow trend and the simple payback time are the other two methods which are used for the system comparison.

3.2.1 ANNUITY METHOD

This chapter presents and explains the most important contents of the VDI Guideline 2067 Part 1 (VDI, 2000) which has been used for the economics calculation within the cost-benefit tool. Some equations and notes have been adapted in order to enhance the understanding for the method and to be suitable for U.S. frame conditions.

The economic benefit respectively the profitability of investments can be calculated or verified with the following procedures:

●   Net present value method

●   Annuity method

●   Internal rate of return

●   Amortization method

A detailed description of these methods can be found in the VDI Guideline 6025. The economics calculation using the annuity method, taking into account replacements, is elaborated and explained below.

With the annuity method it is possible to summarize non-recurring payments/investments and regular payments by using the annuity factor a during an observation period T. (cf. VDI, 2000 p. 14)

3.2.1.1 OUTGOING PAYMENTS

The outgoing payments (costs) are subdivided into single payments respectively non-recurring payments and regular payments. Thus, the following categories of payments are defined:

- Capital-related costs

- Requirement (consumption)-related costs

- Operation-related costs

- Other costs

(cf. VDI, 2000 p. 14)

3.2.1.1.1 CAPITAL-RELATED COSTS

For the observation period of the whole investment profitability calculation, the service life of the less durable and/or more capital-intensive installation components can be used. The residual value respectively the net book value for the remaining system components must be determined.

By using the equation [3.1], the annuity of the capital-related costs can be determined:

$$A_{N,K} = (A_0 + A_1 + A_2 + \cdots A_N - R_w) * a + \frac{f_K}{100} * A_0 * ba_{IN} \qquad [3.1]$$

$A_{N,K}$	annuity of payments linked to capital in \$
A_0	amount of investment in \$
$A_{1,2,\ldots,n}$	cash value of 1st, 2nd, nth replacement
R_W	residual value or net book value
a	annuity factor

f_K factor for repairs in % of the amount of investment per year (see also Table 12 in appendix-chapter 14.1)

ba_{IN} price-dynamic annuity factor for repair payments

To calculate the cash flow of replacements, the equations [3.2] are used:

$$A_1 = A_0 * \frac{r^{(1*T_N)}}{q^{(1*T_N)}}$$ [3.2]

$$A_2 = A_0 * \frac{r^{(2*T_N)}}{q^{(2*T_N)}}$$

$$A_3 = A_0 * \frac{r^{(3*T_N)}}{q^{(3*T_N)}}$$

$$A_n = A_0 * \frac{r^{(n*T_N)}}{q^{(n*T_N)}}$$

By straight-line depreciation of the amount of investment until the end of the observation period and discounting to the beginning of the observation period, the residual value is determined. If the observation period T exceeds the service life T_N of the components under observation, the replacement investment undergoes the straight-line deprecation and not the initial amount of investment.

$$R_w = A_0 * r^{(n*T_N)} * \frac{(n+1)*T_N - T}{T_N} * \frac{1}{q^T}$$ [3.3]

$A_0 * r^{(n*T_N)}$ …price at point of purchase

$\dfrac{(n+1)*T_N - T}{T_N}$ …straight-line depreciation

$\dfrac{1}{q^T}$ …discounted to the beginning

T_N service life of system components in years

T observation period in years

q interest factor

r price change factor

n number of replacements within the observation period

The already mentioned annuity factor is provided by equation [3.4]:

$$a = \frac{q^T * (q - 1)}{q^T - 1} = \frac{q - 1}{1 - q^{-T}}$$ [3.4]

If assumed that during the observation period there will be price changes in the regular payments for maintenance, these payments are multiplied by the price-dynamic annuity factor. These factors, one for every of the four subdivisions of the outgoing payments, are given by equation [3.5]:

$$ba_{IN} = b_{IN} * a$$ [3.5]

$$ba_V = b_V * a$$

$$ba_B = b_B * a$$

$$ba_S = b_S * a$$

All of the price-dynamic annuity factors above are determined with the appropriate cash value factor b (b_{IN}, b_V, b_B, b_S), for which the basic cash value factor is given by equation [3.6]:

$$b = \frac{1 - (\frac{r}{q})^T}{q - r}$$ [3.6]

$$r = q \; implies \; b = T/q$$

(cf. VDI, 2000 p. 14f.)

3.2.1.1.2 REQUIREMENT (CONSUMPTION)-RELATED COSTS

If changes in the power and fuel prices occur, the following calculation approach for the consumption-related costs is used:

$$A_{N,V} = A_{V1} * ba_V \qquad [3.7]$$

$A_{N,V}$	annuity of requirement (consumption)-related costs
A_{V1}	requirement (consumption)-related costs in first year
ba_v	price-dynamic annuity factor for requirement (consumption)-related costs
r_V	annual price change factor for requirement (consumption)-related costs

It should be noted that r_V is used in combination with equation [3.6] to calculate b_V which is used within equation [3.5] to calculated the price-dynamic annuity factor ba_v.

The consumption related costs are determined by using equation [3.8]:

$$A_{V1} = Q_{3,Heat} * Price_{Heat} + Q_{3,Cooling} * Price_{Cooling} \qquad [3.8]$$
$$+Q_{3,Electricity} * Price_{Electricity} + Q_{3,Water} * Price_{Water}$$

$Q_{3,Heat}$	energy effort on heat generation in kWh/year
$Q_{3,Cooling}$	energy effort on cooling in kWh/year
$Q_{3,Electricity}$	electricity effort in kWh/year
$Q_{3,Water}$	water effort in m³/year
$Price$	price in $/kWh or $/m³

(cf. VDI, 2000 p. 17)

3.2.1.1.3 OPERATION-RELATED COSTS

Operation-related costs also be subject to changes that can be caused, among other things, by an alternation in wage levels. For these, the following approach is given, taking into consideration price changes analogous to the consumption-related costs.

$$A_{N,B} = A_{B1} * ba_B \qquad\qquad [3.9]$$

$A_{N,B}$	annuity of the operation-related costs in \$
A_{B1}	operation-related costs in the first year
ba_B	price-dynamic annuity factor for operation-related costs

(cf. VDI, 2000 p. 17)

3.2.1.1.4 OTHER COSTS

Equivalent to the calculation approach above, to determine the other costs equation [3.10] is to be applied:

$$A_{N,S} = A_{S1} * ba_S \qquad\qquad [3.10]$$

$A_{N,S}$	annuity of other costs in \$
A_{S1}	other cost in the first year
ba_S	price-dynamic annuity factor for other costs

(cf. VDI, 2000 p. 17f.)

3.2.1.2 INCOMING PAYMENTS

Incoming payments (revenues) can arise in the same way as the outgoing payments by depending on projects and operators. This applies to capital- (investments, grants), consumption- and operation-related incoming payments. All calculation formulas shall be applied corresponding to chapter 3.2.1.1.

If incoming payments are not differentiated by individual payment types, they can be calculated by equation [3.11] which also assumes price changes:

$$A_{N,E} = E_1 * ba_E \qquad\qquad [3.11]$$

$A_{N,E}$	annuity of revenues in $
E_1	revenues in the first year
ba_E	price-dynamic annuity factor for revenues

(cf. VDI, 2000 p. 18)

3.2.1.3 ANNUITY OF TOTAL ANNUAL PAYMENTS

The total annuity A_N for all payments of a system is determined by calculating the difference between the annuity of the revenues and the sum of the capital-related, requirement (consumption)-related, operation-related and other cost annuities:

$$A_N = A_{N,E} - (A_{N,K} + A_{N,V} + A_{N,B} + A_{N,S}) \qquad\qquad [3.12]$$

Two cases must be distinguished when considering the total annuity:

1. Systems that are supposed to make a profit by selling heat, cold, electricity etc. (e.g. district heating system)
2. Systems that do not generate any revenues (e.g. heating system in a single family house)

In the first case, A_N must be larger than zero ($A_N>0$) in order for the system to be economical. This means that the annuity of all incoming payments is more than the annuity of all outgoing payments. If different systems with $A_N>0$ are being compared with one another, preference should be given to the system which has the largest calculated total annuity.

In the second case, A_N is less than zero ($A_N<0$). The most profitable system is that which generates the fewest costs.

This two cases can be explained through Figure 26. For the system variants V1 and V2 the total annuity A_N is negative. For these systems, no revenues are generated and therefore they correlate to case two from above. Variant V2 is more profitable than V1 because it generates less costs.

In the case of variants V3 and V4, revenues are generated for example from the sale of electricity. V4 is preferable to V3 because A_N is greater and so the profit. (cf. VDI, 2000 p. 18f.)
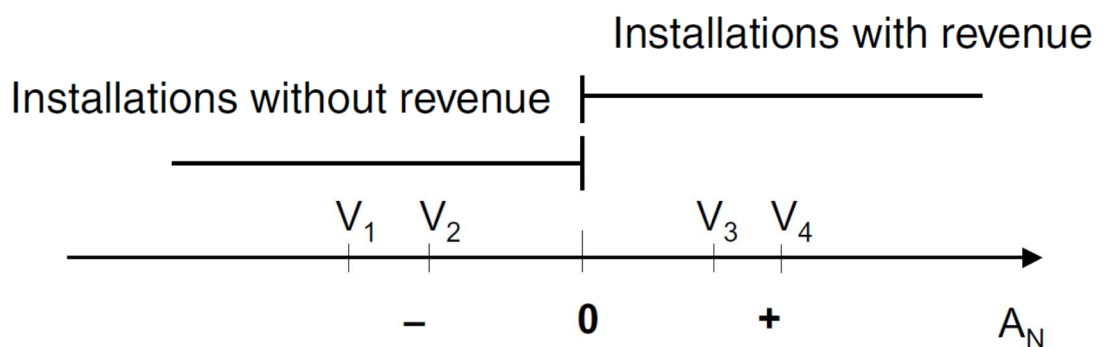
Figure 26: Total Annuity A_N (VDI, 2000 p. 19)

3.2.2 DISCOUNTED ACCUMULATED CASH FLOW

This chapter provides the basic formulas and calculation methods for the discounted accumulated positive cash flow trend. It is used within the cost-benefit tool to compare variations of new installed building services systems. However, the section below only shows basic information and the needed formulas which are used to determine this cash flow trend line. The execution of the calculation is explicated in 4.1.3.2.

3.2.2.1 CASH FLOW

The cash flow is an integral part of most analyses and is needed to compute several economic measures. The explicit definition is difficult because the type of cash flow used for an analyses will vary, depending on the type of analysis conducted.

The cash flow can be distinguished in terms of three different activities performed by a company: operating, investing and financing. Operating activity cash flows include all revenues captured, minus operating and maintenance expenses, interest paid, and income taxes paid. The investing activity cash flows include capital expenditures.

Usually, cash flows occurring within a period are grouped as a lump sum at the start, middle or end of the period. The end-of-the-period cash flows is one of the most common practice. The "period" is defined as a year for most of the capital investment analyses. As a result, an annual discount rate can be used for compounding or discounting the cash flows for the analyses. (cf. Short, et al., 1995 p. 2)

3.2.2.2 DISCOUNT RATE

"Time value is the price put on the time that an investor waits for a return on an investment." (Short, et al., 1995 p. 5). A dollar received today can be invested to earn interest immediately and so it is worth more than a dollar received tomorrow. Vice versa, a dollar received tomorrow is worth less than a dollar received today because the opportunity to invest it and ear interest is lost. The discount rate is central to the calculation of the present value because it acts as a measure of the mentioned time value. A common use for the discount rate is to account for the risk inherent in an investment. Therefore, the choice of the discount rate is very important to any economic analysis.

An analysis can be performed using either current or constant dollar cash flows, but it is important to remain consistent throughout the study. For example, for calculating the present value of a future payment (see also chapter 3.2.2.3), the discount rate can either include the effects of inflation (nominal) or exclude inflation (real). The discount rate used in the economic analysis should be consistent with the form of all cash flows. In summary, that means that the real discount rate and constant dollar cash flows exclude inflation, whereas nominal discount rates and current dollars include inflationary effects. Accordingly, a current dollar analysis needs the use of a nominal discount rate and a constant dollar analysis requires the use of a real discount rate. The following formulas enables the conversion from real to nominal discount rate and vice versa.

$$(1 + d_n) = (1 + d_r) * (1 + e)$$ [3.13]

$$d_n = [(1 + d_r) * (1 + e)] - 1$$

$$d_r = [(1 + d_n)/(1 + e)] - 1$$

d_n	nominal discount rate
d_r	discount rate in the absence of inflation (real)
e	inflation rate

(cf. Short, et al., 1995 p. 5f.)

3.2.2.3 PRESENT VALUE

To account for changing dollar valuations, the present value or present value analysis is used to calculate the today's worth of a transaction that will occur in the future. That means the present value is a measure of today's value of revenues or costs to be incurred in the future. The present value is fundamental for the economics calculation, therefore it is important to understand the issues surrounding its components and what is being assumed in the present value analysis.

By multiplying the future cash flow by a present value discount factor, the present value of a dollar received or paid in the future can be calculated. This is used to discount the future cash flows back to the present. The present value and the present value interest factor can be calculated with the following formulas:

$$PV = PVIF_n * F_n \qquad\qquad\qquad\qquad [3.14]$$

$$PVIF_n = \frac{1}{(1+d)^n}$$

$$Therefore \ldots \qquad PV = PVIF_n * F_n = \frac{1}{(1+d)^n} * F_n$$

PV	present value
$PVIF_n$	present value interest factor
F_n	cash flow n years in the future
d	annual discount rate

Example: A discount rate of 5% is assumed and a cash flow of $1 one year from now. By using equation [4.2], the present value is calculated as follows:

$$PV = \frac{1}{(1+0.05)^1} * \$1 = 0.9524 * \$1 = \$0.95$$

The present value of the future cash flow of $1 is about $0.95 and conversely, if $0.95 was invested with an interest rate of 5%, it would be worth about $1 one year from now. With this formula, the cash flows in any future period or from now to some point in the future can be calculated.

If the present value is a sum of the present values of each future year's cash flow, the following formula is used:

$$PV = \sum_{n=1}^{N} PVIF_n * F_n$$

[3.15]

The future inflows at different points in time respectively years can also have variable values. After these future values are converted to present values, they ca be added. Equation [3.15] is necessary when each future cash flow is uneven or differs in amount and so the present value for each individual future cash flow must be calculated. (cf. Short, et al., 1995 p. 12f.)

3.2.3 SIMPLE PAYBACK TIME

To compare different project alternatives, the simple payback (SPB) is a quick and simple way. It is also known as simple payback period or simple payback time and is relatively easy to utilize and therefore a popular financial tool .The simple payback or simple payback time represents the number of years necessary to recover the project cost of an investment under consideration

The SPB is recommended to use when risk is an issue because it allows a quick assessment of the duration during which an investor's capital is at risk. SPB is not recommended for evaluating alternatives involving financing and tax features, for selecting among mutually exclusive alternatives or when ranking projects. The reason is that the SPB would lose the advantage of simplicity, SPB is not considering the values of differing investment sizes and SPB ignores returns after payback.

SPB is the first point in time at which the following constraint is complied:

$$\sum_n \Delta I_n <= \sum_n \Delta S_n \qquad\qquad [3.16]$$

SPB	minimum number of years required for the nondiscounted sum of annual cash flows net annual costs to exceed or equal the nondiscounted investment costs
ΔI	nondiscounted incremental investment costs
ΔS	nondiscounted sum of the annual cash flows net annual costs.

(cf. Short, et al., 1995 p. 56f.)

It should be noted that the above introduced determination method for the SPB provides information for the use of this key figure and an understanding for it's evaluation. However, for the calculation of the SPB within this thesis, deviations and assumptions on the calculation method apply (see also chapter 4.1.3.3).

3.3   HEAT LOAD AND COOLING LOAD CALCULATION MODEL

This chapter presents all needed theoretical basic information, equations and formulas which are needed to calculate and develop the main heating and cooling load equation of chapter 4.1.2. The same chapter contains the explanation of the basic calculation model which has been developed for the building simulation within the cost-benefit tool.

The heat losses are composed of transmission- and ventilation heat losses. By implementing constructional measures it is possible to use solar energy (passive thermal solar energy use) and thereby reducing particularly the transmission heat losses but also the ventilation heat losses. Due to the daily and yearly fluctuation of the solar irradiation intensity and the outdoor- and indoor air temperature, transient temperature and heat flow relations appear within the structural element and building. Therefore, also the heat storage capacity of the building plays an important role. (cf. Schramek, 2007 p. 482)

3.3.1   TRANSMISSION HEAT LOSSES AND GAINS

The norm-transmission heat losses Φ_T (unit W) of a room are determined with the temperature difference between interior (θ_{int}) and external (θ_e) and the different transmission heat loss coefficients H_T (unit W/K) of the room.

$$\phi_{T,i} = \left(\theta_{int,i} - \theta_e\right) * \left(H_{T,ie} * H_{T,uie} * H_{T,ig} * H_{T,ij}\right) \tag{3.17}$$

The indices of the transmission heat loss coefficients have the following meaning:

"ie"   Heat loss of the heated room directly to the external (e)

"iue"   Heat loss from the interior through an unheated room (u) to the external (e)

"ig"   Heat loss from the interior to the ground soil (g)

"ij"   Heat loss to nearby heated rooms inside the building or an adjacent building

(cf. Schramek, 2007 p. 971)

To simplify the parameter input and the calculation process within the cost-benefit tool, relating to the formula above it is assumed that the calculated buildings consist of "one big room" respectively of one single thermal zone. Thus, heat losses through an unheated room and a nearby heated room are not considered explicitly. Heat losses through the ground soil are only considered if the foundation type "Slab (No Crawl Space)" is selected within the tool. If the foundation type "Crawl Space/Raised Floor" is picked, the floor area is considered as exterior wall within the simulation.

The direct heat losses to the exterior H$_{T,ie}$ (unit W/K) are calculated with the aid of the component area A$_k$ (unit m²), the thermal transmission coefficients of the single components U$_k$ (unit W/(m²K)) and in consideration of thermal bridges.

$$H_{T,ie} = \sum A_k * U_k + \sum \psi_l * l_l$$ [3.18]

(cf. Schramek, 2007 p. 972)

Relating to the cost-benefit tool, for the above presented formula, one assumption is applied. All thermal bridges within the calculation of the transmission losses are neglected due to the fact that the tool should provide a first roughly estimated calculation with a simple input process for a fast use. Therefore, the thermal bridge length l_l (unit m) and the linear heat loss ψl (unit W/(mK)) are not considered.

It is important to mention that the thermal transmission coefficient can also be expressed by the thermal transmission resistance R:

$$R = \frac{1}{U}$$

[3.19]

$R\ [\dfrac{m^2 K}{W}]$ Thermal transmission resistance

Several building input factors within the cost-benefit tool consist of thermal transmission resistance factors for different building components (e.g. roof, floor, etc.).

3.3.2   AIR INFILTRATION HEAT LOSSES AND GAINS

The norm-ventilation heat losses Φ_V (unit W) of a room are calculated by multiplying the temperature difference between interior (θ_{int}) and external (θ_e) with the ventilation heat loss coefficient H_V (unit W/K) of the room.

$$\phi_{V,i} = \left(\theta_{int,i} - \theta_e\right) * H_{V,i}$$

[3.20]

The ventilation heat losses are determined through the inflowing airflow $\dot{V}_i$ (unit m³/h). The ventilation heat loss coefficient H_V is calculated with the following formula:

$$H_V = \dot{V}_i * \rho * c_p = \dot{V}_i * 0.34 \ \frac{Wh}{m^3 * K}$$

[3.21]

$\dot{V}_i\ [\dfrac{m^3}{h}]$ Airflow

$\rho\ [\dfrac{kg}{m^3}]$ Density of the air

$c_p\ \left[\dfrac{Wh}{kgK}\right]$ Specific heat capacity of the air

(cf. Schramek, 2007 p. 972f.)

Instead of the airflow $\dot{V}_i$, often the ventilation number n is used:

$$n = \frac{\dot{V}}{V}$$ [3.22]

$n \ [-]$ Ventilation number

$\dot{V} \ [\frac{m^3}{h}]$ Airflow

$V \ [m^3]$ Ventilated volume

Depending on user behavior, meteorological and climatic boundary conditions and the tightness of the building envelope, the ventilation number n varies. (cf. Schramek, 2007 p. 488)

Within the tool it is assumed, that the calculation of the ventilation heat losses depend on the reference ventilation number n_{50} (unit h^{-1}). This air change rate is a measurement for the air tightness of the building and is measured at a pressure difference of 50 Pa between interior and external. This indicator can be found in the test certificate of every building-tightness-measurement. The n_{50}-values vary, depending on the air tightness of the building and the building type (e.g. $n_{50} = 2 \dots 9 \ h^{-1}$ for very tight … less tight) (cf. Schramek, 2007 p. 973). The ventilation number n is also called air change ACH. According to Sherman and Dickerhoff, for the calculation of ACH respectively n, also the ratio $ACH = ACH_{50}/20$ can be used (cf. Sherman, et al., 1998 p. 2). ACH_{50} is equivalent to n_{50} and by giving this value, the ventilation losses and gains can be determined.

3.3.3   BUILDING HEAT LOAD

For the determination of the norm heat load for a whole building or a part of a building ϕ_{HL} (unit W) only the transmission and ventilation heat losses from the interior rooms to the exterior are considered. All heat flows between the rooms inside the building are neglected.

$$\phi_{HL} = \sum \phi_{T,i} + \sum \phi_{V,i} + \sum \phi_{RH,i} \qquad [3.23]$$

$\sum \phi_{T,i}$ $[W]$ Norm transmission heat losses

$\sum \phi_{V,i}$ $[W]$ Norm ventilation heat losses

$\sum \phi_{RH,i}$ $[W]$ Optional additional heating-up power

(cf. Schramek, 2007 p. 974)

The above quoted optional additional heating-up power for the heat load calculation is not considered within the cost-benefit tool because the required heating-up power is directly simulated in the tool.

3.3.4 SOLAR HEAT GAINS

The heat flow ϕ_S (unit W) through a transparent external building component (window) into the building is calculated with the following formula:

$$transparent: \quad \phi_S = \sum I_i * F_{s,i} * F_{C,i} * F_{F,i} * g_i * A_i \qquad [3.24]$$

I_i irradiation intensity in W/m²

$F_{s,I}$ reduction factor due to shading

$F_{C,i}$ reduction factor due to sunscreen

$F_{F,i}$ reduction factor due to fraction of frame

g_i effective solar heat gain coefficient (SHGC)

A_i area of the transparent component

(cf. Schramek, 2007 p. 490)

In general, the solar heat gain or heat flow within the cost-benefit tool is calculated according to the formula above. The reduction factor $F_{F,i}$ is assumed to be

included in the solar heat gain coefficient g_i (g-value) and hence is not considered explicitly. Within the tool, $F_{s,I}$ and $F_{C,i}$ are combined and called z-value.

3.3.5 INTERNAL HEAT GAINS

For the calculation of the cooling load of a building, five major heat sources are differed:

1.   Solar irradiation through windows clearly account for the biggest part of the heat intake.

2.   Human body heat

3.   Lighting

4.   Office equipment, domestic appliances, water heating, etc.

5.   Outdoor-air-cooling and –dehumidification

(cf. Schramek, 2007 p. 1546)

The determination of the solar heat gain is already presented in chapter 3.3.4.

For the total heat loss of an adult human body (sensible and latent) a value of 120 W is assumed. This number has been chosen and rounded according to the recommendation of 117 W at room temperatures between 18 °C and 30 °C (about 400 Btu/hr). (cf. Porges, 2001 p. 87)

For the heat input through lighting, office equipment, domestic appliances, water heating and other devices inside the building, the cost-benefit tool provides an input mask. Therein the quantity, power and activation time per day can be entered. For the outdoor-air-cooling and dehumidification devices it is assumed, that they are part of the building appliances and thus, they also can be defined through the input mask.

3.4   RESIDENTIAL EFFICIENCY MEASURES DATABASE

The National Renewable Energy Laboratory (NREL), with support from the U.S. Department of Energy, developed the National Residential Measures Database to help users determine the most cost-effective retrofit measures for improving energy efficiency of existing residential homes. It is a publicly available, centralized source of residential building retrofit measures and costs for the U.S. building industry. Some benefits of this database are:

●   Information in a standardized format,

●   Improvement of technical consistency and accuracy of the results of software programs, and

●   Support for building science and development.

The intended primary audience for the database are software developers who require residential retrofit performance and cost data for appliances that evaluate efficiency measures. (cf. National Renewable Energy Laboratory (a), 2012 p. i)

As described above, this database is perfectly suitable for the use within the cost-benefit tool by providing cost and efficiency data for building services systems in residential buildings. Due to the structure of the database, in the cost-benefit tool it is not only used for existing residential buildings but also for the determination and comparison of new installed building services systems in planned future building projects. Further explanations can be found in chapter 4.1.

This chapter describes the structure of the used database and gives information relating to the collection and processing of underlying data.

The database contains information on the performance and costs of energy efficiency improvement measures but it does not include energy savings estimates. These can be determined with building energy simulation tools such

as the cost-benefit tool by accessing the database. (cf. National Renewable Energy Laboratory (a), 2012 p. 1)

3.4.1 DATABASE OVERVIEW

The structure of the database is developed to store properties and costs for measure components and measure actions. To construct a list of measures based on component properties and action types, NREL developed a set of rules which assemble measures from the disparate component and action data. Components, component properties, actions and costs are included in the list of measures where:

● Measures: A combination of a before-component, an action, and an after-component.

● Components: Items (e.g. central air-conditioner), constructed assemblies or parts of assemblies.

● Component properties: Characteristics of the component that define energy-related performance (e.g. SEER), component lifetime and other relevant descriptive attributes.

● Actions: Specific labor operations that are required to implement the after-component.

● Costs: Associated with before-components, actions and after-components.

The NREL database offers a variety of measure types. To organize all data and measures, a classification schema provides the following hierarchy:

● Group: A classification of major house systems (e.g. "Space Conditioning").

●   Component Type: A sub-classification of a "Category". A "Space Conditioning – Cooling" category is for example a "Central Air Conditioner" and a "Room Air Conditioner".

●   Component: It is the lowest level descriptor and includes some of the properties, resulting in a completely unique name for the component. "Component Types" for the "Central Air Conditioner" are for example "CAC (SEER 13)" and "CAC (SEER 15)".

(cf. National Renewable Energy Laboratory (a), 2012 p. 3)

Measures are constructed by using a NREL-developed rule set which evaluates the efficiency properties of the components and combines the components to create a practical list of measures. The NREL measure rule set follows four major principles:

●   The selected after-component must be more energy efficient than the before-component.

●   If it is possible to assess, the after-component must meet energy codes and/or federal standards.

●   The after-component must provide the same level of service as the before-component.

●   The improvement must be practical and reasonable.

(cf. National Renewable Energy Laboratory (a), 2012 p. 3f.)

The following example in Figure 27 demonstrates the use of the data structure presented above with the measure "Replace Central Air Conditioner (SEER 13) with Central Air Conditioner (SEER 15)" by using the action "Replace" and the mentioned before- and after-components.
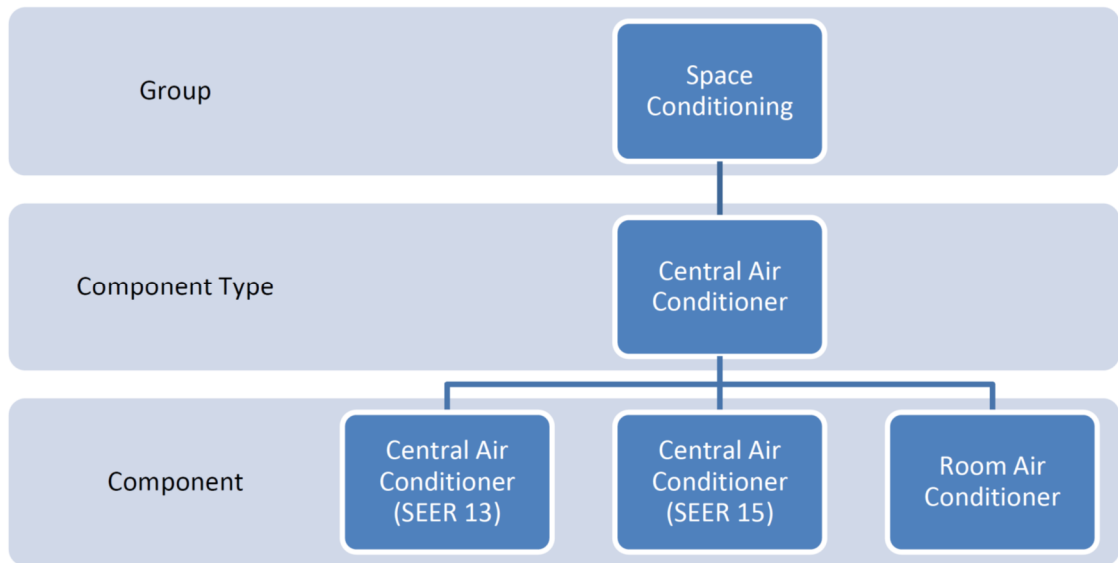
Figure 27: An example diagram database structure and hierarchy (National Renewable Energy Laboratory (a), 2012 p. 4)

3.4.2 ACTION TYPES

The NREL rules use five different actions to form measures, whereat only three of them are of interest to the cost-benefit tool: "Replace", "Remove" and "Install".

●   "Replace": The "Replace"-actions substitute a before-component with a more efficient component (after-component) of the same type (e.g. Central Air Conditioner-SEER 13 to Central Air Conditioner-SEER 15). The "Replace"-type measure assume an 'end of useful life' scenario with respect to a particular component. That means that the action is required of the homeowner if he or she wishes to maintain the existing condition of the home.

●   "Install": The "Install"-actions have no 'end of useful life' assumptions and are actions initiated, but not required, by the homeowner. "Install"-type measures improve the existing condition of the home.

●   "Remove": The "Remove"-actions substitute a before-component with "None". The "Remove Electric Furnace" measure for examples leaves

no Electric Furnace heating system with a cost figure associated with the removal of the electric furnace unit. It is important to mention that the "Remove"-action type can be used along with the "Install"-action type. Therefore, it allows flexibility to define measures across component types. For example, a measure can be formed that replaces a central air conditioner and electric furnace with a central heat pump.

As mentioned above, each measure combines a before-component, an action, and an after-component. The NREL rules account for specific costs associated with different actions and so the three above mentioned action types form measures and costs which are calculated based on the action type according to the following formula:

$$C_{measure} = -M_{before} * C_{before} + C_{action} + M_{after} * C_{after}$$ [3.25]

C is a cost value, M is a cost multiplier and the subscripts "before", "after", "action" and "measure" refer to the before- and after-components, action and total measure, respectively. The three action types described above use the multipliers in Table 8 to calculate the total measure cost according to the formula above. (cf. National Renewable Energy Laboratory (a), 2012 p. 5f.)

Table 8: Cost Multipliers for Action Types in the Database (cf. National Renewable Energy Laboratory (a), 2012 p. 6)

Action Type	M_{before}	M_{after}
Replace	0	1
Install	0	1
Remove	0	0

3.4.3 COST DATA

NREL uses different cost sources and cost units for the diverse groups and component groups. For the here processed cost-benefit tool, only the NREL database group "Space Conditioning" is of importance. Within this group, only five component types are used in the tool which are:

● "Air Source Heat Pump",

● "Ground Source Heat Pump",

● "Furnace",

● "Central Air Conditioner",

● "Room Air Conditioner".

The database indicates the costs of these five component types with the units $ and $/kBtu/h. (cf. National Renewable Energy Laboratory (a), 2012 p. 8f.)

When multiple costs are presented ($ and $/kBut/h) the costs must be combined to obtain the total cost of the measure. For example, a Central Air Conditioner replacement measure has a fixed cost of $1,000 and a variable cost of $55/kBtu/h of capacity. By applying the measure and costs to a 40 kBtu/h AC unit would result in a total measure cost of $3,200 ($1,000 + [40 kBtu/h]*[$55/kBtu/h]). (cf. National Renewable Energy Laboratory (a), 2012 p. 11)

3.4.4 COOLING EQUIPMENT – PROPERTIES AND COSTS

As already listed above, Central Air Conditioner (CAC), Room Air Conditioner (RAC), Air Source Heat Pump (ASHP) and Ground Source Heat Pump (GSHP) are included in the cooling equipment measures within the database. The CAC and ASHP systems have the energy-related property Seasonal Energy Efficiency Ratio (SEER) and the RAC and GSHP systems have the Energy Efficiency Ratio

(EER). All cooling components in the database are normalized to cooling capacity in kBtu/h.

NREL defined three measure types within Cooling Equipment:

● "Replace": Replacing and existing component with a more efficient component of the same component type (e.g. SEER 13 CAC replaced with SEER 15 CAC).

● "Install": Installing a component where none existed previously (e.g. installing a SEER 15 ASHP).

● "Remove": Removing a component and leaving no cooling system (e.g. removing a 9 EER RAC).

By combining the "Remove" and "Install" measure, it is possible to define measures across the component types (e.g. SEER 8 CAC replaced with SEER 15 ASHP). For this example, the total measure costs would include the removal costs of the SEER 8 CAC unit and the component plus installation costs of the SEER 15 ASHP unit. (cf. National Renewable Energy Laboratory (a), 2012 p. 23)

3.4.5 HEATING EQUIPMENT – PROPERTIES AND COSTS

As also mentioned above, the heating equipment measures within the database, which are used for the cost-benefit tool, include Furnaces, Air Source Heat Pumps and Ground Source Heat Pumps. The energy related property for the central Furnace is the Annual Fuel Utilization Efficiency (AFUE). For the ASHP, the energy-related property is the Heating Seasonal Performance Factor (HSPF) and for the GSHP, the Coefficient of Performance (COP). For the central Furnace components, two fuel types (electricity and natural gas) are included and considered in the tool. Also the heating components are normalized to heating capacity in kBtu/h.

Equivalent to the three measure types within Cooling Equipment, there are also three measure types within Heating Equipment. Consequently, only the examples are listed for each of the three measure types:

● "Replace" (e.g. 60% AFUE central Furnace replaced with 98% AFUE central Furnace).

● "Install" (e.g. installing an 8.5 HSPF Air Source Heat Pump).

● "Remove" (e.g. removing an Electric Furnace).

Also here, measures across component types are possible (e.g. electric central Furnace replaced with an 8.5 HSPF Air Source Heat Pump). (cf. National Renewable Energy Laboratory (a), 2012 p. 24f.)

3.4.6 SYSTEM EQUIPMENT AND EFFICIENCY CALCULATION

Space heating accounts for about 45% of energy bills in the average U.S. home and is the largest energy expense (cf. U.S. Department of Energy (b), 2013). However, also 6% of the average household's energy use goes to space cooling (cf. U.S. Department of Energy (c), 2014). Due to this considerable amount of energy used for heating and cooling, it is very important to increase system efficiencies or implement new and more efficient systems to save energy and costs. Almost every used cooling system and also the most common type of heating systems are forced air systems (cf. U.S. Department of Energy (b), 2013). Therefore, the five above already mentioned heating and/or cooling component- or system-types are selected to implement in the cost-benefit tool. These five components are ASHP, GSHP, Furnace, RAC and CAC. In the following, the mentioned energy-related properties respectively efficiency factors of the five systems are explained in detail. Hence, they show the connection between the provided heating and/or cooling energy in the building and the effective energy consumption for heating and/or cooling. The following definitions and formulas are also used in the cost-benefit tool.

By converting the below presented definitions respectively formulas, the effective energy demand for heating and cooling can be calculated with a given efficiency factor and the pre-calculated provided heating and cooling energy.

3.4.6.1 SEASONAL ENERGY EFFICIENCY RATIO (SEER)

The SEER is used to show the efficiency of two types of cooling equipment, the ASHP and the CAC and is defined as follows:

"Seasonal Energy Efficiency Ratio (SEER) – A standardized measure of air conditioner efficiency based on the total cooling output of an air conditioner in Btu/h, divided by the total electric energy input, in watt-hours, under test conditions specified by the Air Conditioning and Refrigeration Institute Standard 210/240." (RESNET, 2014 p. 7)

3.4.6.2 ENERGY EFFICIENCY RATIO (EER)

The EER is used for the cooling efficiency of the GSHP and the RAC and has the following definition:

"Energy Efficiency Ratio (EER) – The ratio of net equipment cooling capacity in Btu/h to total rate of electric input in watts under designated operating conditions." (RESNET, 2014 p. 4)

3.4.6.3 ANNUAL FUEL UTILIZATION EFFICIENCY (AFUE)

The AFUE represents the heating efficiency of the central Furnace and is included in the tool with the following relation:

"Annual Fuel Utilization Efficiency (AFUE) – A measure of the efficiency of gas or oil fired furnaces and boilers calculated as the furnace heating energy output divided by fuel energy input." (RESNET, 2014 p. 2)

It should be mentioned, that the cost-benefit tool also includes an electric operated furnace which always has an AFUE of 100%.

3.4.6.4 HEATING SEASONAL PERFORMANCE FACTOR (HSPF)

For ASHPs, the efficiency of the heating process is expressed through the HSPF and is defined as:

"Heating Seasonal Performance Factor (HSPF) – A standardized measure of heat pump efficiency, based on the total heating output of a heat pump, in Btu, divided by the total electric energy input, in watt-hours, under test conditions specified by the Air Conditioning and Refrigeration Institute Standard 210/240." (RESNET, 2014 p. 5)

3.4.6.5 COEFFICIENT OF PERFORMANCE (COP)

For GSHPs, the COP is used to show the heating efficiency. It has the following definition:

"Coefficient of Performance (COP) – The ratio of the rate of heat delivered to the rate of energy input, in consistent units, for a complete heat pump system under designated operating conditions." (RESNET, 2014 p. 3)

4 PROGRAM DESCRIPTION – COST-BENEFIT TOOL

The basic concept of the cost-benefit tool is the development, the calculation and the combined use of special parameters and charts to evaluate different building services systems. Accordingly, the following chapter provides and overview of tool functioning, the used calculation models and examples, the program structure including flow charts and the human-machine interface with the parameters to be entered.

The main application procedure of the tool is summarized in Figure 28.
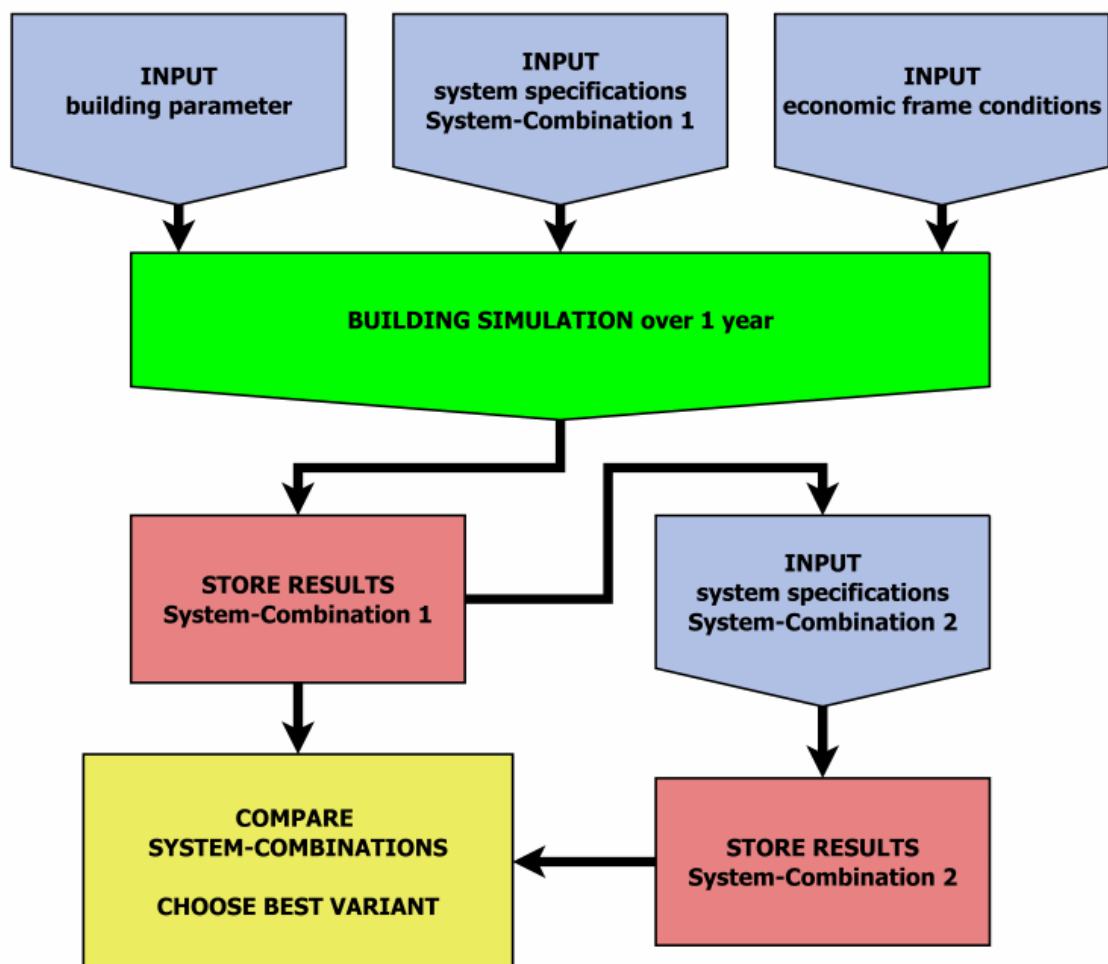
Figure 28: Basic functional principle - Cost-Benefit Tool [Source: own Figure]

The whole process starts with the input of building parameters like building orientation, desired thermal conditions inside the building, construction type and area of conditioned space, building envelope-, window-, door- and ventilation-specifications. In addition, also the basic information for the calculation of the internal gains must be integrated.

The configuration of the first system-combination is the second part for using the program. Therefore, the already explained action type, component types an components must be selected for the heating system as well as for the cooling system of the building. Furthermore, the nominal heating and cooling power must be specified.

For the input of the economic frame conditions, the already inserted default values can be used or new values can be defined.

The annual simulation can be started after all parameter, specifications and conditions are clarified.

After the simulation is completed, the results of the first system-combination can be stored and analyzed. If a system comparison is desired, the second system-combination can selected while keeping all other frame conditions the same. Due to the fact that the simulation only depends on the building itself, it must not be carried out again. The result for the second system-combination can be stored immediately and the systems can be compared.

4.1 CALCULATION MODELS

To provide an understanding for the calculation process of the cost-benefit tool, this chapter indicates the application of the presented formulas and calculation models in chapter 3. Moreover, it demonstrates some calculations via examples and shows which data are used and needed to obtain the desired calculation results.

4.1.1 IMPLEMENTATION OF THE EFFICIENCY MEASURES DATABASE

The following chapter demonstrates the implementation of the above, in chapter 3.4, presented Residential Efficiency Measure Database in the cost-benefit tool. Hence, it explains the searching procedure of the selected building services systems out of the system database which includes the required cost and system performance data. In addition, it gives important information and assumptions made within the procedure and the following calculations.

4.1.1.1 SYSTEM SELECTION

As described in chapter 3.4, the NREL database involves different measures, action types, component types and components. According to these data, also the associated costs, performance factors and lifetimes of the systems vary.

The selected system types and components in the "HEATING AND COOLING SYSTEM"-window of the human-machine interface, within the cost-benefit tool, determines the target of the search procedure and therefore the required data for the selected system components.

The cost-benefit tool offers two options respectively measures for the "Type of System Change":

● "REPLACE component or INSTALL new system":

Similar to the "Replace" action type in chapter 3.4.2, this selection type basically demands the substitution of a before-component with a more efficient after-component of the same type. For example, this can be the change of the before-component "SEER 8, 6.0 HSPF" Air Source Heat Pump (ASHP) to the after-component "SEER 15, 8.5 HSPF" ASHP.

However, this "Type of System Change" also provides the special possibility to compare different new installed building services systems for intended future building projects and not only for already existing buildings. This can be done by selecting the "None" before-component. For example,

the selection of the before-component "None" and the after-component "SEER 15, 8.5 HSPF" ASHP, equals an installation of the after-component "SEER 15, 8.5 HSPF" ASHP. Furthermore, by selecting a more efficient ASHP for the after-component, for example a "SEER 20, 10 HSPF" ASHP, the calculation results of both ASHP-types can be compared. By selecting the measure according to the above presented example, the total costs consist only of the "Install" action plus the component costs and so no "Replace" costs are included.

Generally, after the selection of the before- and after-components, the search procedure can provide all needed parameter and cost data for the economics calculation. The function of the search procedure is described below through an example.

●   "REMOVE old system + INSTALL new system":

This "Type of System Change" includes the described action types "Remove" and "Install" from chapter 3.4.2. As also mentioned above, by combining this two action types, it is possible to create measures across component types. For example, by selecting "Furnace (Remove, OLD)" as type of heating system-old with the before-component "Electric, 100% AFUE" Furnace and the type of heating system-new "Air Source Heat Pump (Remove, NEW)" with the after-component "SEER 15, 8.5 HSPF" ASHP, then a measure which removes the Furnace and installs the ASHP is created.

As already mentioned, after the selection of all before- and after-components, all required system data can be loaded by the search procedure which is demonstrated below.

4.1.1.2 DATA-SEARCH-PROCEDURE

The following flow chart in Figure 29, combined with the appendant explanation below the figure, illustrates and explains the whole searching process within the cost-benefit tool.
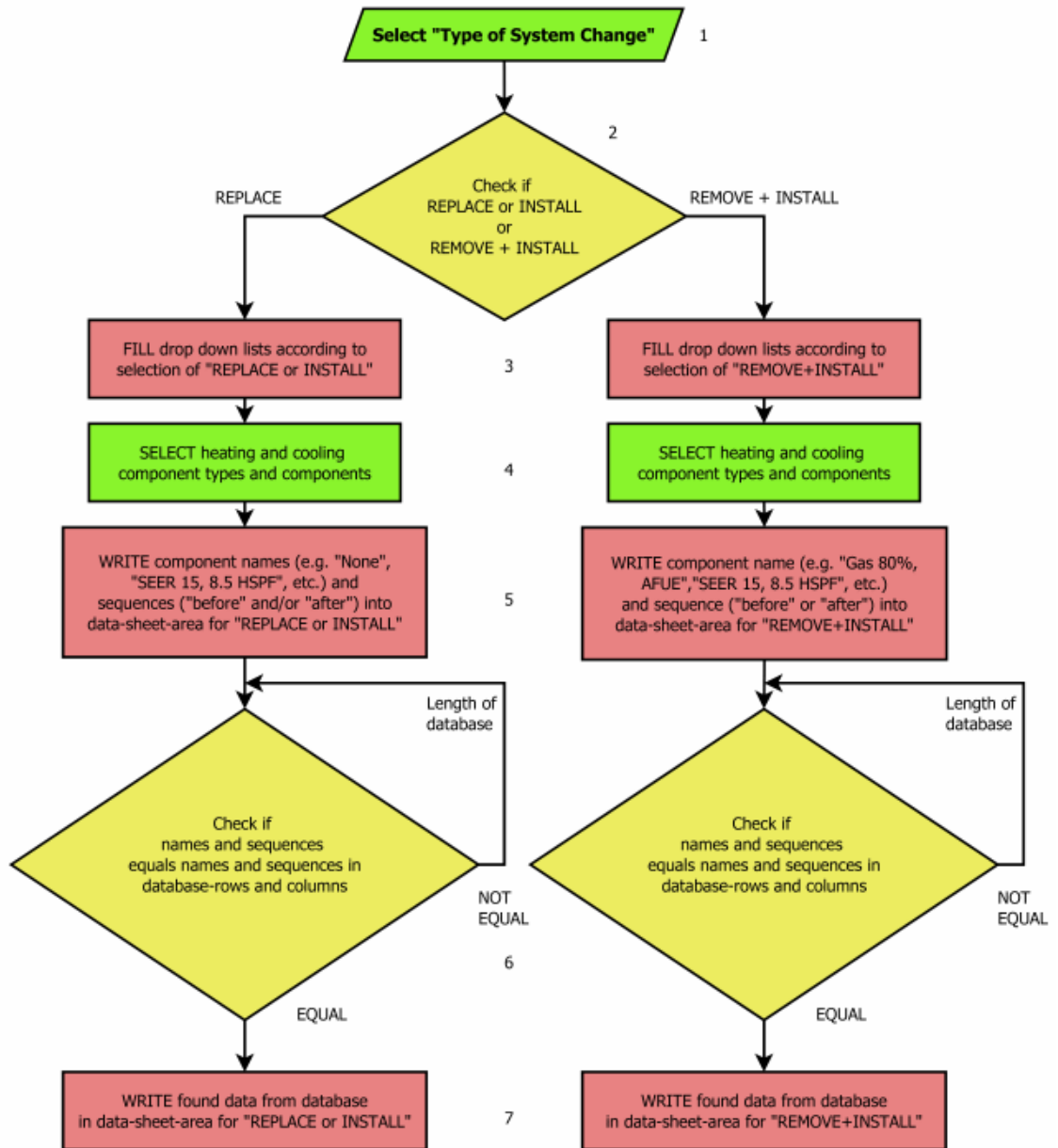

Figure 29: Search procedure for the NREL database [Source: own Figure]

As can be seen in Figure 29, the single procedure steps are indicated with numbers to facilitate the explanation of the process. Green boxes exhibit a user induced action, red boxes represent a sub-program respectively a larger program code and the yellow boxes indicate a query.

St. 1: The whole procedure starts with the user-selection of the above already mentioned "Type of System Change". As explained in chapter 4.1.1.1, it can be chosen if the old system should be replaced by a more efficient type or if a new system should be installed, or if the old system should be removed and a new system should be installed.

St. 2: According to the selection in step 1, the program sets different actions in the following steps.

St. 3: The drop down lists for the component types of the heating and cooling system (e.g. "Air Source Heat Pump (Replace, OLD)", "Furnace (Remove, NEW)", etc.) are filled according to the selection in step 1. After the component types are selected, the drop down lists for the system components are filled according to the selected component type. Step 3 and 4 are shown in simplified form instead of the twofold filling and selection process.

St. 4: According to the selected measure and component types in the previous steps, the single components (e.g. "SEER 15, 8.5 HSPF", "SEER 12", etc.) can be selected by the user and also which component is the before- and after-component of the measure.

St. 5: The information of the selections from previous steps is stored. The data-sheet-areas where the data get stored are different according to the choice of "REPLACE or INSTALL" or "REMOVE + INSTALL" in step 1.

St. 6: In this step, the stored system information is compared row by row to the whole NREL database list. The following example suggests the removal of

an inefficient Furnace and the installation of an more efficient Air Source Heat Pump. If a first match of the data combination, consisting of component name and sequence (e.g. "Gas, 60% AFUE" and "before" for a gas-fired Furnace as before-component), is found, it has to be checked if the second data combination can be found in the following rows of the first match (e.g. "SEER 20, 10 HSPF" and "after" for a ASHP). If the second data combination does not fit to the selected component, the row by row enquiry continues with the first data combination. If also the second combination matches with the database, the correct information for the whole measure (replace and install) is found. As displayed in the figure above, the query is done for the whole length of the database. If no double-match of the two data combinations is found, the data for the selected system measure does not exist and an error message occurs.

St. 7: After the right data combinations are found, the required cross-referenced data (e.g. performance factors, costs, lifetime, etc.) are stored out of the database. These data are the basis for the economics calculation.

4.1.1.3 ADDITIONAL INFORMATION AND ASSUMPTIONS

The above presented selection and procedure is done separately for the heating system(s) and for the cooling system(s). As a result, it is possible to examine the heating and cooling systems individually but also as a combined system.

One assumption occurs for the specific selection of the ASHP or GSHP as before- and after-components. If the before-component of the heating system is exactly the same type as the cooling system and/or the after-component of the heating system is exactly the same type as the cooling system, then it is assumed that the same device is responsible for heating and cooling of the building. For example, the selected after-component of the heating system is a "SEER 15, 8.5 HSPF" ASHP and the selected after-component of the cooling system is a "SEER 15, 8.5 HSPF" ASHP, then this assumption is used. Thus, for the economical

examination of the combined building system (heating and cooling), the costs are also only considered for one device and not for a separate heating and cooling system respectively component.

The second main assumption applies to the selection and input data for Room Air Conditioners (RAC). The deposited data in the NREL database for RACs only include costs in $ for a unit with a specific capacity (e.g. $530 for a "11 kBtu/h, EER 10.8" RAC). However, there a no costs with the unit $/kBtu/h. That means, if the input of the Nominal Cooling Power of the cooling system is not equal to the cooling power of the RAC unit in the database, then the costs for the RAC unit are chanced proportional to the cooling power proportion. For example, if the Nominal Cooling Power is 20 kBtu/h and the selected RAC system is "11 kBtu/h, EER 10.8", then the costs are assumed to be $963 instead of $530 ($530*[20kBtu/h / 11kBtu/h] = $963). This assumption was made because, theoretically, in the case of the example, more than one RAC unit would be necessary to meet the cooling demand. Moreover, the RAC cost source within the NREL database is partly generated on estimations and so, for the cost-benefit tool it is assumed that the RAC costs are rising linearly.

4.1.2 PHYSICAL BUILDING CALCULATION

According to the provided formulas in chapter 3.3, this chapter demonstrates the most important calculation approaches for the simulation of the thermal building behavior.

By considering all main heat flows through the thermal balance boundary of a building and all internal heat gains and losses, the main heat balance respectively thermal equation can be established. This equation is illustrated in the following formula:

$$\dot{Q}_{total} = \quad \dot{Q}_{heating} - \dot{Q}_{cooling} - \dot{Q}_{trans.\ total} - \dot{Q}_{vent./inf.} \qquad [4.1]$$
$$+ \dot{Q}_{solar} + \dot{Q}_{internal}$$

This is the first of the two most important formulas on which the simulation of the cost-benefit tool is based on.

It can be seen that it includes $\dot{Q}_{heating}$ (unit W) and $\dot{Q}_{cooling}$ (unit W) which represent the given heating and cooling power of the heating and cooling system of the building.

$\dot{Q}_{trans.\ total}$ (unit W) comprises all transmission losses and gains through walls, roof, floor, windows and doors which are calculated according to the provided formulas in chapter 3.3.1.

The calculation of the included ventilation and infiltration losses and gains $\dot{Q}_{vent./inf.}$ (unit W) is already presented and explained in chapter 3.3.2.

For the determination of the solar heat gains $\dot{Q}_{solar}$, generally the formula according to chapter 3.3.4 is used. As already noted in chapter 3.1.3, the data are pre-calculated to consider each hour of the year, incident angle, position of the sun, window- respectively building-orientation, window area and the different irradiation types. Also the internal heat gains $\dot{Q}_{internal}$ are generally determined related to chapter 3.3.5 and considered according to the flow chart in chapter 4.2.

Figure 30 shows all above mentioned parts of the main equation to determine $\dot{Q}_{total}$ (unit W). As revealed by the figure, the total transmission losses and/or gains split up in several parts based on the different building components mentioned above. Also the internal and solar heat gains are illustrated in the figure. The heating and cooling power have the function to balance all gains and losses and therefore try to keep $\dot{Q}_{total}$ at zero.
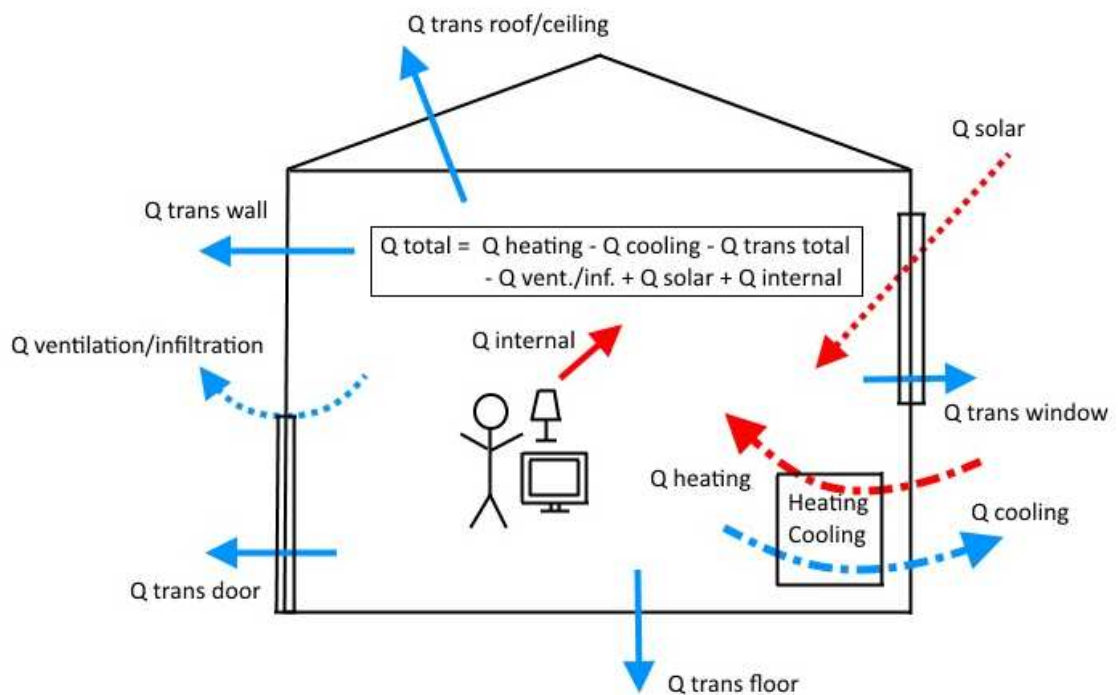

Figure 30: Thermal balance of a building - heat gains and losses [Source: own Figure]

If the desired thermal conditions inside the building are met by the compensation of all heat gains with losses, no additional heating or cooling power of the building services system is necessary. If either gains or losses predominate, and the desired thermal conditions get out of range, the system has to take action and provide additional heating or cooling until the value of $\dot{Q}_{total}$ goes back to zero.

The following formula enables to simulate the behavior of a building according to the changing gains, losses, heating and cooling and therefore the fluctuation of $\dot{Q}_{total}$. It represents the second most important formula for the simulation.

$$\vartheta_{int.} = \vartheta_{int.} + \Delta t * \frac{\dot{Q}_{total}}{C_{effective}} \qquad \qquad [4.2]$$

$\vartheta_{int.}$	Internal temperature or room temperature in K or °C
Δt	Time interval for the simulation/calculation in seconds
$\dot{Q}_{total}$	Resulting heating or cooling load from equation [4.1] in W
$C_{effective}$	Thermal mass of the building in Ws/K

Due to the possibility of a building to store heat, the thermal mass $C_{effective}$ provides an inertia against temperature changes within the building. The higher the thermal mass the slower is the temperature change. The cost-benefit tool provides the possibility to select three different building construction types with different thermal mass. Referred to Schramek, a light construction type with 50 Wh/(Km²), a middle construction type with 90 Wh/(Km²) and a heavy construction type with 130 Wh/(Km²) can be selected for $C_{effective}/A_G$ (cf. Schramek, 2007 p. 496). The value of the construction type within the tool is shown with the unit Btu/ft²-°F and also a manual user-input for this value is possible. To receive the unit Ws/K, the value of the selected construction type is multiplied with the net floor area in m² and with 3600 to change from hours (h) to seconds (s). It is assumed that the net floor area A_G is equal to the area of the conditioned space.

For $\dot{Q}_{total}$ the opposite is true, the higher the positive or negative value is, the faster the temperature rises or drops. The time interval Δt determines the resolution of the simulation and therefore also the accuracy of the results. For the cost-benefit tool, a time interval of 60 s has been chosen.

With every simulation cycle, the current value of the temperature $\vartheta_{int.}$ is calculated by adding the temperature change during one time step ($\Delta t * \frac{\dot{Q}_{total}}{C_{effective}}$) to the temperature value of the previous time step.

4.1.3 ECONOMICS CALCULATION

This chapter shows the application of the economics calculation model in chapter 3.2 and additionally it provides a brief explanation how the system-efficiency and –price data are selected.

4.1.3.1 ANNUITY METHOD – IMPLEMENTATION IN THE COST-BENEFIT TOOL – ADJUSTMENTS AND ASSUMPTIONS

This chapter demonstrates the application of the, in chapter 3.2.1 provided, basic method for the determination of the annuity. Thereby it also indicates assumptions and modifications within the cost-benefit tool compared to this basic model.

First of all, with the tool, the annuity is calculated separately for the heating and cooling system as well as for the total system respectively for the heating and the cooling system together.

4.1.3.1.1 CALCULATION – CAPITAL-RELATED COSTS

The first point is the determination of the capital-related costs respectively the annuity of the capital-related costs $A_{N,K}$ according to [3.1]. This is only possible by the calculation of several other parameters which are needed to calculate the annuity value.

Therefore, the first step is the determination of cash flow of the system (component) replacements $A_{1...n}$ after the service life T_N of these system components is over. According to the equations [3.2] also the price change factor for capital-related costs r_{IN}, the interest factor q and the amount of investment A_0 is required. The following assumptions and data are used:

● T_N: This parameter is provided by the system data source, according to the selected system variant.

- A_0: This parameter is provided by the system data source, according to the selected system variant.

- q: A predicted nominal discount rate d_n of 3.4% for a 30-year maturity is assumed (Office of Management and Budget, 2014). The nominal interest rate factor q is calculated below and amounts 1.034.

$$q = 1 + \frac{d_n}{100} = 1 + \frac{3.4\%}{100} = 1.034$$

- r_{IN}: The price change rate of the capital-related costs is assumed to be equal to the inflation rate e which is calculated below according to the formulas [3.13]. Therefore, a nominal discount rate d_n of 3.4% and a real discount rate d_r of 1.4% over 30 years is used (Office of Management and Budget, 2014). Hence, the price change factor r is assumed to be 1.0197 as calculated below.

$$e = [(1 + d_n)/(1 + d_r)] - 1 = [(1 + \frac{3.4\%}{100})/(1 + \frac{1.4\%}{100})] - 1 = 0.0197$$

$$r_{IN} = 1 + \frac{e}{100} = 1 + \frac{1.97\%}{100} = 1.0197$$

After the calculation of the cash flow of replacements, the residual value of the system components at the end of the observation time is calculated. Subsequently, equation [3.3] is used to determine this value by using again numerous additional parameters within the formula. Beside the already defined parameters above, the observation period T and the number of replacements n within this observation period are needed:

- T: A total observation period of 30 years has been chosen for the consideration of the investment project according to (cf. VDI, 2000 p. 46).

- n: The number of replacements is based on a simple division of the observation period T and the component's service life T_N. The result is

rounded down. In the following example the component is replaced only once in 30 years:

$$e.g.: \quad n = T/T_N = 30\,years/16\,years = 1.875 \approx 1$$

With this additional two parameters, the residual value can be calculated for the heating and cooling system with equation [3.3].

The determination of the annuity factor a with equation [3.4] and the cash value factor for capital-related cost b_{IN} with equation [3.6] is the next step. All needed parameters to solve this equations are already defined above. According to the formulas [3.5], the annuity factor and the individual cash value factor are used to determine the price-dynamic annuity factor ba_{IN} for the capital-related part of the outgoing payments.

To calculate the annuity of the capital-related costs, the factor f_K for repairs in % of the amount of investment per year is left:

- f_K: According to the guiding values in Table 12 in appendix-chapter 14.1 (middle column), f_K is assumed to be 2% of the amount of investment per year. On the one hand, all values for effort on repairs in the mentioned table are between 1 and 3% and on the other hand this value has to fit for all in the tool selectable system types. The table includes a variety of different system components which are also available in the tool or have strong similarities relating to the structure and function.

Finally the annuity of the capital-related costs for heating and cooling can be determined with the formula [3.1].

4.1.3.1.2 CALCULATION – REQUIREMENT (CONSUMPTION)-RELATED COSTS

To consider changes in power and fuel prices, the annuity of the requirement (consumption)-related costs $A_{N,V}$ is determined according to [3.7]. Therefore, the

requirement (consumption)-related costs in the first year A$_{V1}$ and the price-dynamic annuity factor for requirement (consumption)-related costs ba_V are used.

To determine ba_V, the annuity factor a and the cash value factor b_V are required as can be seen in [3.5]. This cash value factor is calculated by means of the already specified parameters which are the interest factor q and the observation period T. Equation [3.6] shows that the price change factor r_V for requirement (consumption)-related costs is also necessary:

● r_V: Due to the possible selection of gas or electricity driven heating within the tool, also two different price change factors have to be determined. The estimated annual price growth rate from 2012 to 2040 for gas is 3.4% and the electricity price growth rate is assumed to be 2.2% according to (U.S. Energy Information Administration (EIA) (i), 2014 pp. A-7). Both price change factors are calculated below.

$$r_{v-electrictiy} = 1 + \frac{2.2\%}{100} = 1.022$$

$$r_{v-gas} = 1 + \frac{3.4\%}{100} = 1.034$$

After the determination of the cash flow factor, also the price-dynamic annuity factor can be calculated according to formula [3.5].

The consumption related costs in the first year A$_{V1}$ are calculated by using equation [3.8]. The energy effort (consumption) data are provided by simulation result and the energy costs are based on the nominal dollar per million Btu price from (U.S. Energy Information Administration (EIA) (i), 2014 pp. A-7). The electricity and water effort is not considered.

After these pre-calculations, the annuity of the requirement (consumption)-related costs for heating and cooling are calculated with equation [3.7].

4.1.3.1.3 CALCULATION – OPERATION-RELATED COSTS

Similar to the consumption-related costs, the annuity of the operation-related costs $A_{N,B}$ can be calculated with the formula [3.9]. To determine the therefore necessary parameter of the operation-related costs in the first year A_{B1}, a factor for the amount of effort on servicing is assumed. Similar to the factor f_K above, this factor has been selected according to the provided guiding values in Table 12 in appendix-chapter 14.1 (right column). The factor for the effort on servicing is assumed to be 1% of the amount of investment per year. The same assumptions and explanations apply on the choice of this factor such as for the factor f_K.

By multiplying the amount of investment with the factor for the effort on servicing, the operation-related costs in the first year A_{B1} are received.

The price change factor r_B for the operation-related costs is required to calculate the cash value factor b_B with equation [3.6] and furthermore the price-dynamic annuity factor ba_B with equation [3.5]:

● r_B: It is assumed that the price change of the operation-related costs is equal to the inflation. Accordingly, similar to the price change rate of the capital-related costs, the rate for the operation-related costs is calculated in the following:

$$r_B = 1 + \frac{e}{100} = 1 + \frac{1.97\%}{100} = 1.0197$$

By determining the parameters above, the annuity of the operation-related costs can be calculated with the formula [3.9].

4.1.3.1.4 CALCULATION – OTHER COSTS AND INCOMING PAYMENTS

Due to the equation [3.10], the calculation process of the amount of other costs is basically similar to the determination of the requirement (consumption)-related

costs and the operation related costs. Nevertheless, the amount of other costs is assumed to be zero ($A_{N,S} = 0$) within the cost-benefit tool.

This thesis deals only with systems that cover the heating, cooling and air supply need within a building. Hence, they do not generate any revenues which are usually also be considered for the economical calculation by calculate them with equation [3.11]. Therefore, the incoming payments for the annuity calculation in the cost-benefit tool equal zero ($A_{N,E} = 0$).

4.1.3.1.5 CALCULATION – ANNUITY OF TOTAL ANNUAL PAYMENTS

For the determination of the total annuity A_N which includes all payments and revenues of a system, the three above explained parts of the outgoing payments:

●   capital-related costs,

●   requirement (consumption)-related costs and

●   operation-related costs

are processed in the formula [3.12].

As can be seen in this equation, the incoming payments respectively the annuity of revenues $A_{N,E}$ as well as the annuity of other costs $A_{N,S}$ are also included. As mentioned above, the other costs are assumed to be zero and therefore they do not have any effect on the result of the annuity calculation. The incoming payments are zero. As a result, the value of the total annuity A_N is also negative as equation [3.12] reveals. According to 3.2.1.3, that means that the most profitable system is the one which generates the fewest costs and so the smallest negative total annuity value respectively the closest value to zero.

As noted earlier, within the cost-benefit tool the value of the total annuity is determined for the heating and the cooling system separately. To calculate the total annuity value for the total system (heating and cooling) it must be

considered, if the heating and cooling component is used for heating and cooling or if each of this functions are executed by an independent system component.

If the latter is the case, the annuity of the total system is calculated by simple generate the sum of the determined annuity values for the heating and cooling system.

If the heating and cooling function is provided by the same system component (e.g. ASHP), several assumptions for the determination of the total annuity are made:

● For the calculation of the total annuity, only the higher value for the annuity of the capital-related costs from the heating or cooling system is taken into account. The capital-related cost annuity values can be unequal due to a higher heating power and lower cooling power or vice versa and therefore also the amount of investment provided by the system data sheet. If the values for the annuity of the capital-related costs are equal, only one of the two values is taken into account for the annuity of the total system. The same applies to the annuity of the operation-related costs.

● Only for the requirement (consumption)-related costs, the annuity values for heating plus cooling are taken into account for the calculation of the total annuity of the total system.

4.1.3.2 CALCULATION - DISCOUNTED CASH FLOW - IMPLEMENTATION IN THE COST-BENEFIT TOOL – ADJUSTMENTS AND ASSUMPTIONS

With the help of the provided information and formulas in chapter 3.2.2, this chapter presents the calculation and representation of the discounted accumulated positive cash flow trend within the cost-benefit tool.

Table 9 illustrates and example how the data for the cash flow trend line are calculated and which assumptions have been made. The description of the single columns and their determination is described below. It should be noted that Table 9 and Table 10 include only selected sections and therefore not the full number of rows compared to the actual calculation.

Table 9: Example - Calculation of the cash flow trend line [Source: own Figure]

Year	Investment (a)	Revenues (b)	Costs (c)	Cash Flow (d)=(b-a-c)	Present Value	Accumulated Present Value	Accumulated Present Value (positive)
0	2448.0	0.0	0.0	-2448.0	-2448.0	-2448.0	2448.0
1	0.0	0.0	413.5	-413.5	-399.9	-2847.9	2847.9
2	0.0	0.0	422.5	-422.5	-395.1	-3243.1	3243.1
3	0.0	0.0	431.6	-431.6	-390.4	-3633.5	3633.5
4	0.0	0.0	440.9	-440.9	-385.7	-4019.2	4019.2
5	0.0	0.0	450.4	-450.4	-381.1	-4400.3	4400.3
6	0.0	0.0	460.2	-460.2	-376.5	-4776.8	4776.8
7	0.0	0.0	470.1	-470.1	-372.0	-5148.8	5148.8
8	0.0	0.0	480.2	-480.2	-367.5	-5516.3	5516.3
9	0.0	0.0	490.6	-490.6	-363.1	-5879.4	5879.4
10	0.0	0.0	501.2	-501.2	-358.8	-6238.2	6238.2
11	0.0	0.0	512.0	-512.0	-354.5	-6592.7	6592.7
12	0.0	0.0	523.1	-523.1	-350.2	-6942.9	6942.9
13	0.0	0.0	534.4	-534.4	-346.0	-7288.9	7288.9
14	0.0	0.0	545.9	-545.9	-341.9	-7630.7	7630.7
15	0.0	0.0	557.7	-557.7	-337.8	-7968.5	7968.5
16	3346.1	0.0	569.8	-3915.8	-2293.5	-10262.0	10262.0
17	0.0	0.0	582.1	-582.1	-329.7	-10591.7	10591.7
…	…	…	…	…	…	…	…

- Year: This column indicates the single years over the whole observation period of the financial analysis. A period-length of 30 years is assumed.

- Investment (a): All initial investments and investments for replacements are listed in this column. It is assumed that in general the replacement costs are the same costs as the initial investment costs in year 0. However, the price change rate r_{IN} for this capital-related costs has to be considered. This rate is assumed to be equal to the inflation rate e as already mentioned above. The calculation of the inflation rate is explained in chapter 4.1.3.1.1. As can be seen in the figure above, after 16 years a replacement is needed. The calculation of this replacement costs can be seen below:

$$A_{16} = A_0 * r_{IN}{}^n = 2448 * 1.0197^{16} \approx \$3364.1$$

- Revenues (b): The system is not producing any incoming payments and so all revenues are zero.

- Costs (c): The cost values in Table 9 are the yearly sums of the requirement (consumption)-related costs, the operation-related costs and the efforts on repairs. Table 10 shows an example of the three different cost types. Similar to the last calculation above, the requirement (consumption)-related costs consider the energy price change or growth factor. The operation-related costs consider the price change of these costs and the effort on repairs consider the price change factor on repair costs. For the last two parts, it is assumed that the change factor is equal to the inflation factor.

Table 10: Example - Determination of the cost/expanses [Source: own Figure]

Year	Requirement -related Costs	Operation – related Costs	Effort on repairs
0	0.0	0.0	0.0
1	338.7	25.0	49.9
2	346.1	25.5	50.9
3	353.7	26.0	51.9
4	361.5	26.5	52.9
5	369.5	27.0	54.0
…	…	…	…

● Cash Flow: (d)=(b-a-c): The cash flow is calculated as revenues minus expenditures and is therefore a negative value.

● Present Value: Chapter 3.2.2.3 and particularly equation [3.14] shows how to calculate the present values for this economic analysis. The therefore required nominal annual discount rate is assumed to be 3.4% according to (Office of Management and Budget, 2014).

● Accumulated Present Value: Every value in this row is the sum of the present values of all previous years. That means for example that the accumulated present value in year 30 is the sum of 30 annual present values.

● Accumulated Present Value (positive): this row shows all accumulated present values with positive prefix and therefore they can be interpreted as costs in a graphical representation. This is possible due to the fact that the expenditures are zero for this application.

4.1.3.3 SIMPLE PAYBACK TIME - IMPLEMENTATION IN THE COST-BENEFIT TOOL – ADJUSTMENTS AND ASSUMPTIONS

For the calculation of the simple payback time within the cost-benefit tool, some deviations to the in chapter 3.2.3 presented approach apply. As mentioned in the

same chapter, to keep the advantage of simplicity for the simple payback (SPB), it is not recommended for evaluating alternatives involving financing and tax features. Thus, for the calculation of the SPB in this thesis, it is assumed that the annual savings for expenses on electricity or gas are the only cost savings when comparing two different system types or variants. Furthermore, no electricity or gas price changes, inflation or any other price changes are considered. Since it is assumed that costs for service and maintenance are approximately would be the same for different system variants, they are not considered in the determination of the SPB. When changing an old building services system (e.g. heating system) to a new system and if the value of the SPB for this system change is higher than the system lifetime of the newer system, than the SPB should be disregarded due to the neglect of replacements for system components within the SPB determination.

Under the consideration of the above described assumptions, the simple payback time within the cost-benefit tool is calculated according to equation [4.2]. It can be seen that it is simple the calculation of the initial investment costs or initial investment cost difference divided by the simple energy cost savings per year.

$$SPB = \frac{I_0}{\Delta S_0} \qquad\qquad [4.3]$$

SPB	minimum number of years required to save the value of the initial investment costs through energy cost savings
I_0	Initial investment costs or initial investment cost difference in \$
ΔS_0	Energy cost savings per year in \$/year (difference between energy costs from old system and new system)

The following example shows the application of the theory and formulas for the simple payback time and reveals it's calculation for a selected system variant. Therefore, a realistic system exchange scenario, at which the old heating and

cooling system is removed and a new system is installed, is selected in the cost-benefit calculation tool.

It is assumed that the old heating system is an electrical driven Furnace and the old cooling system is a Central Air Conditioner. The new heating and cooling system is combined via an Air Source Heat Pump. Table 11 shows the system characteristics. Additionally, it is assumed that the nominal heating power as well as the nominal cooling power is 12,000 Btu/h.

Table 11: Example - REMOVE old system + INSTALL new system (Furnace - ASHP, CAC - ASHP)

Furnace (Remove, OLD)	*Electric, 100% AFUE*
Air Source Heat Pump (Remove, NEW)	*SEER 21, 10 HSPF*
Central Air Conditioner (Remove, OLD)	*SEER 8*
Air Source Heat Pump (Remove, NEW)	*SEER 21, 10 HSPF*

As can be seen above, the heating and cooling parts of the system are firstly considered separate. In the example, the old heating system had an energy consumption of 2874 kWh/a. The old cooling system consumed about 2455 kWh/a. The new ASHP needs about 981 kWh/a for heating and 935 kWh/a for cooling. By considering the gas and/or electricity prices, the heating energy cost savings amounts about $225.3 per year and the cooling energy cost savings are about $180.8 per year. Due to the fact that the new ASHP system is responsible for heating and cooling, also the investment costs count for heating and cooling ($3100). The removal costs for the old heating ($230) and cooling ($440) system are separate and so both have to be considered.

$$SPB_{total\ System} = \frac{I_0}{\Delta S_0} = \frac{(\$3100 + \$230 + \$440)}{\left(225{,}3\frac{\$}{a} + 180.3\frac{\$}{a}\right)} \sim 9.3\ years$$

The calculation above shows the application of equation [4.3] and gives the result for the SPB of the total system. It is also possible to calculate the SPB separately for the heating and cooling systems if the new systems for heating and cooling are not the same construction and are also used separately.

4.2 PROGRAM STRUCTURE - COST-BENEFIT TOOL

The content of this chapter presents the step by step calculation and simulation way which is used within the cost-benefit tool to determine the desired thermal building parameter and results. In order to enable a tractability of the simulation process, this explanation of the program-code is done with the aid of flow charts and appendant notes. Moreover, explanatory notes and additional calculations are also explained below.

4.2.1 SIMULATION PROCESS AND PROGRAMMING WORK

The following figures displays the main simulation steps represented by a flow charts. All necessary supplements to the figures, to improve the understanding of the process and other notations, are mentioned below each of the following charts.

All figures are self-explanatory for the most part in which the two green boxes (step 1 and step 47) indicate the start and the end of the simulation process. Blue boxes exhibits a direct execution of a command whereas red boxes represent a sub-program part or a more comprehensive calculation. The yellow dyed rhombs exhibits an "If case structure" which means, that different decisions depending on a certain condition are made.

As already mentioned, almost every simulation step is consecutively numbered to clear the structure of the process and to facilitate the explanation of the simulation procedure.

Figure 31 shows the part of the program which is responsible for the definition of all needed parameters and the import of the parameters and values which are given by the tool user or provided by the outside temperature data sheet and the irradiation data sheet. Additionally, it illustrates a decision-making structure which is responsible for setting initial values depending on the requested climatic interior conditions.

After pressing the "Start Simulation" button, the simulation is started and then begins with the definition of the parameters which afterwards will be read from the "INPUT" sheet (step 1 to 3). To do this, an additional program module is included which indicates all mentioned data from the sheet as part of a public variable type. These variables are presented with the name "INPUT.", as can be seen in the flow charts. The data reading process is also separated with an extra module and assigns each building-parameter to the indicated value from the "INPUT" sheet.

Step 4 on Figure 31 includes the definition for all needed internal simulation parameter as for example counting variables and calculation factors. The above mentioned set temperature and the current building temperature are assigned to their simulation variables which can be seen in step 5.
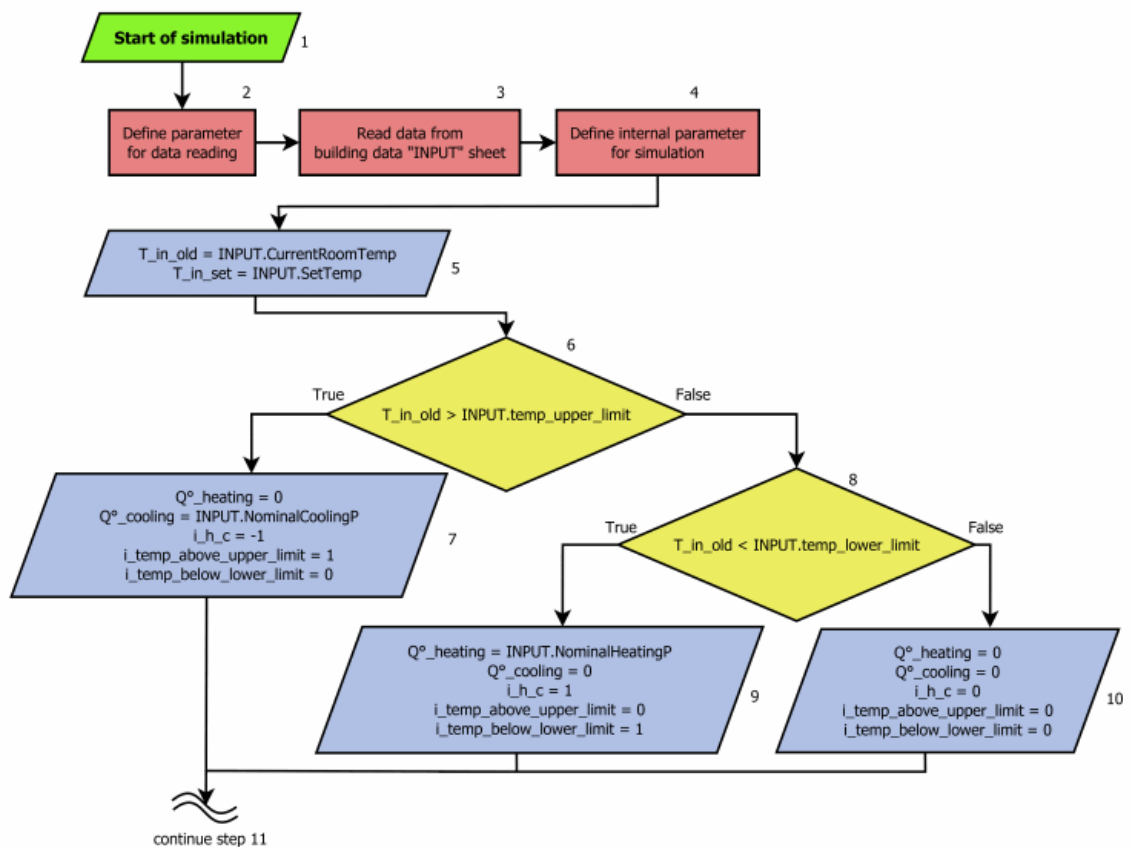
Figure 31: Simulation flow chart - step 1 to 10 [Source: own Figure]

Step 6 to 10 demonstrate the comparison of the current room temperature (T_in_old) with the defined upper and lower limit temperatures and the resulting subsequent actions. Depending on if the set temperature is above the upper limit, between the limits or below the lower limit, the heating or cooling power is set to their nominal power or to zero and two boolean variables are set to 0 or 1. The auxiliary variable i_h_c, which is responsible to notify if heating, cooling or neither of them is activated, is set to 1, -1 or 0.

Figure 32 involves the initialization for most of the variables to prepare the start of the simulation loop which can be seen in the steps 11, 12 and 13. Beside the import of the first values of the outdoor-temperature and the irradiation via the corresponding counting variables, several counter-variables are set to their initial values so that the do-while simulation loop can be started.
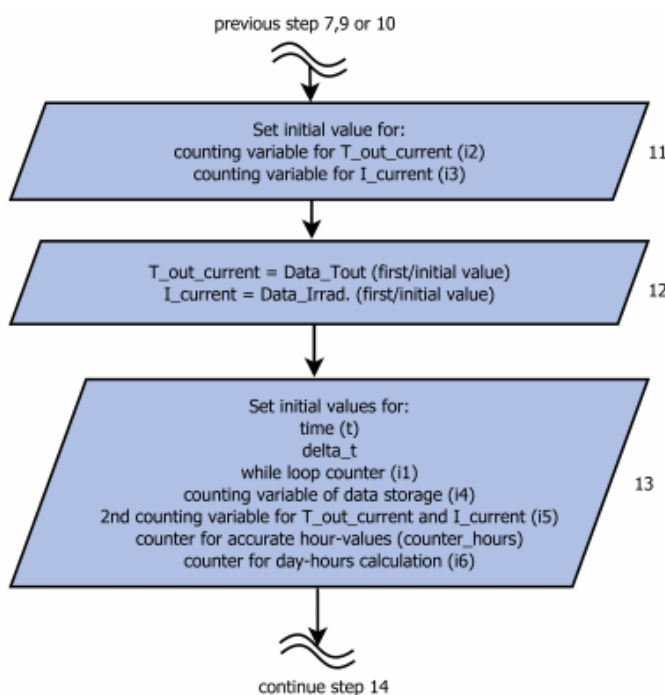
Figure 32: Simulation flow chart - step 11 to 13 [Source: own Figure]

As illustrated in Figure 33, the steps 14 to 16 demonstrate decision-making structures to set initial values depending on the user-specifications on the "INPUT" sheet. Step 14 and 15 are responsible for setting the variables

i_heating_time and i_cooling_time to 0 or 1, depending on the already mentioned variable i_h_c. The two variables are needed to calculate the heating and cooling hours in a subsequent step. Step 16 sets the exterior temperature for the calculation of the transmission losses and gains through the floor (foundation), depending on the given input. If a crawl space (raised floor) exists instead of a soil touching slab, the outside temperature of the floor area is assumed to follow the hourly alternating values from the Data_Tout source. If there is a soil touching slab instead of a crawl space, it is assumed that the outside temperature of the floor (soil-temperature) equates the average temperature of all hourly values over one year.
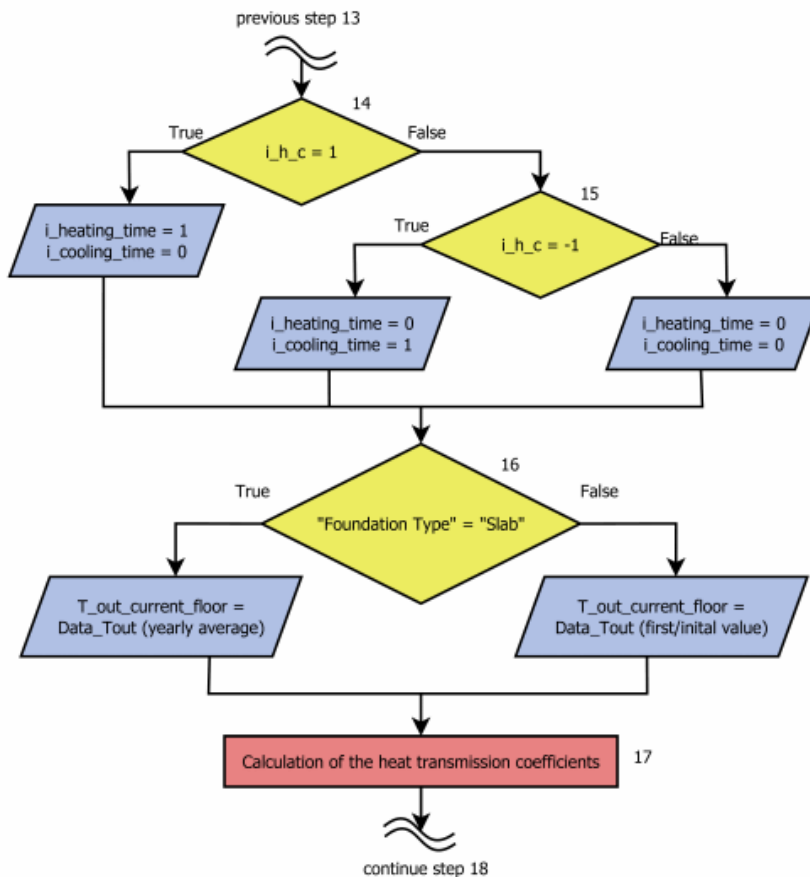
Figure 33: Simulation flow chart - step 14 to 17 [Source: own Figure]

Step 17 contains the calculation of transmission coefficients for the walls, roof, floor, windows and doors according the formulas in chapter 3.3.1.

At the beginning of the following Figure 34, the start of the main program simulation loop can be seen at step 18. This process is continued until the loop counter exceeds 8760 hours respectively exactly one year has been simulated. The loop is responsible for the prime calculations and the storage of the simulation results. The 8760 hours are split into a 24 hour scale to determine the current hour of the day. The value of the current calculation/simulation hour within this 24h-period is attached to the variable i_hours_human via the counting variable i6 in step 19.
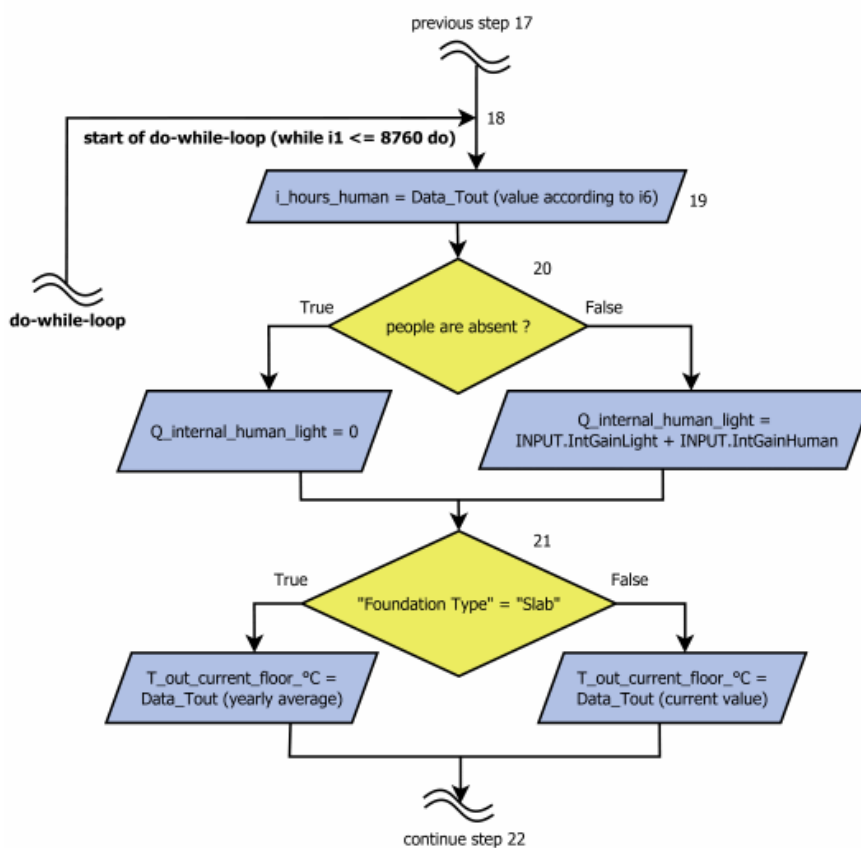
Figure 34: Simulation flow chart - step 18 to 21 [Source: own Figure]

In step 20 it is checked if the current simulation hour is inside the user defined human-absent-period or not. It is assumed, that the heat gains through human presence and lighting are only considered outside of the absent-period. Step 21 again proves the foundation type to select the right exterior temperature for the calculation.

Step 22 in Figure 35 places the previous room temperature value as the current room temperature for the next loop cycle. All steps from 23 to 26 are responsible for the calculation of the heating and cooling demand of the building respectively the gains and losses.
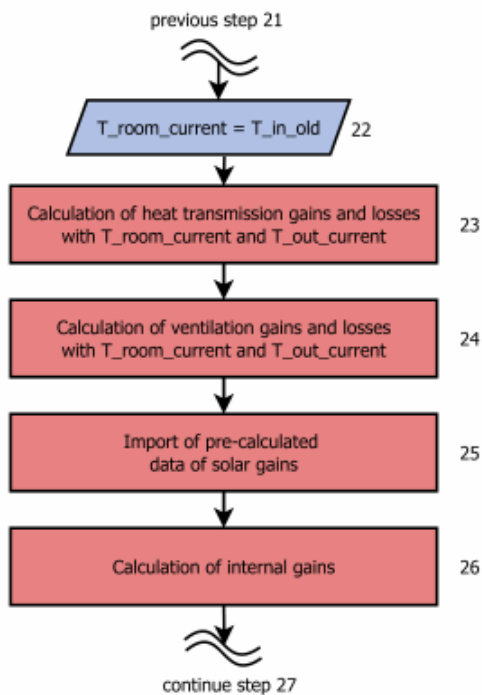
Figure 35: Simulation flow chart - step 22 to 26 [Source: own Figure]

The calculation of the transmission losses and gains is done by multiplying the pre-calculated transmission coefficients with the temperature difference between the current room temperature and outside temperature. Only for the floor-area, a special consideration is required because of the temperature differentiation between slab- and crawl space- selection.

Ventilation respectively infiltration losses and gains are calculated according to the formulas in chapter 3.3.2.

Step 25 is responsible for the import of the already calculated solar heat gain data.

The calculation of the internal gains in step 26 can be found in chapter 3.3.5.

Another decision-making structure can be seen in Figure 36 which includes the steps 27 to 32. Depending on the current room temperature (T_in_old) and the value of the variable i_h_c, the heating and/or cooling power are set to their nominal values or zero. In addition, i_h_c itself is set to a certain value depending on the decision rules. The figure illustrates the control process if the desired thermal room conditions are met or if additional heating or cooling power is needed.
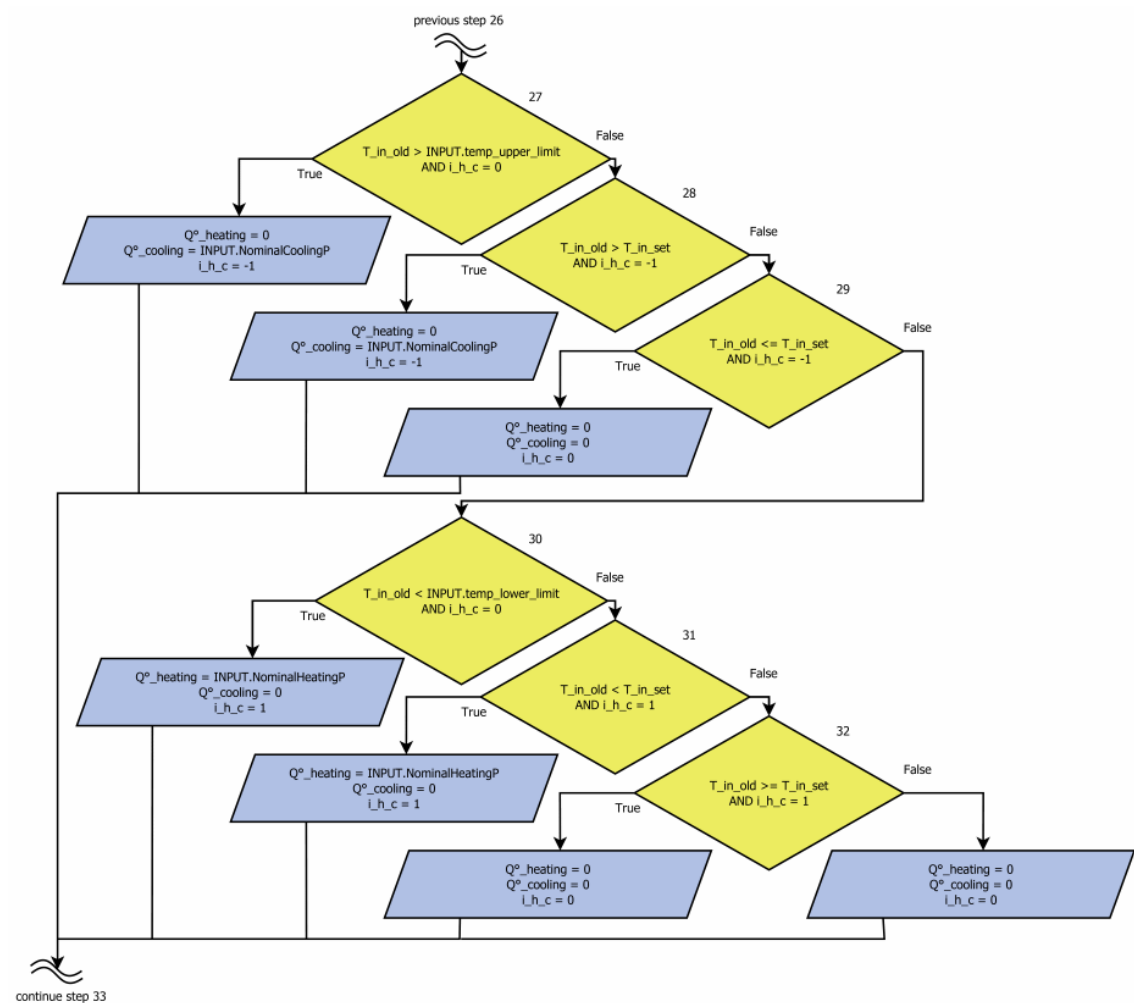
Figure 36: Simulation flow chart - step 27 to 32 [Source: own Figure]

Step 33 and 34 in Figure 37 show the two main simulation formulas which are already presented and explained in chapter 4.1.2.
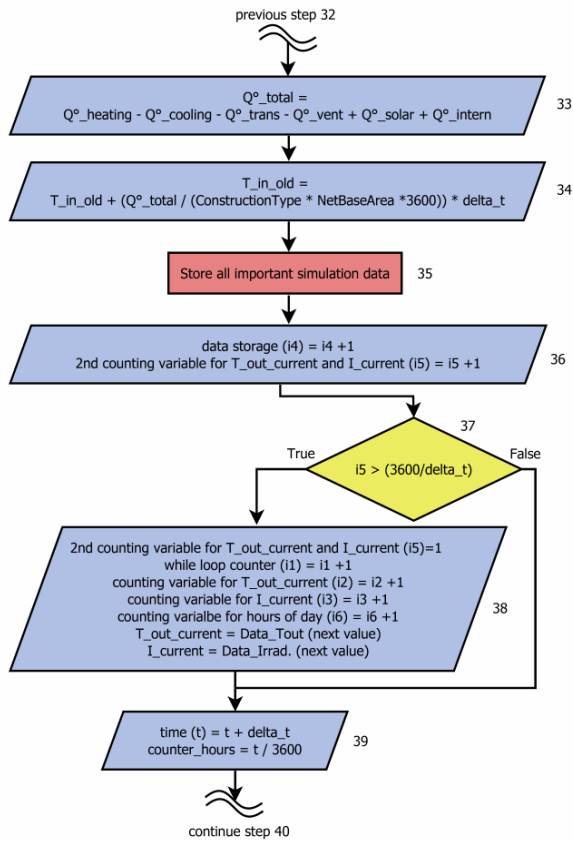
Figure 37: Simulation flow chart - step 33 to 39 [Source: own Figure]

The storage of all important parameters and calculated values is done in step 35. It is the basis for the post processing of the simulation. Consequently, these results are used to develop specific parameters and charts which are the outcome of the program.

After the increase of divers counting variables in step 36, a case structure is performed in step 37. It verifies if the next hourly values for the ambient temperature and the irradiation data should be loaded or if the program progress have not reached that requirement. If the condition of the case structure is "true", multiple counting variables are initialized again or become increased. As noted above, also the next hourly value for the outdoor temperature as well as the value for the irradiation are loaded. Step 39 is responsible for the increase of the simulation time with the determined simulation time step. The current value for the counter of the calculation time is also calculated in this step.

The first two steps (40 and 41) in Figure 38 present a decision-making structure whereat the counter variables to the heating and cooling time are increased or not, depending on if heating or cooling power is currently provided.
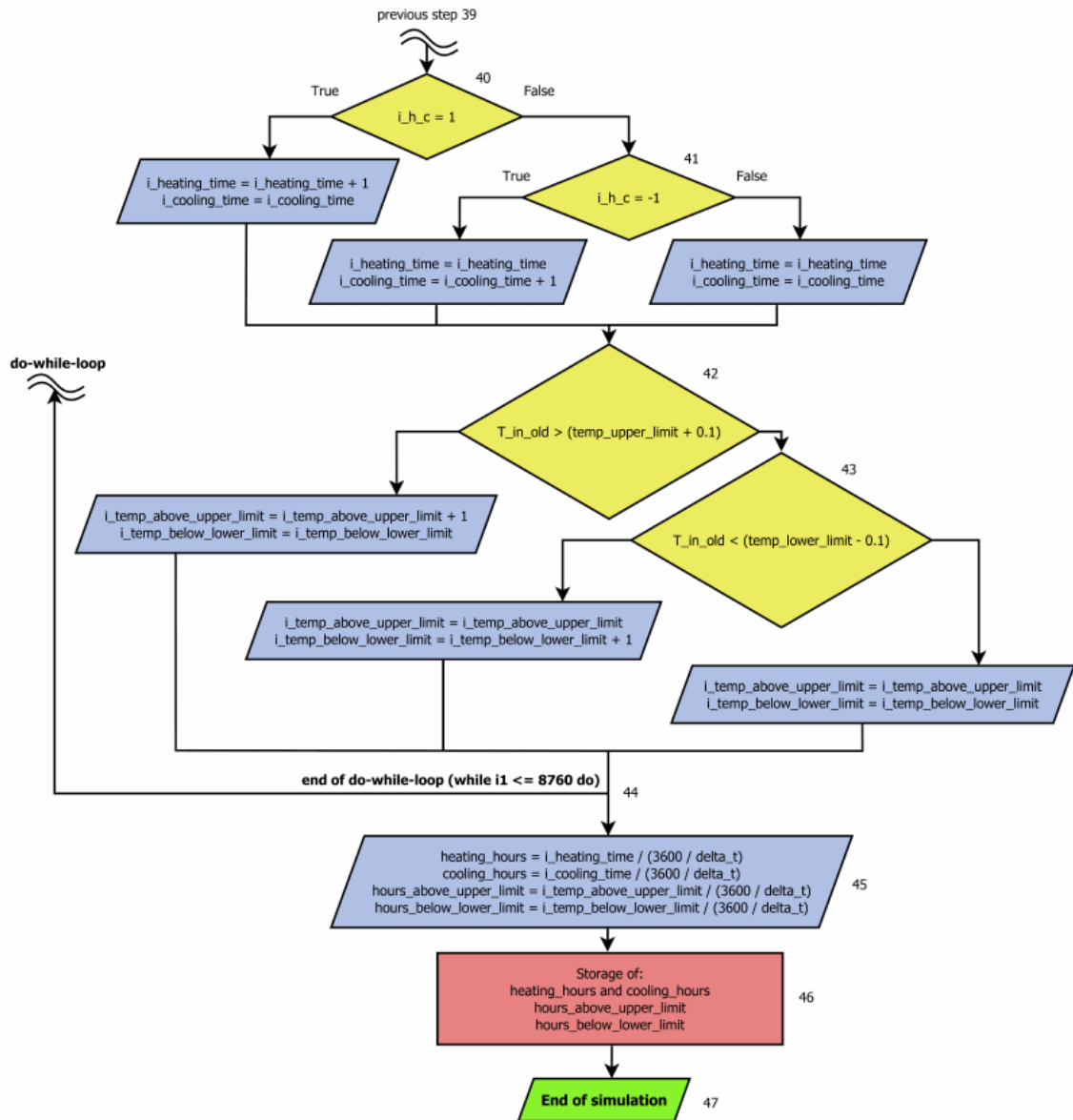
Figure 38: Simulation flow chart - step 40 to 47 [Source: own Figure]

Step 42 and 43 demonstrate case structures which help to determine the hours above the upper temperature limit or below the lower temperature limit. In the process, a temperature tolerance of +0.1 °C above the upper limit and -0.1 °C

below the lower limit is considered. If the false condition of the do-while simulation loop is reached and consequently the time span of one year has been simulated, the program steps out of the loop at step 44. Step 45 and 46 are responsible for the calculation and the storage of the heating hours, cooling hours, hours above the upper limit and hours below the lower limit. Step 47 indicates the end of the simulation.

4.2.2 EXPLANATORY NOTES AND CALCULATIONS

This chapter gives information on assumptions within the simulation and a short explanation on the calculation of several important results.

The cost-benefit tool - "INPUT" sheet offers the possibility to select, if the heating and/or cooling system includes a duct system or not. If such a system is included, it can be selected if it is located in the conditioned space or the unconditioned space. If the latter is the case, the duct system causes a substantial amount of losses which need to be considered. Hence, it is assumed, that a certain amount is added to the calculated value of the provided heating and cooling energy and thus, also to the energy consumption of the systems. The duct systems typically lose 25% to 40% of the heating or cooling energy that passes through them in attics or crawl spaces (National Renewable Energy Laboratory (b), 2004 S. 1). Hence, a value of 30% is assumed for the cost-benefit tool.

The previously mentioned heating and cooling hours as well as the hours above the upper limit and the hours below the lower limit are calculated by dividing the corresponding counting variable i by $\frac{3600}{\Delta t}$. One hour has 3600 seconds and Δt is the simulation period (60 sec.). The provided heating and cooling energy is the product of heating and cooling hours and the nominal heating and cooling power.

Saved CO_2-emissions are calculated by multiplying the energy savings for heating and/or cooling with the appropriate emission factor for electricity and/or gas.

4.3 HUMAN – MACHINE INTERFACE

This chapter gives a short introduction on the sheets of the cost-benefit tool, which can be seen and used by the tool user.

4.3.1 "GENERAL INFORMATION" SHEET

The first of the three, for the user visible, EXCEL-sheets is called "GENERAL INFORMATION". This sheet comprises general information about the tool, a short instruction manual, which things should be considered for using the tool and warnings. An example of the "GENERAL INFORMATION" sheet can be found in appendix-chapter 14.2.

4.3.2 DATA "INPUT" SHEET

This sheet is responsible for the supply and specification of all needed input values. That means, bevor the simulation can be started, various frame conditions have to be drafted. Appendix-chapter 14.3 shows an example for the whole data input sheet.

The section "BUILDING ORIENTATION" is the first condition on the sheet and it is responsible for the orientation of the applied building. Hence, the user of the cost-benefit tool specifies the deviation of the perpendicular for that side of the building, which is the south facing most. The unit of the divergence is given in degree and if the south side of the building deviates eastwards, the angle is recorded in minus degree. In contrast, a westwards deviating building south side is specified with positive degree values. Consequently, if the south side of the building points toward south without any deviation, the divergent angle to south equals zero.

The "BUILDING TEMPERATURES" section imports further important data for the preparation of the simulation such as the current room temperature respectively the starting temperature of the simulation. Moreover, the set temperature for the

building interior, which satisfies the wished room temperature of the building residents, has to be indicated. Both values are given in degree Fahrenheit and are intern initially converted into degree Celsius as several other characteristic values are given in Celsius or keep Celsius in there unit. The set temperature is one of the most important values for the simulation because it is one of the targets which should be reached by using all building services systems.

The measure-, component type- and component-selection in the "HEATING AND COOLING SYSTEM" section is already exemplified through chapter 3.4 and particularly chapter 4.1.1. Also the selection of the duct location in the same section is demonstrated in chapter 4.2.2. Additionally, the nominal heating and cooling power of the heating and cooling systems is inserted by the tool-user. It must be noted, that the generation of the above mentioned building services system-charts implies the diversification of these power values to draft different curves for all kinds of systems.

The section "BUILDING TYPE" enables the selection of the construction type of the building which influences the heating and cooling process inside the building. It is represented through the thermal mass of the building which is given via the effective inner heat storage capacity. By using a drop-down list, the user can choose between a light, middle and heavy construction type or can define this value by his own between certain limits. The values which are deposited to the construction type are approximate values (see also chapter 4.1.2).

The building construction itself is roughly divided into four different components which are essential to calculate gains and losses through heat transmission. These components represent the building envelope which are fragmented into the roof of the building or the topmost ceiling, the basement floor of the building or the lowermost floor, all walls of the building toward ambient atmosphere and all windows and doors toward ambient air. Each of these components is defined by its U-value or the reciprocal R-value and its area. An additional adjustment for the floor is the foundation type (see also chapter 3.3.1). The g-value and the z-

value are additional specifications for the windows (see also chapter 3.3.4). The settings for the roof, floor and walls are done in the section "BUILDING ENVOLOPE – SPECIFICATION" and the windows and doors are adjusted in the section "WINDOW AND DOOR – SPECIFICATION".

After the transmission-data section follows the ventilation-data sector "VENTILATION – SPECIFICATION" which includes all data to determine the interior air volume of the building and the ventilation number. The air volume calculation is done through the main length, width and height of interior building rooms ("Vi-calculated") or the direct input of "Vi-direct". If the ventilation number is not prompt by the user, it is set to a required minimum ventilation number (see also chapter 3.3.2).

The "INTERNAL GAINS" section has a strong influence on the simulation. The gains are caused by people, lighting and other technical small and large appliances and devices. They are entered into the tool via their quantity, their "heating" power respectively capacity and their usage in hours per day. For the internal gains caused by people, additional inputs for the absent-hours per day and the leaving time are possible (see also chapter 4.2.1).

Before pressing the "Start Building Simulation"-button, the parameter for the economics calculation can be adjusted. The following default values are assumed if no adjustment is made:

- A Nominal Interest Rate of 3.4 %/a and a Real Interest Rate of 1.4 %/a (cf. Office of Management and Budget, 2014) (see also chapter 4.1.3.1.1).

- A Residential Electricity Price of 0.119 $/kWh and an Electricity Price – Growth Rate of 2.20 %/a (U.S. Energy Information Administration (EIA) (i), 2014 p. A19) (see also chapter 4.1.3.1.2).

●   A Residential Natural-Gas Price of 0.036 $/kWh and an Electricity Price – Growth Rate of 3.40 %/a (U.S. Energy Information Administration (EIA) (i), 2014 p. A7) (see also chapter 4.1.3.1.2).

●   An Effort on servicing of 1 %/a and an Effort on repairs of 2 %/a (see chapter 4.1.3.1.1 and 4.1.3.1.3).

●   A Price Change Rate for the maintenance and capital-related costs of 1.97 %/a (see chapter 4.1.3.1.1 and 4.1.3.1.3).

4.3.3   "RESULTS" SHEET

Chapter 14.4 in the appendix shows an example for the results of the simulation and calculation of the cost-benefit tool. The result sheet is split in three different sections.

The "MAIN SIMULATION RESULTS" section shows all essential results out of the building simulation and also the most important input parameter such as the nominal heating and cooling power. The heating and cooling hours, the provided heating and cooling energy, the hours above and below the temperature limits and the energy- and CO_2-savings are the energy related results out of the simulation.

The second section within the results sheet deals with the "MAIN ECONOMICS RESULTS". It lists the, in the input sheet, selected system-combination including the component types and the components. Furthermore, the investment costs of the heating-, the cooling- and the total system are included. The quoted energy consumptions consider the efficiency factors of the systems. The energy cost savings, the annuity and the simple payback time are further economic results.

The tool provides the possibility to store and delete the "MAIN ECONOMICS RESULTS" of two system-combinations to enable a comparison of them. Further, three cash-flow diagrams compare this two system-combinations which is the third section of the "RESUTS" sheet.

5 RESULTS

The following chapter shows the basic simulation results to illustrate the correct functionality of the simulation tool. Moreover, on the basis of a practical example building, the simulation results of the cost-benefit tool are compared to another building simulation program to proof the validness of the results. Also the economic results for the example building are shown. By varying certain input parameter, the potential cost and energy savings can be discussed. An example for the change of an old inefficient heating and cooling system to a new more efficient system is demonstrated. As already mentioned, the tool can also be used to compare several new installed building services systems for future building projects, what is also shown in an example below.

5.1 BASIC SIMULATION RESULTS

Figure 39 illustrates the simulation results for the temperature course over 1 year.
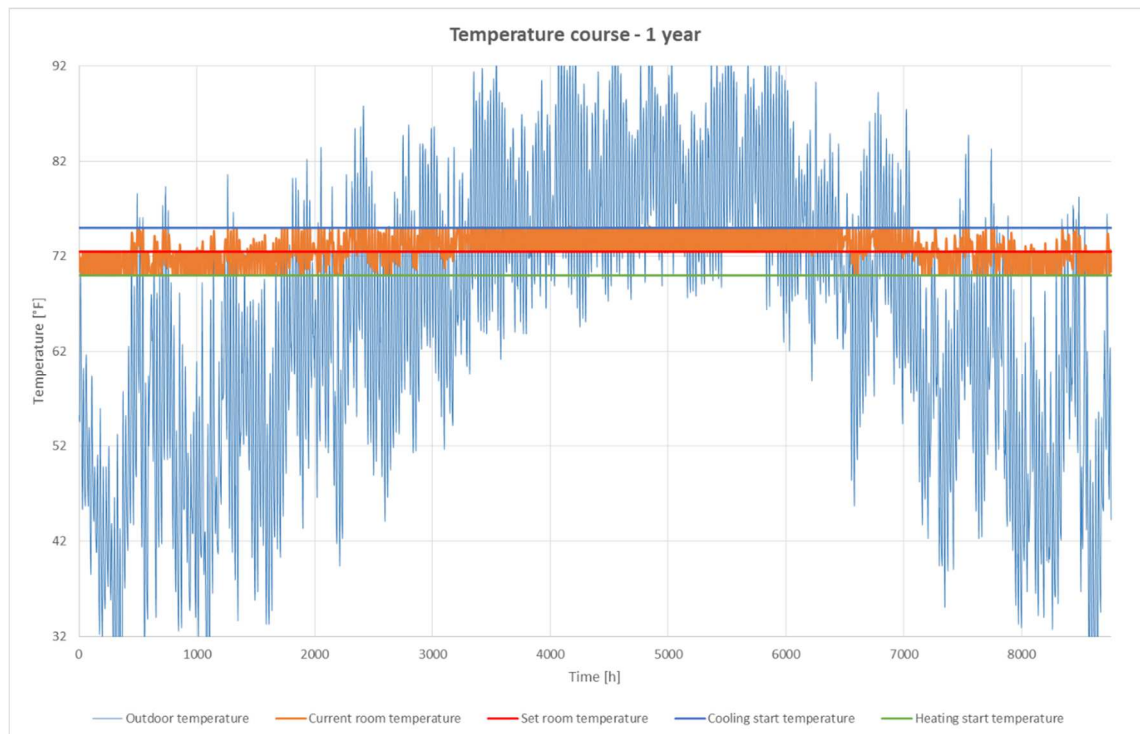
Figure 39: Simulation - temperature profiles over 1 year [Source: own Figure]

The diagram displays the profile for an example building whereat the temperature is displayed in °F on the x-axis from 32 °F to 92°F and the hours of the year on the y-axis from 0 to 8760. One of the best ways to proof the correct functionality of the cost-benefit tool is to look at the temperature profiles of the outside-temperature and all, in the input sheet, specified temperatures in comparison to the course of the simulated room temperature. The straight blue, red and green lines in Figure 39 indicate the upper temperature limit (cooling start temperature), the set temperature respectively the aimed interior temperature and the lower temperature limit (heating start temperature). As can be seen, the orange line equals the current room temperature which stays between the upper and lower limit over the whole year. As a result, the thermal boundary conditions are fulfilled because no hours with a room temperature above the upper limit and below the lower limit occur. The light blue line shows the outside-temperature course with lower temperatures over the winter time and higher temperatures in summer time. Equivalent to this temperature course, the trend of the current room temperature fluctuates between the set temperature and the lower limit in winter most of the time and between the set temperature and the upper limit in summer time. That shows that the basic temperature control through the heating and cooling system is working.

On closer examination of the following two figures can be seen that the behavior of the temperature change inside the building is adjusted to a real temperature profile of the interior air temperature. Figure 40 presents the temperature and irradiation course of an example building for the first week of January. Additionally to the previous diagram, this diagram includes also the Global Horizontal Irradiation course which is indicated as yellow line. As shown in the diagram, the current room temperature stays always between the set temperature and the lower limit. Only if the lower limit is reached, the heating system is activated and the building is heated till the set temperature is reached. As long as the heating system is activated, the counter for the heating hours per year increases. The heating process has a time delay because of the thermal mass of the building.

The room temperature drops due to the low outside-temperature. The internal gains and solar gains caused by the irradiation would help to keep the set temperature, but they are not high enough compared to the transmission and ventilation losses. If no heating system would be installed or the heating power of the system would not be enough, the room temperature would continue to fall. If the current room temperature drops below the lower limit, the counter for the calculation of the "Hours below the lower limit" starts to count. All time below this limit is summed up to receive the hours per year. Depending on the amount of heating power, more or less "Hours below the lower limit" per year are accounted. The size of heating power also affects the size of the system and the investment costs. This reciprocal dependency is discussed in the results below. As long as the room temperature stays between the limits, the heating or cooling system is not activated.
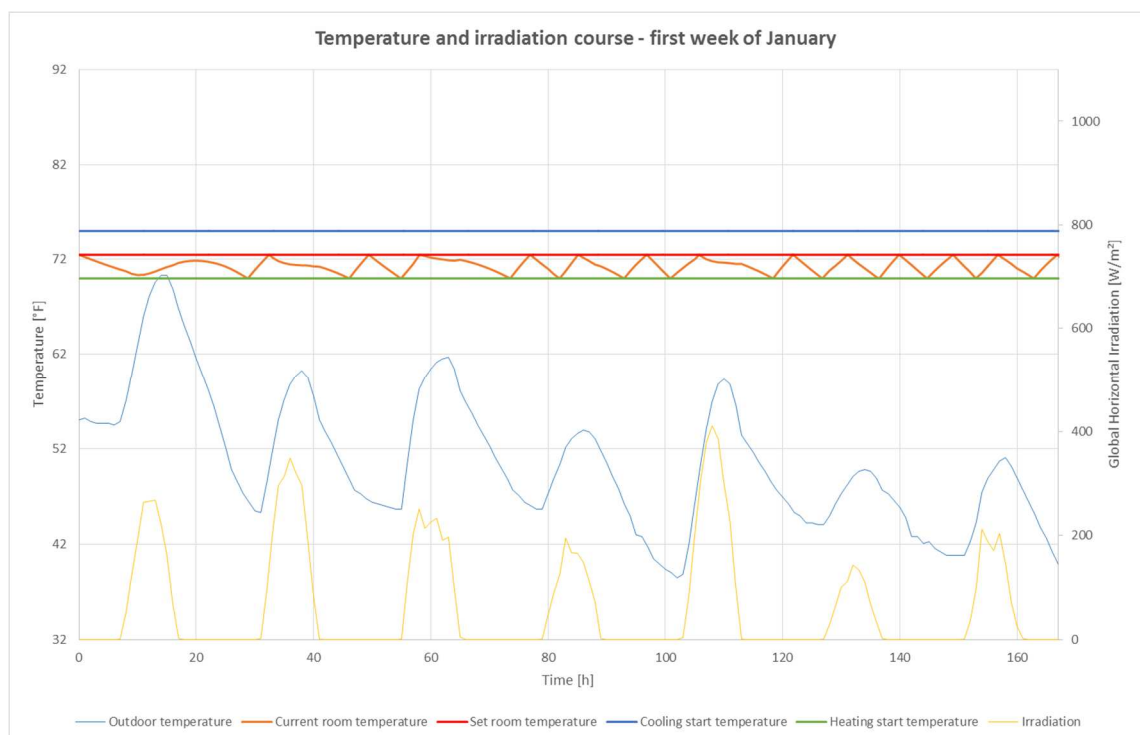
Figure 40: Simulation - temperature profiles - first week of January [Source: own Figure]

Figure 41 illustrates generally the same diagram as the previous one with the difference that the first week of July is displayed. Due to the fact that the outside-

temperature is most of the time higher than the set temperature and the solar gains are also higher during this time of the year, the room temperature fluctuates between the set temperature and the upper temperature limit. That means that cooling system has to provide at least the same or more cooling power as the sum of all heat gain sources together, to keep the room temperature below the upper limit. It can be seen that the cooling system starts to work as soon as the room temperature reaches the upper limit and stops if the set temperature is reached. The counter for the yearly cooling hours-calculation increases according to the activation time of the cooling system. Similar to the previous figure, if no cooling system would be installed or the cooling power would not be enough, the room temperature would get higher than the upper limit. If this is the case, the counter for the calculation of the "Hours above the upper limit" per year starts to count and increases as long as the room temperature is above the upper limit. The connection between the cooling power and the investment costs is discussed below.
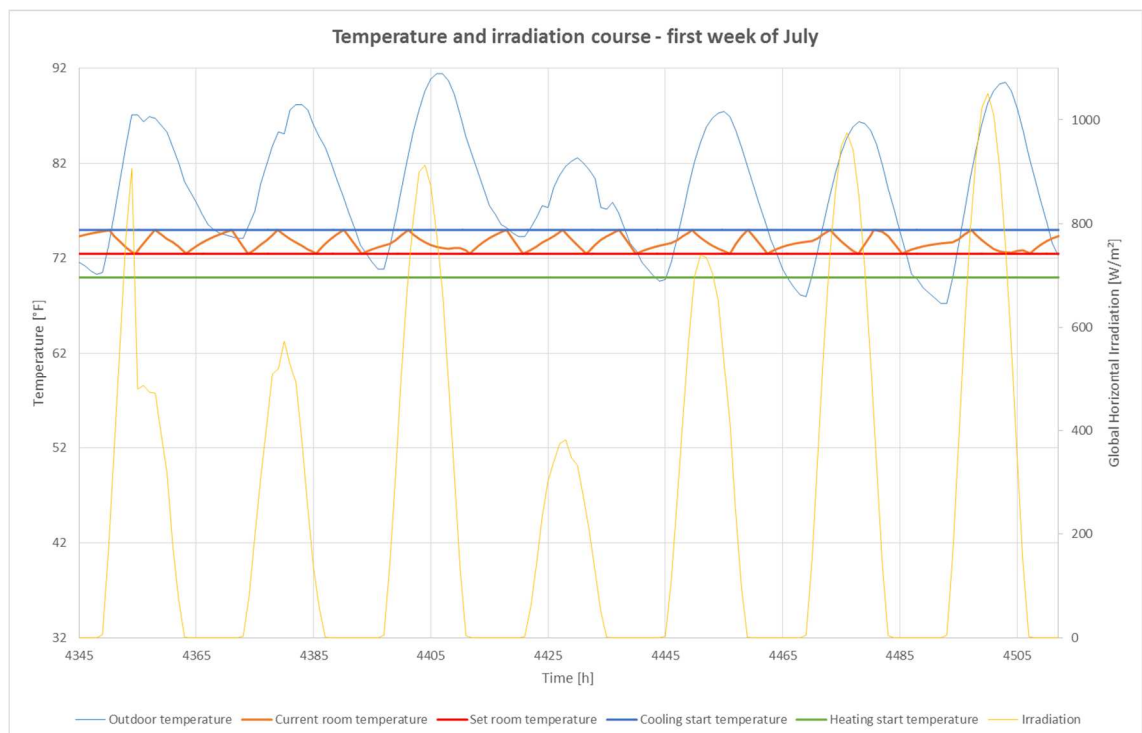
Figure 41: Simulation - temperature profiles - first week of July [Source: own Figure]

5.2 DEFAULT PARAMETER FOR BUILDING SIMULATION

This chapter summarizes the default parameter which are used within the cost-benefit tool to simulate the example building if no other values for the below presented parameter are given. If possible, the default parameter-values should be the same for each building to obtain an equal calculation basis.

If not announced otherwise or included in the provided data and plans, in the "BUILDING ORIENTATION" section, a deviation from South of 0° is assumed. Windows and doors must be filled in the specific building side with the correct orientation (south, east, west, and north).

In contrast to the below following REMrate-comparison-calculations, different temperature default values are assumed for the "BUILDING TEMPERATURES" section in the cost-benefit tool. The set point for the room temperature itself is set to 72.5 °F (22.5 °C) which is an averaged value assumed due to (cf. RESNET, 2014 p. 32). The temperature band around the desired room temperature has also been adjusted with assumed values. The heating start temperature or lower limit is set to 70 °F (~21.1 °C) and the cooling start temperature or upper limit is set to 75 °F (~23.9 °C) which are chosen according to (cf. RESNET, 2014 p. 32).

For the, in chapter 4.1.2, already mentioned and explicated construction type in the "BUILDING TYPE" section, the "Light Construction Type" is assumed as default value because of the general light method of construction of typical houses in the south-east U.S. (see also appendix-chapter 14.5)

According to Brainerd, a ventilation rate n respectively air change rate (ACH_{50}-Default) of 7 h^{-1} is assumed as default value. (Brainerd (b), 2015)

According to Figure 25 in Hendron and Engebrecht 2010, the "People absent-hours per day" are assumed to be 8 h per day and the "Time people leaving building" is assumed to be 8 AM. (cf. Hendron, et al., 2010 p. 64)

5.3　System Consideration – Sample Application

The used example to execute and check the programmed cost-benefit tool are shown in this chapter. Therefore, at first the basic information and data on the example building are provided and it is shown how these data are prepared to use within the tool. Moreover, the comparison-software REMrate is introduced and the calculation of the example building with this software is explained. The same building is calculated with the cost-benefit tool by a best possible adaption of the frame conditions for the simulation, to provide the same initial situation for both simulation programs. Afterwards, the main results from REMrate and the cost-benefit tool are compared and discussed to proof the validation of the tool. Additionally, more results of the cost-benefit tool are presented which show the innovational and beneficial value of the tool. Hence, also examples of a chosen typical system change and new installation of different building services systems are provided.

5.3.1　Sample Building: "12 Greencottage Way"

All needed data for the example building are provided by two sources. The first one is the building plan for the so called "12 Greencottage Way" building which can be found in appendix-chapter 14.5. The second source is an already existing REMrate calculation data file of the building which also provides many data about used building components and building loads such as appliances.

Figure 42 shows a picture of the front view on the building. It can be see that it is a one story house and represents a typical U.S. single family home which are also part of the public building projects in Savannah. Thus, also this building is part of the, in chapter 1.1.3, introduced Savannah Affordable Housing Fund projects. It is used as baseline building for the validation of the tool because of its common and widespread architectural style. Therefore, the gained calculation results can be used for comparisons in future projects.

Figure 42: Image - "12 Greencottage Way" Front View [Source: own Figure]

Based on the already mentioned building plan, a 3D-model of the "12 Greencottage Way" house is drawn. To do this, the plan is analyzed and all important areas and dimensions are selected to build a model in Google SketchUp. It is illustrated in Figure 43.
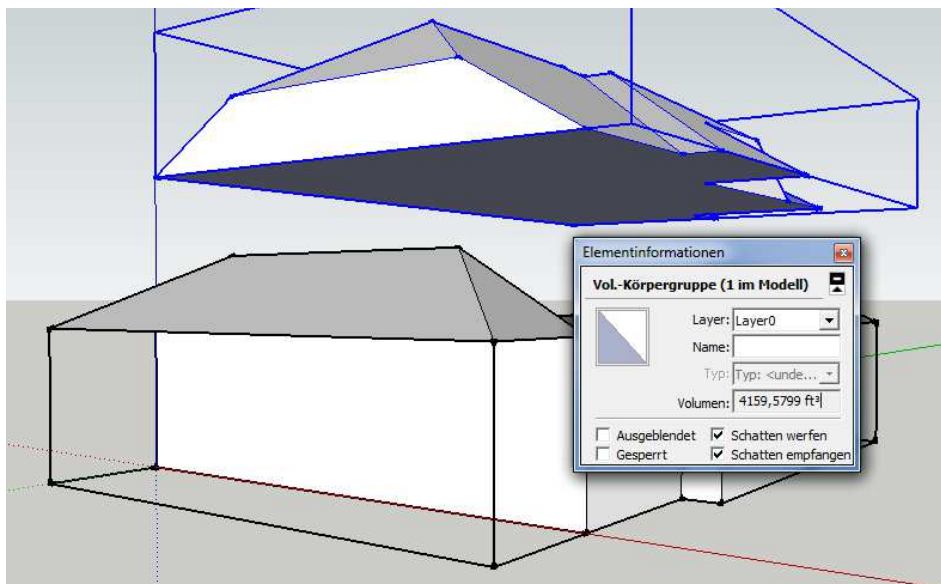
Figure 43: SketchUp - "12 Greencottage Way" [Source: self-created in Google SketchUp 2015]

The model building is required to receive surface areas for walls, floor respectively area of conditioned space and roof as well as the volume of the

conditioned space (conditioned volume), which are needed for the simulation in REMrate and the cost-benefit tool. With Google SketchUP it is easy to measure the volume of different building areas which can be seen in Figure 43. The example building's area of conditioned space amounts 1172 ft² and the volume of conditioned space (Vi-direct) amounts 13536 ft³.

5.3.2 CALCULATION WITH THE SIMULATION PROGRAM REMRATE^{TM}

Before the calculation preparation and the results are shown, a short introduction of the software REM/Rate™ (also called REMrate) is provided in the following.

The software REMrate is used to rate the energy efficiency of homes to identify cost-effective improvements and provide energy-efficient mortgages. It is a user-friendly, yet highly sophisticated residential energy analysis, code compliance and rating program. The software calculates heating, cooling, hot water, lighting and appliance energy loads, consumption and costs for new and existing single- and multi-family-homes and the provided climate data are available for cities and towns throughout North America. It also complies with National Home Energy Rating Standards as promulgated by RESNET and provides features such as including a simplified input procedure, extensive component libraries, automated energy efficient improvement analysis, duct conduction and leakage analysis, latent and sensible cooling analysis, lighting and appliance audit, and active and passive solar analysis. (cf. Lubliner, et al., 2012 p. 31f.)

The REMrate input mask for the frame conditions of the building simulation includes the following required sections and detail-information:

●   "General Building Information": area of conditioned space (sq ft), volume of conditioned space (cu ft), number of bedrooms and foundation type

●   "Slab Floor Properties Summary": area and U-value (reciprocal R-value) (see also chapter 3.3.1)

●   "Above-Grade Wall Properties Summary": area and U-value (reciprocal R-value) (see also chapter 3.3.1)

●   "Window and Glass Door Properties Summary": area, U-value, orientation, SHGC (g-value) and shading (z-value) (see also chapter 3.3.4 and 3.3.1)

●   "Door Properties Summary": area and U-value (reciprocal R-value) (see also chapter 3.3.1)

●   "Ceiling Properties Summary": area and U-value (reciprocal R-value) (see also chapter 3.3.1)

●   "Mechanical Equipment Properties Summary": mechanical equipment type (e.g. GSHP) and equipment capacity (kBtu/h)

●   "System-Wide Properties": setpoint temperatures for heating and cooling

●   "Duct System Selector": duct location

●   "Whole House Infiltration": infiltration value

●   "Lights & Appliances Audit Summary": total consumption of the single appliances (kWh/yr)

It should be noted, that REMrate offers additional input sections for the calculation of further specific results which are not needed for the comparison with the cost-benefit tool and therefore are not mentioned above.

The already existing REMrate calculation file is adapted to the special calculation needs to enable a representative comparison with the tool. The measured value for the conditioned space area and volume is entered in the REMrate input mask. All other result-affecting input values remain unchanged within the existing file and serve as specification for the cost-benefit tool.

After all input masks are set, the REMrate-calculation can be done. The annual load for heating is 12.8 MMBtu/a (million Btu per year) and 25.3 MMBtu/a for cooling. These two result-values are the crucial factors on which the validation of the tool is based on.

5.3.3   CALCULATION WITH THE COST-BENEFIT TOOL

Generally, the above already mentioned adjustments and input values for the REMrate simulation are adopted for the cost-benefit tool simulation. Therefore, the provided data are used to fill the "INPUT" sheet of the cost-benefit tool (only called tool below) which can be seen in appendix-chapter 14.3 for the example building "12 Greencottage Way". Despite the attempt to take over all data and values as good as possible, a view adaptions and modifications are done which are listed in the following:

- The number of occupants is assumed to be equal to the number of bedrooms plus one (cf. RESNET, 2014 p. 33). Consequently, the number of occupants is assumed to be 4 people in the tool.

- The thermal resistance value R of the slab floor is declared in an internal database within REMrate and is also not noted on the building plan. Therefore, no value is provided to adobe for the tool. It is assumed, that the concrete floor and/or the total floor installation has a thermal resistance value of two-thirds of the "Exterior Wall" value and therefore is set to 8 h-ft²-°F/Btu. The reason for this assumption is, that the wall usually needs a higher insulation value compared to the floor but also the floor area has a certain value of thermal resistance due to its composition.

- The coefficient for the calculation of the transmission losses for the walls and for the ceiling/roof is given as thermal transmission coefficient U. It is converted with formula [3.19] to receive the thermal resistance R which is inserted in the tool.

- Basically all provided data for the window specification are adopted directly from the existing REMrate file. Only if more than one window or glass door are located on the same building-wall-orientation and they have different specifications, than an average value is built to include in the tool.

- The provided data of the mechanical equipment are only used to adopt the nominal heating and cooling power of the system. The heating capacity is listed with 20.5 kBtu/h and the cooling capacity with 20.9 kBtu/h. These values are used for the direct comparison of REMrate and the cost-benefit tool and to show the potential savings with the tool.

- The "System-Wide Properties" provide to different set temperatures. One for heating with 68 °F and one for cooling with 78 °F. These two temperatures are used for the seasonal calculation of generalized heat balance equations in REMrate, by considering the temperature differences between these setpoints and the average outdoor seasonal temperature (Salcido, 2015). Due to a different calculation method of REMrate, these temperatures are not adopt for the tool. The temperatures are selected according to chapter 5.2.

- In contrast to REMrate, the tool is not considering waste heat recovery for the ventilation/infiltration part.

- For the tool-calculation of the internal gains caused by lighting and appliances, the provided yearly total consumption values are split up to quantity (number), capacity (wattage) and usage (hours/day). So, the appliances data can be used for the input section of the tool whereas the total consumption value for one year stays the same. The capacity for small and large appliances is distributed over 24 hours for the consideration in the hourly simulation. For the internal gains caused by human, the same approach is used but with special consideration of the human absent-hours and people leaving time.

By multiplying the, from REMrate adopted, nominal heating power of 20.5 kBtu/h with the simulated heating hours of 470.3 h/a, the provided heating energy amounts 9.64 MMBtu/a. The nominal cooling power of 20.9 kBut/h multiplied with the simulated cooling hours of 934.5 h/a amounts a provided cooling energy of 19.53 MMBtu/a.

5.3.4 RESULT-COMPARISON AND DISCUSSION – REMRATE/COST-BENEFIT TOOL

The above already listed REMrate and cost-benefit tool results of the provided heating energy respectively annual load for heating and the provided cooling energy respectively annual load for cooling are compared below.

Both calculation results are based on a nominal heating capacity of 20.5 kBtu/h and a nominal cooling capacity of 20.9 kBut/h which are suggested for the mechanical equipment in REMrate.

The REMrate results are set as basis and the deviation of the cost-benefit tool results is calculated and discussed in the following. The determined provided heating energy of 9.64 MMBtu/a form the tool is 24.7% ([9.64-12.8]/12.8) lower than the annual load for heating of 12.8 MMBtu/a form REMrate. The provided cooling energy of 19.53 MMBtu/a, determined with the tool, is 22.8% lower than the annual load for cooling of 25.3 MMBtu/a, calculated with REMrate. These deviations of about a quarter in both cases can have several reasons which are discussed below.

Basically it should be mentioned, that one of the main reasons for the discrepancy of the results could be the different method of calculation. Whereas the tool-simulation is done on a hourly basis, with hourly data of outside temperatures and irradiation (see also chapter 4), REMrate is a seasonal energy simulation tool with generalized heat balance equations determined from a proprietary climate similarity analysis. That means, REMrate takes also TMY3 hourly weather data and synthesizes them down to seasonal weather data to use them for the model simulation. Then the REMrate engine takes the building inputs, weather data and temperature setpoints to determine the heating and cooling loads. As already mentioned above, there is no temperature deadband consideration in REMrate. Thus, the annual loads are simply determined with the temperature differences between the setpoints and the average outdoor seasonal temperatures. (Salcido, 2015)

Beside this main difference, the above in chapter 5.3.3 listed adaptions and modifications between REMrate and the tool can also have an influence on the result-discrepancy.

Especially the ventilation/infiltration part is considered in a more complex way in REMrate. Moreover, it is not revealed in REMrate how the internal gains through humans, lighting and appliances are considered and if a load profile is applied. As already explained, if a "Slab (No Crawl Space)" is selected in the tool, like in the case of the example building, the transmission losses through the floor are calculated with the yearly average of the outside temperature data. It is not known if REMrate has the same or a similar approach to determine the losses through the slab floor and so this could also be one reason for the result-differences.

It is also very important to mention, that the tool is primarily generated to compare different system types and specifications. Therefore, all compared results are based on the same building frame conditions and so it is possible to make statements within the different system types although the simulation results deviate from the results of another simulation software.

5.3.5 FURTHER RESULTS OF THE COST-BENEFIT TOOL

The following chapter shows three different types of results which represent the main purpose of the cost-benefit tool. The first part reveals the determination of size- and cost-savings compared to the originally intended building services systems respectively mechanical equipment for the example building in the provided REMrate file. Furthermore, an example for a typical system change shows the advantage of the tool to determine the cost- and energy-saving potential of such a measure. In addition, the same potential determination is presented by the comparison of new system installations for future building projects.

5.3.5.1 VARIATION OF THE NOMINAL HEATING AND COOLING CAPACITY

This chapter illustrates the behavior of several building performance parameter as a function of a varied system heating power and cooling power. During the evaluation of the results, the heating and cooling power is kept at the same level (e.g. 12,000 Btu/h heating capacity and 12,000 Btu/h cooling capacity) even if the results for the heating system part are only negligible low effected by the value of the nominal cooling power and vice versa.

The results generally show, that the hours where the room temperature is over the specified upper limit (called Over-Temperature Hours) and the hours where the room temperature is under the specified lower limit (called Under-Temperature Hours) are heavily dependent form the heating and cooling capacity of the building services systems respectively mechanical equipment. With the default values from REMrate, 20,500 Btu/h nominal heating power and 20,900 Btu/h nominal cooling power, the Under- and Over-Temperature Hours are both zero. That means that the room temperature stays the whole year within the set limits and therefore, the system's heating and cooling power is high enough to balance all emerging thermal losses and gains.

By reducing the nominal heating and cooling power of the system, also the equipment size and investment costs drop. On the other hand, the risk, that the system's capacity is too low to maintain the desired thermal conditions, increases. At a certain point the heating and cooling power is too low and the Under- and Over-Temperature Hours start to rise. This can be seen in Figure 44 for the Heating Power compared to the Under-Temperature Hours per year.
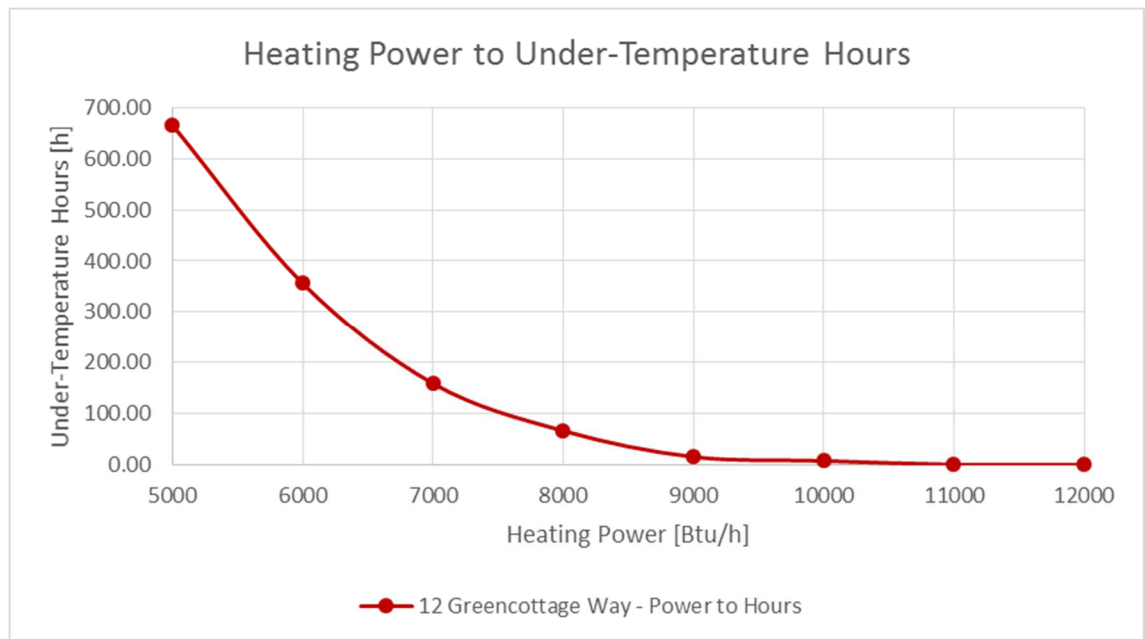
Figure 44: Heating Power to Under-Temperature Hours - "12 Greencottage Way" [Source: own Figure]

Additionally the figure reveals, that even at a heating power of 11,000 Btu/h no Under-Temperature Hours occur. Compared to the intended capacity of 20,500 Btu/h, this is a considerable amount of power- and therefore size-reduction. Only at a heating power of 10,000 Btu/h, a small amount of about 7 h/a arises. With decreasing heating power, the hours rise increasingly.

The same trend can be seen in Figure 45 for the Cooling Power and the Over-Temperature Hours per year. The power can be decreased to 12,000 Btu/h and no Over-Temperature Horus occur. Also here a high power- and size-reduction is possible without losing the ability to maintain the desired thermal interior conditions. At a cooling power of 11,000 Btu/h, a small amount of about 9 h/a arises.
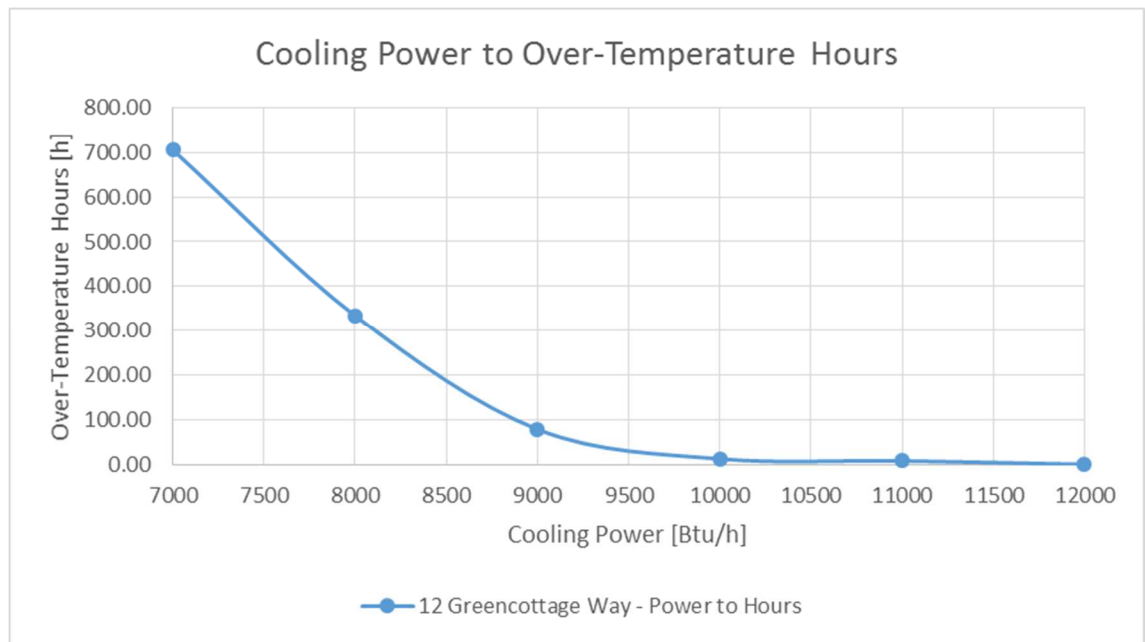
Figure 45: Cooling Power to Over-Temperature Hours - "12 Greencottage Way" [Source: own Figure]

The above presented curves are exemplarily applied to an Air Source Heat Pump to show the development of investment costs compared to the development of the Under- and Over-Temperature Hours. The used data are based on the presented Residential Efficiency Measure Database.

Figure 46 illustrates the same curve as Figure 44, but with the difference that the investment costs in $, for the installation of a SEER 21, 10 HSPF ASHP, are outlined on the x-axis instead of the heating power. For example, the installation of an ASHP with 12,000 Btu/h heating capacity would cost $3,100. Enormous cost savings are possible compared to the originally intended mechanical equipment respectively heating system with a heating capacity of 20,500 Btu/h and investment costs, applied to the same ASHP, of $4,375.
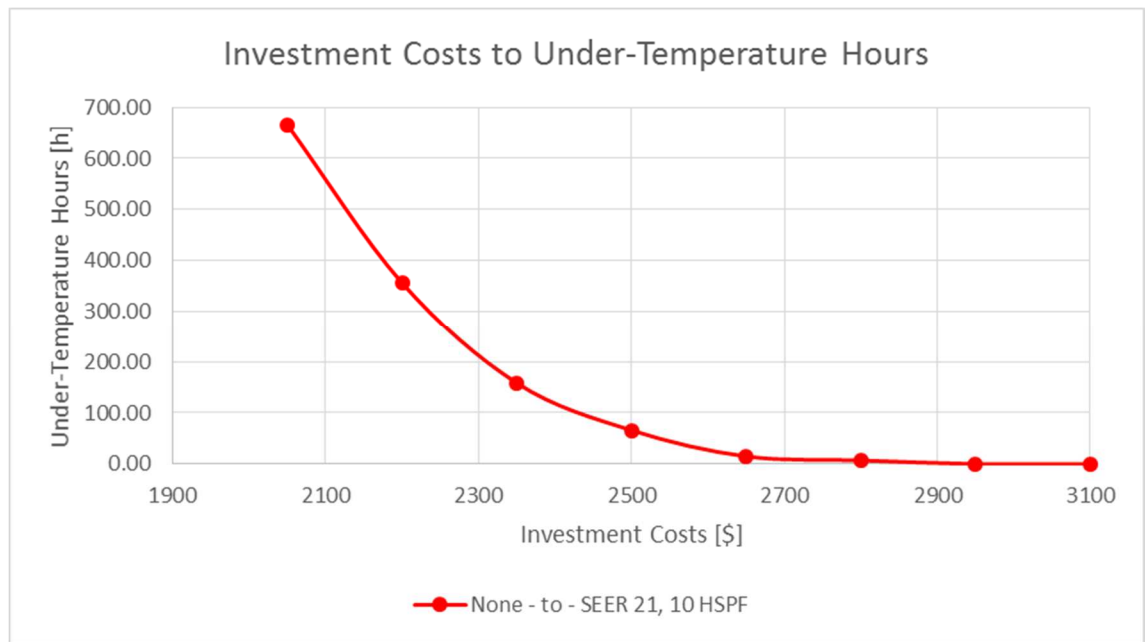
Figure 46: Investment Costs to Under-Temperature Hours - ASHP SEER 21, 10 HSPF [Source: own Figure]

The same connection applies to Figure 47 and Figure 45, whereat in Figure 47 the investment costs in $ are referenced for the SEER 21, 10 HSPF ASHP instead of the cooling capacity. For logical reasons, in this case, the same heat pump would be used for heating and cooling and the investment costs would accrue only once. If only the cooling part is considered, the same huge cost-saving potential occurs at which the ASHP with 12,000 Btu/h cooling capacity would cost also $3,100 and the same heat pump with the originally intended 20,900 Btu/h cooling capacity would cost $4,435.
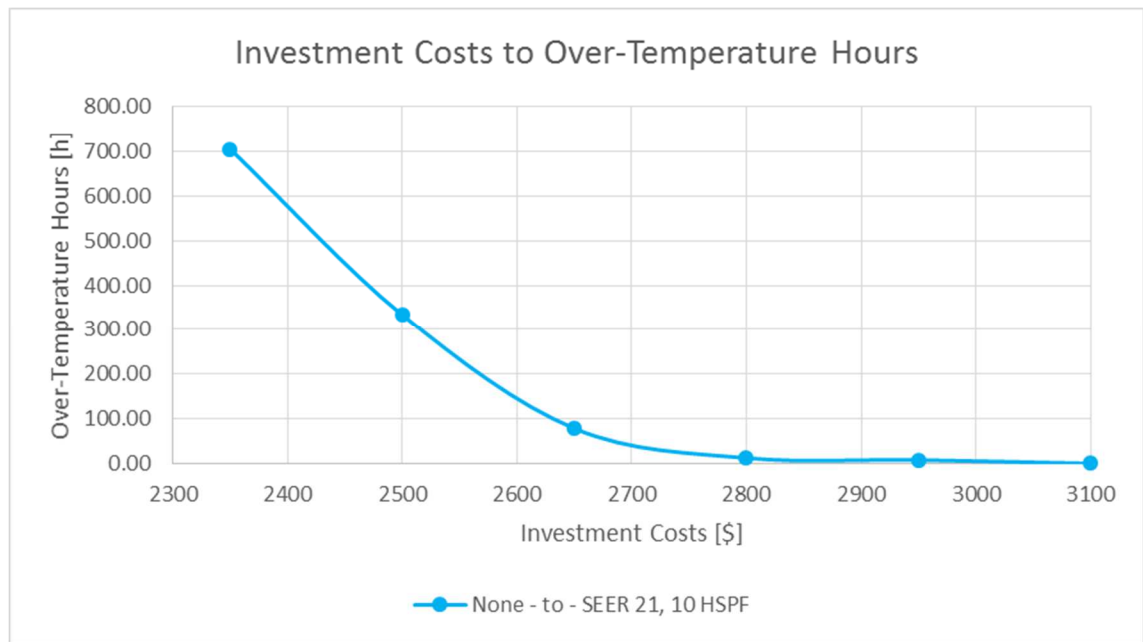
Figure 47: Investment Costs to Over-Temperature Hours - ASHP SEER 21, 10 HSPF [Source: own Figure]

The cost-saving potential is even higher, if a few Under- or Over-Temperature Hours per year are accepted and the system is dimensioned to maintain the desired thermal conditions at least most of the time. For example, if the above presented ASHP is selected with 11,000 Btu/h heating and cooling capacity, then 0 Under-Temperature Hours and about 9 Over-Temperature Hours occur. By accepting this 9 h/a, another 150 $ investment costs could be saved compared to a heating and cooling capacity of 12,000 Btu/h.

The last two presented Hours-Costs-Curves do not apply only for the example of the ASHP, but also for all other building services systems which are implemented in the cost-benefit tool. If the heating and cooling system are not the same component and a separate heating and cooling system is used, the investment costs for both systems respectively components must be considered.

5.3.5.2 EXAMPLE – COMPARISON OF SYSTEM CHANGE MEASURES

The following example shows the advantage of the cost-benefit tool to reveal the cost- and energy-saving potential of a system change measure whereat an old inefficient system is removed and a new more efficient and sustainable system is installed. Additionally, it is illustrated how the comparison and selection of one out of two different new more efficient systems can be done.

Due to the results of the chapter above, the nominal heating and cooling capacity for the chosen example is set to 12,000 Btu/h because this is the limit where no Under- and Over-Temperature Hours occur for the example "12 Greencottage Way".

The whole example contains the removal of an old electrical powered Furnace (100% AFUE) as heating system and an old inefficient SEER 8 Central Air Conditioner as cooling system. Instead of this two components, one SEER 21, 10 HSPF Air Source Heat Pump is installed which is responsible for heating and cooling. By implementing this measure, the following calculation results are obtained:

●   Total Energy Savings of about 3,400 kWh/a

● CO_2-Emission Savings of about 3,600 lbs-CO_2/a

●   Total Energy Cost-Savings of more than 400 \$/a

●   A Simple Payback Time for the total system of about 9.3 years

The whole simulation results for this example are summarized in appendix-chapter 14.4. As can be seen, with the tool it is easy to determine which advantages or disadvantages a system change could have.

To find the best solution for such a system change, different alternatives for the new installed systems can be calculated and compared. Figure 48 and Figure 49 display examples for the comparison of the above already mentioned SEER 21, 10 HSPF ASHP with an EER 20.2, COP 4.2 Ground Source Heat Pump. Both

diagrams show the calculated parameter over a varied system's heating and cooling capacity.

Figure 48 illustrates the determined values for the economic parameter Simple Payback Time (SPB). As can be seen, the measure with the ASHP (blue) has clearly shorter payback times than the same measure with the GSHP (orange). At a heating and cooling power of 12,000 Btu/h, the SPB for the ASHP is about 9.3 years compared to a SPB for the GSHP of about 18.5 years. The figure also illustrates again, that the SPB for both components would decrease if a few Under- and/or Over-Temperature Hours would be accepted and therefore lower system capacities could be used. Also the comparison to the originally intended capacity values is presented.
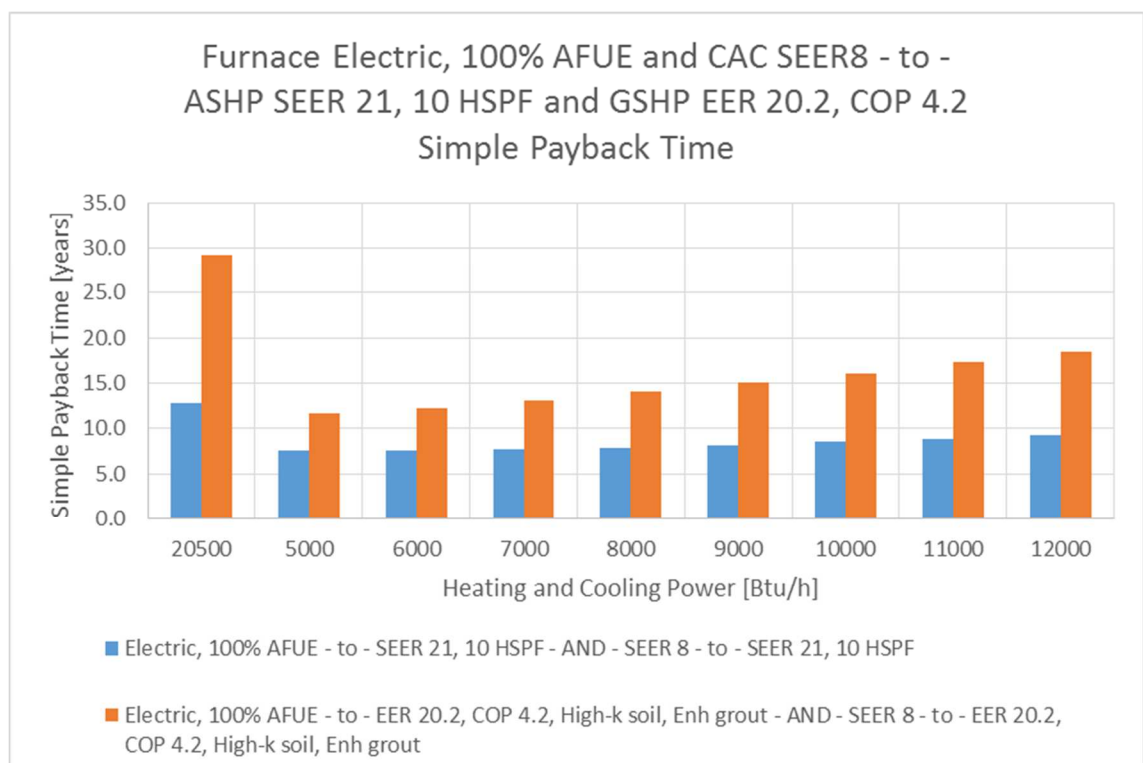
Figure 48: Measure-Comparison of ASHP and GSHP – Simple Payback Time [Source: own Figure]

The same system- or component-comparison is done in Figure 49, but with the difference that the Energy Savings are charted. By comparing this energy related parameter, the figure reveals, that the GSHP offers slightly higher energy savings

than the ASHP. The reduction of the heating and cooling capacity shows, that the energy savings in both cases decrease, but only marginal.
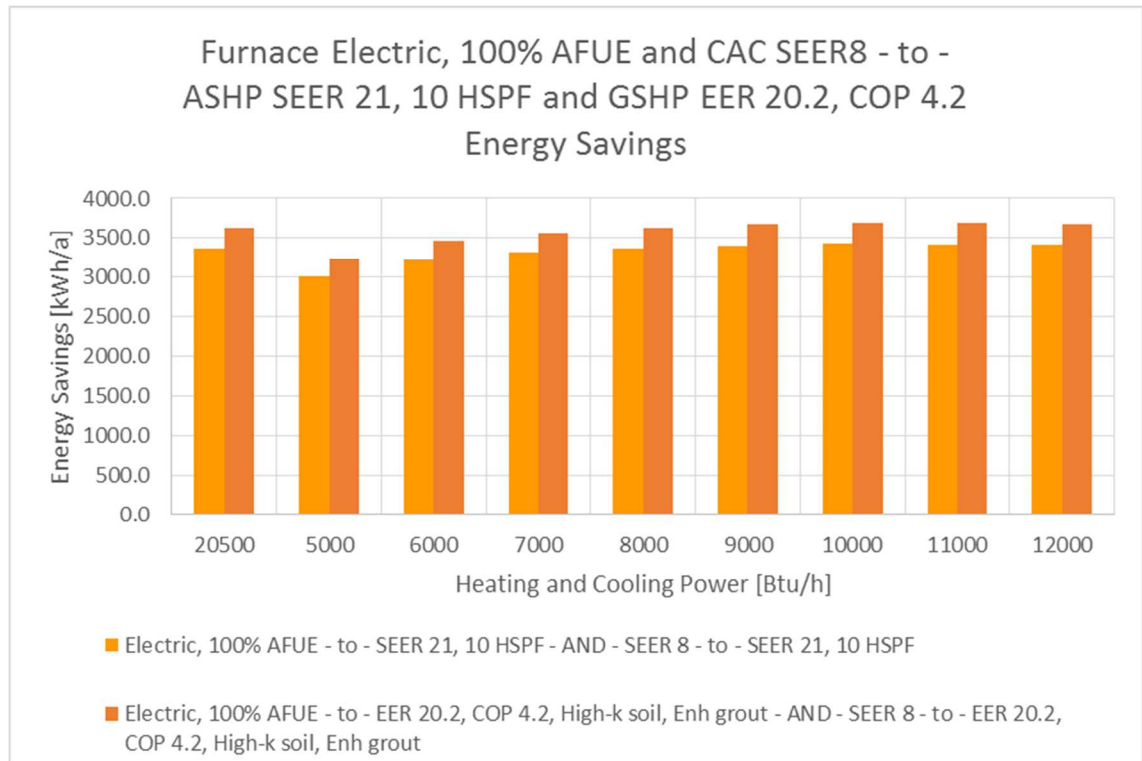
Figure 49: Measure-Comparison of ASHP and GSHP – Energy Savings [Source: own Figure]

The GSHP has a considerable higher SPB than the ASHP but only a little higher energy savings. Also the comparison of both values for the economic parameter Annuity at 12,000 Btu/h component capacities shows, that the ASHP with the value -798 $/a is a much better solution than the GSHP with the value -1326 $/a.

5.3.5.3 EXAMPLE – COMPARISON OF SYSTEM INSTALLATIONS

This chapter shows the possibility to compare different new installed building services systems which can be implemented in future building projects. Therefore, the in chapter 4.1.1.1 already explained selection of the measure for new system installations is done.

The comparison of two ASHPs with different efficiency data is done based on the data of the building example "12 Greencottage Way". The component with the

lower efficiency is a SEER 13, 7.7 HSPF ASHP and the component with the higher efficiency is a SEER 21, 10 HSPF ASHP. The aim is to determine which component would be the more cost- and energy-efficient solution for the implementation if the example would be built new.

All relevant calculation results for both options can be seen in appendix-chapter 14.4. Therein it can be seen that the total energy consumption of the SEER 13, 7.7 HSPF ASHP amounts about 2,780 kWh/a and is clearly higher than the total energy consumption of the SEER 21, 10 HSPF ASHP with about 1,916 kWh/a. On the other hand, the results for the annuity, which amount -702.7 $/a for the less efficient system and -710.0 $/a for the more efficient system, reveals that the SEER 13, 7.7 HSPF component would be the better solution from an economic stand point.
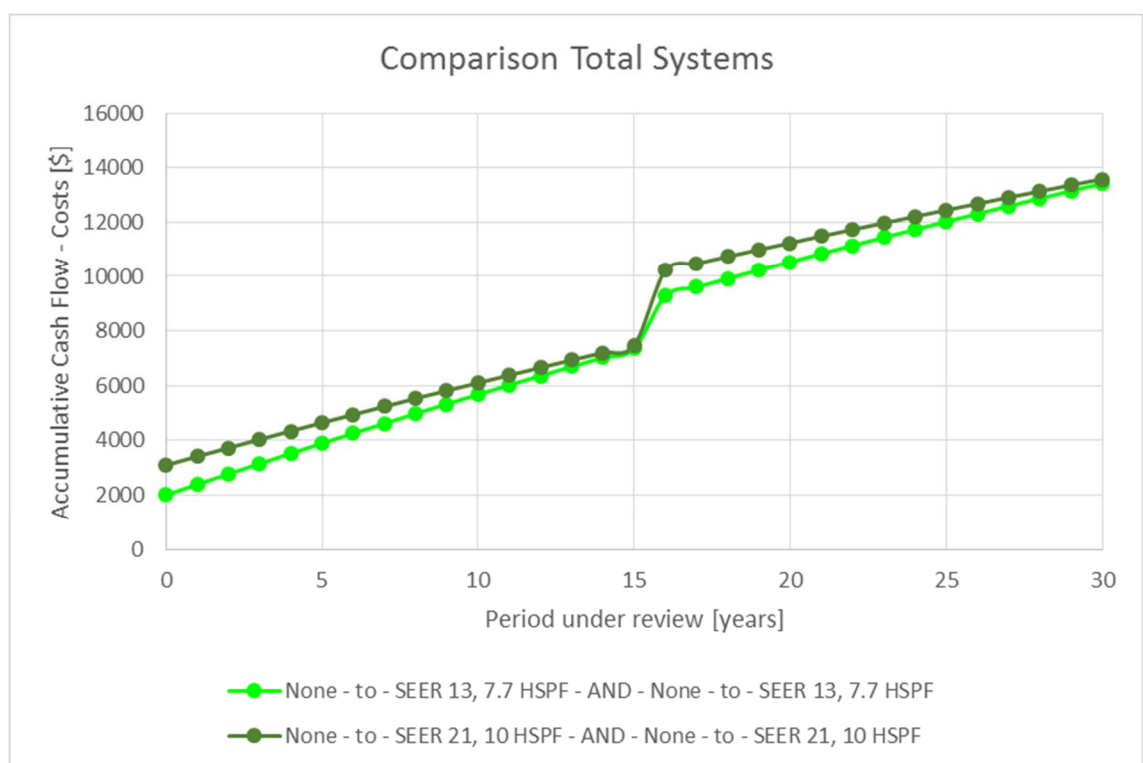
Figure 50: Comparision of different ASHPs - Accumulative Cash Flow/Costs [Soure: own Figure]

Also the course of the accumulative positive discounted cash flow shows that the less efficient system has light advantages, as can be seen in Figure 50.

However, the figure also shows that the more efficient ASHP has almost the same value after 15 years and then the value gets higher again because of the considered component lifetime of 16 years.

By considering the fact that the component maybe lasts longer than the listed 16 years, the more efficient component would be the better choice. Additionally, from an energy saving stand point, the system with the higher efficiency is much better. Therefore, if energy- and CO_2-saving has first priority, the SEER 21, 10 HSPF ASHP would be the better solution. Otherwise the SEER 13, 7.7 HSPF ASHP would be the best solution from an economic stand point because it is a bit cheaper based on the calculation period of 30 years. Also the variation of the economic factors, for example a rise of the electricity prices, would lead to a preference of the more efficient component.

Beside the presented examples of total system considerations (heating plus cooling), also the heating and cooling part can be calculated, analyzed and selected independent from each other.

6 OUTLOOK AND FUTURE IMPROVEMENTS

The following chapter provides suggestions and annotations for possible future improvements of the cost-benefit tool and reasonable enhancements.

Basically, the above presented default values and the from REMrate adopted values of the input sheet can be adjusted and diversified in a way to get the simulation results and values of the tool closer to the REMrate results. To do this, a more accurate and profound research on suitable default values for the appropriate area can be done.

A big step to extend the functionality of the tool and to adapt the simulation further towards real consumer behavior would be the implementation and more complex modulation of a programmable thermostat. Consequently, a user defined heating- and cooling-behavior of the system could be simulated which includes the consideration of day-night-switching, seasonal temperature settings, weekdays and weekend adjustments, holidays and other temperature set point and limit adjustments. It should be considered, that the user behavior has a big impact on the real heating and cooling loads of a building and therefore the comparison for the simulation results with real measured data is always difficult.

Another point could be the implementation of a larger number of foundation types beside the already existing "Slab"- and "Crawl Space"-type. Hence, according to the selected type, a more complex and adapted temperature consideration could be done to receive more realistic simulation results.

Furthermore, the input process for the building components such as walls, floors, roofs, ceilings, windows and doors could be refined. That means, that for example more than one floor area and type is possible, at which the different areas can also have different thermal characteristics, composition and surface area. This also applies to windows and doors whereat, for example, windows are not combined anymore and instead different windows are located in the same wall and/or in different walls with the same orientation.

Also the value for the construction type could be adapted and refined through a more detailed research on the U.S. building industry to find specific values for a certain building type.

Another big step to increase the accuracy of the simulation results is the improvement of the ventilation and infiltration modeling within the simulation process. Thus, inlet and exhaust air of mechanical ventilations systems as well as waste heat recovery could be considered.

A great implementation step would be a more sophisticated consideration and adjustment of the "People absent hours" respectively the selection-offer of several different building load profiles. Accordingly, the simulation of different residential building types and even commercial building types would be facilitated.

In a similar way, the number and diversity of the appliances and lighting could be considered. Therefore, the activation time of the single devices would have a greater involvement in the simulation.

To make the whole functionality of the cost-benefit tool usable for commercial buildings, the implementation of a Commercial Efficiency Measures Database as cost basis would be possible.

The current status of the tool and its results are more suitable for residential buildings and especially due to the cost data for residential buildings. The comparison with the software REMrate shows, that the tool-results fit for limited duties for the dimensioning of building services systems. On the other hand, the tool and its results have shown, that they are very well-suited for the comparison of systems and components and therefore are exceptional useful for making decisions which system, component type or component should be used. Thus, the intended use and functionality of the cost-benefit tool and the thesis is satisfactory fulfilled. A further improvement of the tool, as described above, would need great additional programing and research effort

7 SUMMARY – CONCLUSION

Until now, there was no free accessible general approach to determine and decide which building services system would be the best solution for residential buildings in need of refurbishment or also buildings which are part of future public building projects. This approach includes the analysis of all needed background information and data, a general model with the essential model parameter and an assessment approach combined with a calculation tool. Thus, the determination of parameters, which can help to decide if a refurbishment of old building services systems or the installation of new systems is economically and ecologically worthwhile or not, can be done.

The first step is the elaboration of the background information. Therefore, the energy sector is analyzed and especially the situation in the state of Georgia and the City of Savannah is examined. Hence, all important frame conditions about energy, building and consumer structure are gained to focus the tool on the special needs of these regions. Additionally, also the climatic conditions are analyzed.

With the aid of the theoretical formulas about the calculation of heat loads and cooling loads in buildings and the determination of cost effectiveness and other economic parameter, the physical building and economics calculation model is developed. Combined with the implementation of an efficiency measure cost database, the program structure is prepared. A user-friendly human-machine interface which includes an input-sheet for the entry of global building parameter as well as a general-information sheet and a results-sheet is included. After the input of the calculation parameter and the simulation of the building, all technical and economical results are available to use in the results-sheet.

The developed cost-benefit tool is validated and compared with an external building simulation software which is called REM/Rate™. Due to a comparison of the simulation results of both programs for the example building "12 Greencottage

Way", it can be seen that the results of the cost-benefit tool differ about 23 to 25% from the REMrate results. The possible reasons for the deviation can be easily explained and are discussed above. Amongst others, the very different simulation approach of both programs can be on main reason.

Furthermore, the comparison of the simulation results show, that the cost-benefit tool can be used to reveal great potential savings. It has been shown that the capacities of the building services systems can be decreased without losing the ability to maintain the desired thermal conditions inside the building. Accordingly, also a high cost saving potential exists.

Further applications of the cost-benefit tool show, that the easy comparison of different calculation results enable the determination of the best cost- and energy-effective solution for different building services systems in a specific building.

The cost-benefit tool is not developed for the detailed dimensioning planning of a building's heating, cooling and ventilation system, but it can provide first assessments and approaches for the right system selection. It can be used within the planning process for residential building refurbishments as well as for future building projects such as the Savannah Affordable Housing Projects. Due to the general building input mask within the tool, it can be used for a wide variety of building types. As a result, the main targets for this thesis are achieved and the scientific question is answered.

8 LIST OF ABBREVIATIONS

Abbreviation	Explanation
AEO2015	Annual Energy Outlook 2015
AFUE	Annual Fuel Utilization Efficiency
ASHP	Air Source Heat Pump
CAC	Central Air Conditioner
COP	Coefficient Of Performance
EER	Energy Efficiency Ratio
EIA	Energy Information Agency
GSHP	Ground Source Heat Pump
HSPF	Heating Seasonal Performance Factor
IECC	International Energy Conservation Code
NREL	National Renewable Energy Laboratory
RAC	Room Air Conditioner
RECS	Residential Energy Consumption Survey
SAHF	Savannah Affordable Housing Fund
SHGC	Solar Heat Gain Coefficient
SPB	Simple payback (Simple payback time)
SEER	Seasonal Energy Efficiency Ratio
TMY	Typical Meteorological Year
USA	United States of America
U.S.	United States of America
VDI	Verein Deutscher Ingenieure

9 GLOSSARY

Term	Explanation
Homeowner vacancy rate	"The homeowner vacancy rate is the proportion of the homeowner housing inventory which is vacant for sale. It is computed by dividing the number of vacant units for sale only by the sum of owner-occupied units and vacant units that are for sale only, and then multiplying by 100." (U.S. Census Bureau (c), n.a.)
Rental vacancy rate	"The proportion of the rental inventory which is vacant for rent. It is computed by dividing the number of vacant units for rent by the sum of the renter-occupied units and the number of vacant units for rent, and then multiplying by 100." (U.S. Census Bureau (d), n.a.)
Average household size	"A measure obtained by dividing the number of people in households by the total number of households (or householders)." (U.S. Census Bureau (e), n.a.)
Under-Temperature Hours	Amount of hours where the room temperature is below the lower limit of the adjusted temperature dead band. Usually given in hours per year (h/a) [Source: own Definition]
Over-Temperature Hours	Amount of hours where the room temperature is above the upper limit of the adjusted temperature dead band. Usually given in hours per year (h/a) [Source: own Definition]

10   LIST OF FIGURES

11 LIST OF TABLES

12   LIST OF EQUATIONS

No.	Name	Equation
[3.1]	annuity of the capital-related costs	$$A_{N,K} = (A_0 + A_1 + A_2 + \cdots A_N - R_w) * a + \frac{f_K}{100} * A_0 * ba_{IN}$$
[3.2]	cash flow of replacements	$$A_1 = A_0 * \frac{r^{(1*T_N)}}{q^{(1*T_N)}} \qquad A_2 = A_0 * \frac{r^{(2*T_N)}}{q^{(2*T_N)}}$$ $$A_3 = A_0 * \frac{r^{(3*T_N)}}{q^{(3*T_N)}} \ldots \qquad A_n = A_0 * \frac{r^{(n*T_N)}}{q^{(n*T_N)}}$$
[3.3]	residual value	$$R_w = A_0 * r^{(n*T_N)} * \frac{(n+1)*T_N - T}{T_N} * \frac{1}{q^T}$$
[3.4]	annuity factor	$$a = \frac{q^T * (q-1)}{q^T - 1} = \frac{q-1}{1 - q^{-T}}$$
[3.5]	price-dynamic annuity factors	$$b_{IN} = b_{IN} * a \qquad ba_V = b_V * a$$ $$ba_B = b_B * a \qquad ba_S = b_S * a$$
[3.6]	cash value factor b	$$b = \frac{1 - \left(\frac{r}{q}\right)^T}{q - r}$$
[3.7]	annuity of requirement(consumption)-related costs	$$A_{N,V} = A_{V1} * ba_V$$
[3.8]	requirement(consumption)-related costs in first year	$$A_{V1} = Q_{3,Heat} * Price_{Heat} + Q_{3,Cooling} * Price_{Cooling}$$ $$+ Q_{3,Electricity} * Price_{Electricity} + Q_{3,Water} * Price_{Water}$$

No.	Name	Equation
[3.9]	annuity of the operation-related costs	$$A_{N,B} = A_{B1} * ba_B$$
[3.10]	annuity of other costs	$$A_{N,S} = A_{S1} * ba_S$$
[3.11]	annuity of revenues	$$A_{N,E} = E_1 * ba_E$$
[3.12]	total annuity	$$A_N = A_{N,E} - (A_{N,K} + A_{N,V} + A_{N,B} + A_{N,S})$$
[3.13]	nominal discount rate real discount rate inflation rate	$$(1 + d_n) = (1 + d_r) * (1 + e)$$ $$d_n = [(1 + d_r) * (1 + e)] - 1$$ $$d_r = [(1 + d_n)/(1 + e)] - 1$$
[3.14]	present value present value interest factor	$$PV = PVIF_n * F_n$$ $$PVIF_n = \frac{1}{(1 + d)^n}$$ $$Therefore \dots PV = PVIF_n * F_n = \frac{1}{(1 + d)^n} * F_n$$
[3.15]	present value	$$PV = \sum_{n=1}^{N} PVIF_n * F_n$$
[3.16]	constraint for simple payback	$$\sum_n \Delta I_n <= \sum_n \Delta S_n$$
[3.17]	norm-transmission heat losses	$$\phi_{T,i} = \left(\theta_{nt,i} - \theta_e\right) * (H_{T,ie} * H_{T,uie} * H_{T,ig} * H_{T,ij})$$

No.	Name	Equation
[3.18]	direct heat losses to the exterior	$$H_{T,ie} = \sum A_k * U_k + \sum \psi_l * l_l$$
[3.19]	thermal transmission resistance	$$R = \frac{1}{U}$$
[3.20]	norm-ventilation heat losses	$$\phi_{V,i} = \left(\theta_{int,i} - \theta_e\right) * H_{V,i}$$
[3.21]	ventilation heat losses	$$H_V = \dot{V}_i * \rho * c_p = \dot{V}_i * 0.34 \, \frac{Wh}{m^3 * K}$$
[3.22]	ventilation number	$$n = \frac{\dot{V}}{V}$$
[3.23]	Heat load	$$\phi_{HL} = \sum \phi_{T,i} + \sum \phi_{V,i} + \sum \phi_{RH,i}$$
[3.24]	heat flow through a transparent external building component	$$\phi_S = \sum I_i * F_{s,i} * F_{C,i} * F_{F,i} * g_i * A_i$$
[3.25]	measure costs	$$C_{measur} = -M_{before} * C_{before} + C_{action} + M_{after} * C_{after}$$
[4.1]	thermal equation for a building	$$\dot{Q}_{total} = \dot{Q}_{heating} - \dot{Q}_{cooling} - \dot{Q}_{tra\ s.\ total} - \dot{Q}_{vent./inf.} + \dot{Q}_{solar} + \dot{Q}_{internal}$$
[4.2]	Building simulation formula	$$\vartheta_{int.} = \vartheta_{int.} + \Delta t * \frac{\dot{Q}_{total}}{C_{effective}}$$

No.	Name	Equation
[4.3]	simple payback time	$$SPB = \frac{I_0}{\Delta S_0}$$

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14 APPENDIX

The appendix contains all supplements for the thesis which are necessary to improve the understanding of the context.

14.1 EFFORT ON REPAIRS AND SERVICING

Table 12: Effort on repairs and servicing of heating and ventilation and air-conditioning systems – example values (cf. VDI, 2000 pp. 21-29)

	Effort on repairs*	Effort on servicing*
1 Heating		
1.3 Generation		
1.3.1 Heat generator		
1.3.1.1 Gas fireplace with burner or fan		
1.3.1.1.2 Hot-air heaters		
Gas-fired hot-air heaters for detached family houses	1.5	0.5
1.3.1.8 Electric heating		
Electrode boiler	1	1.5
1.3.1.9 Heat pumps		
Electricity	3	1
2 Ventilation and air-conditioning		
2.1 Benefit transfer		
2.1.2 Heat		
2.1.2.1 Air heaters		
2.1.2.1.1 Direct-central		
Gas	1	1
Electric	1	0.5
2.1.2.1.2 Direct-local		
Gas	1	1
Electric	1	0.5
2.1.3 Cooling		
2.1.3.1 Air coolers		
Water	2	4
*) in percentage of investment total per year and components		

14.2 EXAMPLE – "GENERAL INFORMATION" SHEET

Cost - Benefit Analysis Tool - GENERAL INFORMATION

IMPORTANT NOTES

This cost-benefit analysis tool has the purpose to simulate different housing and building facilities to gain an decision making guidance on several types of building services systems.

Generally the current tool is designed for the analysis and determination of heating and cooling systems in residential buildings in the area of Savannah, GA. However, the tool can also be used for other building types and places by changing weather data in the sheets "Data_Tout" and "Data_Irrad.". For commercial building system prices, also the data in the sheet "System_Data" must be changed.

- All cells that are dyed with the following color are indicating a cell which has to be filled in by the user:

- All cells that are dyed with the following color are indicating a cell which contains a default value or a result of a calculation. However, the cell value can be changed too:

- All cells that are marked with the following sign indicate an explanatory comment liked to the cell:

- The following sign indicates that the input-cell or button is filled in or already processed:

- The following sign indicates that input-cell or button must be filled in or processed before the simulation is started:

WARNING: The startet process by clicking the "Load System Data" button can take a few minutes. The simulation process which is startet by clicking the "Start Building Simulation" button can, depending on the processing power of the computer, take up to 20 minutes. After the simulation is finished, the EXCEL file size can be more than 100 MB. This can be reduced by the deletion of the calculated data in the sheet "Data_Simulation".

14.3 EXAMPLE – "INPUT" SHEET

CITY OF savannah

Cost - Benefit Analysis Tool - INPUT

BUILDING ORIENTATION

Deviation from South	0 °	✔

BUILDING TEMPERATURES

Set Temperature	72,5 °F	✔
Cooling Start Temp./Upper Limit	75,0 °F	✔
Heating Start Temp./Lower Limit	70,0 °F	✔

HEATING AND COOLING SYSTEM

System Change

Type of System Change — REMOVE old system + INSTALL new system

Duct System

Duct Location — Conditioned Space

Heating System

Type of Heating System - OLD	Furnace (Remove, OLD)
Type of Heating System - NEW	Air Source Heat Pump (Remove, NEW)
Before-Component	Electric, 100% AFUE
After-Component	SEER 21, 10 HSPF

Cooling System

Type of Cooling System - OLD	Central Air Conditioner (Remove, OLD)
Type of Cooling System - NEW	Air Source Heat Pump (Remove, NEW)
Before-Component	SEER 8
After-Component	SEER 21, 10 HSPF

Load System Data ✔

System Power

Nominal Heating Power	12000 Btu/h	✔
Nominal Cooling Power	12000 Btu/h	✔

BUILDING TYPE

Building Construction Type

Construction Type	Light Construction Type	
Net Floor Area, Area of conditioned space	1172 ft²	✔
Construction Type - Manually	8.80 Wh/(K*m²)	✔

BUILDING ENVELOPE - SPECIFICATION

Roof:

$R_{Roof/Ceiling}$	24,4 h-ft²-°F/Btu	✓
$A_{Roof/Ceiling}$	1357 ft²	✓

Floor:

Fondation Type	Slab (No Crawl Space) ▼	
R_{Floor}	8,0 h-ft²-°F/Btu	✓
A_{Floor}	1172 ft²	✓

Exterior Wall:

R_{Wall}	12,0 h-ft²-°F/Btu	✓
A_{Wall} (incl. Windows and Doors)	1346,5 ft²	✓

WINDOW AND DOOR - SPECIFICATION

Window and Door-South:

$U_{Window-South}$	0.34 Btu/h-ft²-°F	✓
$A_{Window-South}$	17.41 ft²	✓
g-value$_{Window-South}$	0.26 -	✓
$U_{Door-South}$	0.144 h-ft²-°F/Btu	✓
$A_{Door-South}$	11.0 ft²	✓
z-value$_{Glass-South}$	0.70 -	✓

Window and Door-East:

$U_{Window-East}$	0.35 Btu/h-ft²-°F	✓
$A_{Window-East}$	41.0 ft²	✓
g-value$_{Window-East}$	0.27 -	✓
$U_{Door-East}$	0 h-ft²-°F/Btu	✓
$A_{Door-East}$	0 ft²	✓
z-value$_{Glass-East}$	0.77 -	✓

Window and Door-West:

$U_{Window-West}$	0.35 Btu/h-ft²-°F	✓
$A_{Window-West}$	108.8 ft²	✓
g-value$_{Window-West}$	0.27 -	✓
$U_{Door-West}$	0 h-ft²-°F/Btu	✓
$A_{Door-West}$	0 ft²	✓
z-value$_{Glass-West}$	0.76 -	✓

Window and Door-North:

$U_{Window-North}$	0.34 Btu/h-ft²-°F	✓
$A_{Window-North}$	31 ft²	✓
g-value$_{Window-North}$	0.26 -	✓
$U_{Door-North}$	0 h-ft²-°F/Btu	✓
$A_{Door-North}$	0 ft²	✓
z-value$_{Glass-North}$	0.70 -	✓

VENTILATION - SPECIFICATION		
ACH$_{50}$ - Default	7.00 h^{-1}	✓
l	40.0 ft	
b	40.0 ft	
h	8.0 ft	
Vi-calculated	12800 ft³	
Vi-direct	13536 ft³	✓

INTERNAL GAINS		
PEOPLE		
People living in building	4 -	✓
Power per person (heat)	409,6 Btu/h	✓
People absent-hours per day	8,0 h	✓
Time people leaving building	8 AM	✓
LIGHTING		
Light bulbs in building	10 Units	✓
Average wattage of light bulbs	40,19 W	✓
Usage (Hrs/day)	5,0 h/day	✓
LARGE APPLIANCES		
Refrigerator		
Quantity	1 Units	✓
Capacity	78,88 W	✓
Usage (hours/day)	24,0 h/day	✓
Stove		
Quantity	0 Units	✓
Capacity	0,00 W	✓
Usage (hours/day)	0,0 h/day	✓
Oven		
Quantity	1 Units	✓
Capacity	1227,40 W	✓
Usage (hours/day)	1,0 h/day	✓
Clothes Washer		
Quantity	1 Units	✓
Capacity	376,44 W	✓
Usage (hours/day)	0,5 h/day	✓
Clothes Dryer		
Quantity	1 Units	✓
Capacity	1342,33 W	✓
Usage (hours/day)	2,0 h/day	✓
Dishwasher		
Quantity	1 Units	✓
Capacity	467,67 W	✓
Usage (hours/day)	1,0 h/day	✓
SMALL APPLIANCES		
Number of small appliances	1 Units	✓
Average capacity	997,21 W	✓
Average usage (hours/day)	5,0 h/day	✓

Start Building Simulation

CITY OF savannah

ECONOMICAL FRAME CONDITIONS

PARAMETER FOR ECONOMICS CALCULATION

Nominal Interest Rate	3,40 %/a	✔
Real Interest Rate	1,40 %/a	✔
Residential Electricity Price	0,119 $/kWh	✔
Residential Natural-Gas Price	0,036 $/kWh	✔
Electricity Price - Growth Rate	2,20 %/a	✔
Natural-Gas Price - Growth Rate	3,40 %/a	✔
Effort on servicing (%-Investmentcosts/a)	1,00 %/a	✔
Effort on repairs (%-Investmentcosts/a)	2,00 %/a	✔
Maintenance costs - Price Change Rate	1,97 %/a	✔
Capital-related costs - Price Change Rate	1,97 %/a	✔

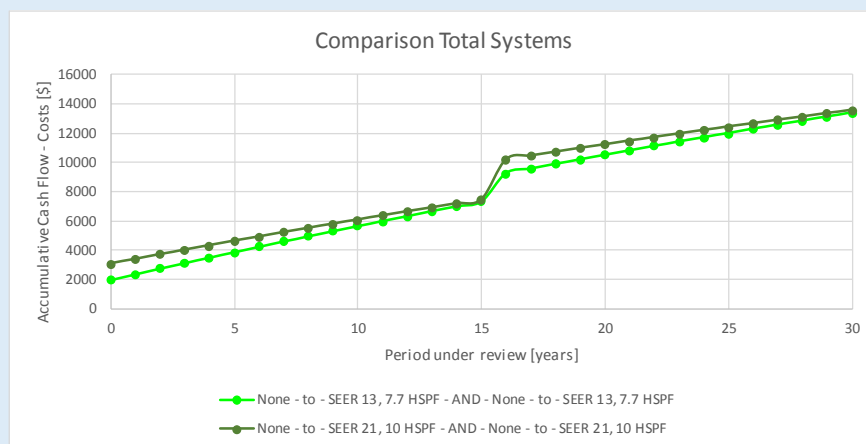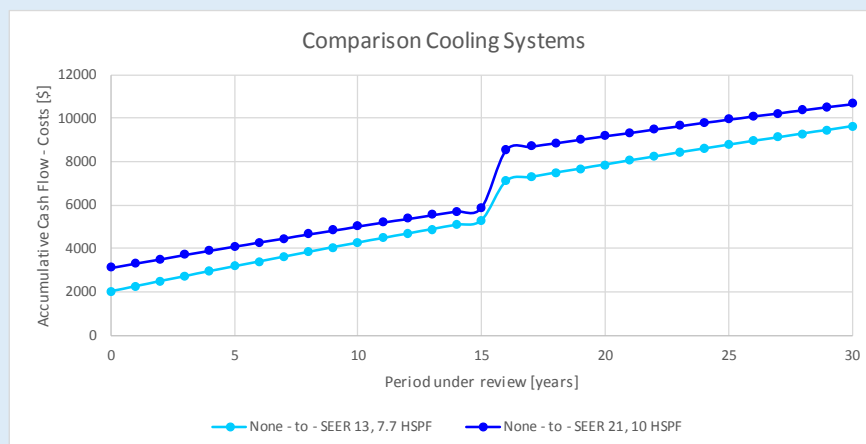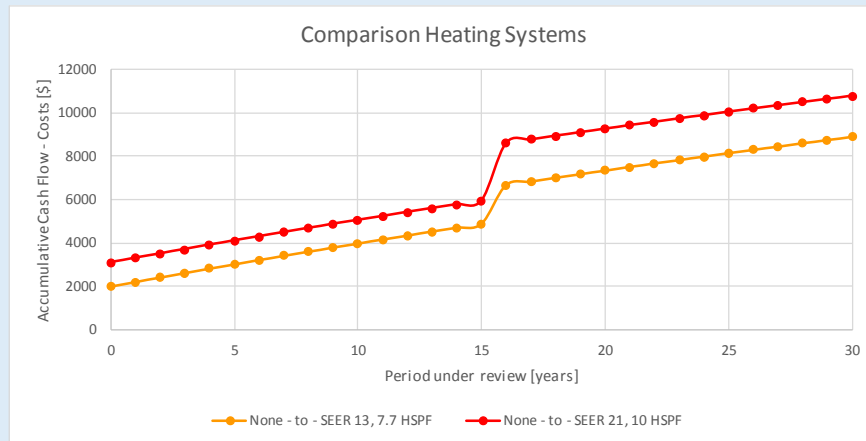*After "ECONOMICAL FRAME CONDITIONS" were changed, also system-combination-data in RESULTS must be stored new!*

14.4   EXAMPLE – "RESULTS" SHEET

Cost - Benefit Analysis Tool - RESULTS

MAIN SIMULATION RESULTS

SIMULATION RESULTS FOR GIVEN BUILDING INPUT

Calculated Hours	8760 *h*
Nominal heating power	12000 *Btu/h*
Nominal cooling power	12000 *Btu/h*
Heating hours	817.5 *h/a*
Cooling hours	1636.5 *h/a*
Provided heating energy	9809.60 *kBut/a*
Provided heating energy [kWh]	2874.21 *kWh/a*
Provided cooling energy	19637.80 *kBut/a*
Provided cooling energy [kWh]	5753.88 *kWh/a*
Provided heating energy + Duct Losses	9809.60 *kBut/a*
Provided heating energy [kWh] + Duct Losses	2874.21 *kWh/a*
Provided cooling energy + Duct Losses	19637.80 *kBut/a*
Provided cooling energy [kWh] + Duct Losses	5753.88 *kWh/a*
Hours above the upper limit	0.0 *h/a*
Hours below the lower limit	0.0 *h/a*
Energy Savings for Heating	1893.25 *kWh/a*
Energy Savings for Cooling	1519.59 *kWh/a*
CO_2-Emission Savings for Heating	2010.63 *lbs CO_2/a*
CO_2-Emission Savings for Cooling	1613.81 *lbs CO_2/a*

14 Appendix

MAIN ECONOMICS RESULTS

CHOOSEN SYSTEM COMBINATION

Furnace (Remove, OLD)	*Electric, 100% AFUE*
Air Source Heat Pump (Remove, NEW)	*SEER 21, 10 HSPF*
Central Air Conditioner (Remove, OLD)	*SEER 8*
Air Source Heat Pump (Remove, NEW)	*SEER 21, 10 HSPF*

Store as "SYSTEM - COMBINATION 1"   Store as "SYSTEM - COMBINATION 2"

RESULTS FOR CHOOSEN SYSTEM COMBINATION

Investment Costs for Heating System	3330.00	*$*
Investment Costs for Cooling System	3540.00	*$*
Investment Costs for Total System	3770.00	*$*
Energy Consumption of Heating System	980.96	*kWh/a*
Energy Consumption of Cooling System	935.13	*kWh/a*
Energy Consumption of Total System	1916.09	*kWh/a*
Energy Cost-Savings for Heating	225.30	*$/a*
Energy Cost-Savings for Cooling	180.83	*$/a*
Total Energy Cost-Savings	406.13	*$/a*
Annuity - Heating System calculated for 30 years	-593.18	*$/a*
Annuity - Cooling System calculated for 30 years	-613.65	*$/a*
Annuity - Total System calculated for 30 years	-798.28	*$/a*
Simple Payback Time - Heating	14.8	*years*
Simple Payback Time - Cooling	19.6	*years*
Simple Payback Time - Total System	9.3	*years*

14 Appendix

| Delete "SYSTEM - COMBINATION 1" | Delete "SYSTEM - COMBINATION 2" |

SYSTEM - COMBINATION 1

Air Source Heat Pump (Replace, OLD)	None	
	SEER 13, 7.7 HSPF	
Air Source Heat Pump (Replace, OLD)	None	
	SEER 13, 7.7 HSPF	
Investment Costs for Heating System	2008.00 $	
Investment Costs for Cooling System	2008.00 $	
Investment Costs for Total System	2008.00 $	
Energy Consumption of Heating System	1273.97 kWh/a	
Energy Consumption of Cooling System	1510.60 kWh/a	
Energy Consumption of Total System	2784.57 kWh/a	
Energy Cost-Savings for Heating	None	$/a
Energy Cost-Savings for Cooling	None	$/a
Total Energy Cost-Savings	None	$/a
Annuity - Heating System calculated for 30 years	-465.0 $/a	
Annuity - Cooling System calculated for 30 years	-502.3 $/a	
Annuity - Total System calculated for 30 years	-702.7 $/a	
Simple Payback Time - Heating	None	years
Simple Payback Time - Cooling	None	years
Simple Payback Time - Total System	None	years

SYSTEM - COMBINATION 2

Air Source Heat Pump (Replace, OLD)	None	
	SEER 21, 10 HSPF	
Air Source Heat Pump (Replace, OLD)	None	
	SEER 21, 10 HSPF	
Investment Costs for Heating System	3100.00 $	
Investment Costs for Cooling System	3100.00 $	
Investment Costs for Total System	3100.00 $	
Energy Consumption of Heating System	980.96 kWh/a	
Energy Consumption of Cooling System	935.13 kWh/a	
Energy Consumption of Total System	1916.09 kWh/a	
Energy Cost-Savings for Heating	None	$/a
Energy Cost-Savings for Cooling	None	$/a
Total Energy Cost-Savings	None	$/a
Annuity - Heating System calculated for 30 years	-562.9 $/a	
Annuity - Cooling System calculated for 30 years	-555.7 $/a	
Annuity - Total System calculated for 30 years	-710.0 $/a	
Simple Payback Time - Heating	None	years
Simple Payback Time - Cooling	None	years
Simple Payback Time - Total System	None	years

Comparison Heating Systems

Comparison Cooling Systems

Comparison Total Systems

14.5 BUILDING PLAN – "12 GREENCOTTAGE WAY"

SITE PLAN
12 Greencottage Way
Lot 213
1" = 10'

FRONT ELEVATION PLAN 0.28.2W-1ST-0705D-1172SF
3/16" = 1'-0"

LEFT SIDE ELEVATION PLAN 0.28.2W-1ST-0705D-1228SF-A
PORCH COLUMN OPTIONS: CCCC, CCEC
3/16" = 1'-0"

ROOF C

ROOF E

ROOF F

ROOF B

ROOF D

ROOF A

NOTE: Whether Noted On Plans Or Not, All Work
To Be Performed In Accordance With Locally
Adopted Building Codes.

Finish Grade.

Stucco Applied Over Concrete
Block with Smooth Finish.
Color Selected By Housing
Department.

RIGHT SIDE ELEVATION PLAN 0.28,0W-1ST-0705D-1172SF
PORCH COLUMN OPTIONS: CCCC, CCEC
3/16" = 1'-0"

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NOTE: Whether Noted On Plans Or Not, All Work
To Be Performed In Accordance With Locally
Adopted Building Codes. Materials And Products
Must Be Installed Following Manufacturer's
Technical Specifications And Instructions.

Exterior Dusk to Dawn
Motion Sensor Floodlight

Finish grade

REAR ELEVATION PLAN 0.28,2W-1ST-0705D-1172SF
3/16" = 1'-0"

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FOUNDATION PLAN 0.28.2W-1S-0705D-1172SF
3/16" = 1'-0"

FLOOR PLAN 0.28.2W-1S-0705D-1172SF
3/16" = 1'-0"

MECHANICAL PLAN 0.28.2W-IS-0705D-1172SF
3/16" = 1'-0"

Wall Cabinets

1 - 3012 Above Range
1 - 3318 Above Refrigerator
1 - 1230
1 - 2430 Diagonal Corner
2 - 3030

Base Cabinets

1 - 9" Base With Drawer
1 - 21" Base With Drawer
1 - 30" Base With Drawer
1 - 36" Sink Base
1 - 48" Blind Corner With Drawer

NOTE: Field Verify Cabinets Sizes
Prior To Ordering.
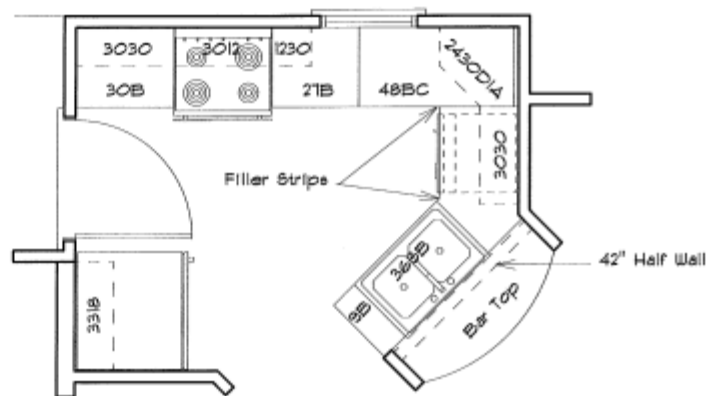
KITCHEN CABINET PLAN 0.28.2W-IS-0705D-1172SF
1/2" = 1'-0"

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CROSS SECTION DIAGRAM — A

Minimum 2"x6" Rafters 16" OC

2"x6" Bracing 16" OC

2"x6" Vaulted Ceiling Min 2"x6" 16" OC

2"x4" studs 16" OC with R-13 fiberglass batt insulation.

4" thick 3000PSI reinforced concrete slab and vapor barrier over compacted and treated fill.

Living

Dining

Open Display Shelf

Soffit

Open

Bar Top

1'-2"

1'-0"

3'-6"

12
7

5
12

Ceiling height

8'-0"

Floor Slab

Fill Dirt

26'-8"

Compacted Fill and Vapor Barrier

28'-0"

Greater of 12" below grade or frost line.

NOTE: Construct house in accordance with all locally adopted codes and manufacturer specifications regardless if shown or not shown on plans.

Apply Open Cell Icynene insulation with ignition barrier between rafters per code and manufacturer requirements.

NOTE: Use gypsum manufacturer recommended materials and finishing techniques for vaulted ceilings depicted in plans.

Gypsum Finishing Note: Use appropriate type 1/2" gypsum on walls and ceilings with 3 coat, smooth, finish. Use Levelline tape with Durabond 90 bed mud, or approved equals, at all intersecting surface joints greater or less than 90 degrees.

NOTE: Locate water heater and HVAC air handler in Attic unless otherwise noted on plans. Attic floor to accomodate installation and servicing of mechanical equipment. It is not to be used for general storage unless permitted by Code.

NOTE: Insulate attic envelope using Open Cell Icynene insulation installed between rafters in accordance with code requirements and manufacturer installation instructions including those related to thickness and use of ignition barrier. Use R-13 unfaced fiberglass batt insulation at all perimeter walls in house and attic. Include vapor barrier if warranted by climatic conditions.

CROSS SECTION DIAGRAM — A
PLAN 0.28.2W-IS-0705D-1178SF
1/4" = 1'-0"

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CROSS SECTION DIAGRAM — B

Minimum 2"x6" Rafters 16" OC

2"x6" Bracing 16" OC

12'-3"

Knee Wall

3/4" T&G Platform for HVAC and WH Placement and Service. Not for storage.

Minimum 2"x8" Ceiling Joist 16" OC

Bedroom #1
10'-8"

Hallway
3'-6"

Laundry Closet
5'-7"

Vaulted Ceiling 2"x6" Min 16" OC

Kitchen
8'-9½"

Beam

2"x4" studs 16" OC with R-13 fiberglass batt insulation.

4" thick 3000PSI reinforced concrete slab and vapor barrier over compacted and treated fill.

12
7

5
12

Ceiling height

8'-0"

Floor Slab

Fill Dirt

9'-9¼" 1'-4" 1'-11" 2'-0" 4'-5" 1'-4" 7'-10¾"

Compacted Fill and Vapor Barrier

30'-0"

Greater of 12" below grade or frost line.

NOTE: Construct house in accordance with all locally adopted codes and manufacturer specifications regardless if shown or not shown on plans.

Apply Open Cell Icynene insulation with ignition barrier between rafters per code and manufacturer requirements.

NOTE: Use gypsum manufacturer recommended materials and finishing techniques for vaulted ceilings depicted in plans.

Gypsum Finishing Note: Use appropriate type 1/2" gypsum on walls and ceilings with 3 coat, smooth, finish. Use Levelline tape with Durabond 90 bed mud, or approved equals, at all intersecting surface joints greater or less than 90 degrees.

NOTE: Locate water heater and HVAC air handler in Attic unless otherwise noted on plans. Attic floor to accomodate installation and servicing of mechanical equipment. It is not to be used for general storage unless permitted by Code.

NOTE: Insulate attic envelope using Open Cell Icynene insulation installed between rafters in accordance with code requirements and manufacturer installation instructions including those related to thickness and use of ignition barrier. Use R-13 unfaced fiberglass batt insulation at all perimeter walls in house and attic. Include vapor barrier if warranted by climatic conditions.

CROSS SECTION DIAGRAM — B
PLAN 0.28.2W-IS-0705-1172SF
1/4" = 1'-0"

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NOTE: Construct house in accordance with all locally adopted codes and manufacturer specifications regardless if shown or not shown on plans.

Apply Open Cell Icynene insulation with ignition barrier between rafters per code and manufacturer requirements.

NOTE: Use gypsum manufacturer recommended materials and finishing techniques for vaulted ceilings depicted in plans.

Gypsum Finishing Note:
Use appropriate type 1/2" gypsum on walls and ceilings with 3 coat, smooth, finish. Use Levelline tape with Durabond 90 bed mud, or approved equals, at all intersecting surface joints greater or less than 90 degrees.

NOTE: Locate water heater and HVAC air handler in Attic unless otherwise noted on plans. Attic floor to accomodate installation and servicing of mechanical equipment. It is not to be used for general storage unless permitted by Code.

NOTE: Insulate attic envelope using Open Cell Icynene insulation installed between rafters in accordance with code requirements and manufacturer installation instructions including those related to thickness and use of ignition barrier. Use R-13 unfaced fiberglass batt insulation at all perimeter walls in house and attic. Include vapor barrier if warranted by climatic conditions.

Minimum 2"x6" Rafters 16" OC

12
7

2"x6" Bracing 16" OC

Minimum 2"x8" Ceiling Joist 16" OC

Ceiling height

Bedroom #2
10'-1½"

Master Bedroom
13'-0"

8'-0"

4" thick 3000PSI reinforced concrete slab and vapor barrier over compacted and treated fill.

2"x4" studs 16" OC with R-13 fiberglass batt insulation.

Floor Slab

9'-2¾"   1'-4"   12'-1¼"

Fill Dirt

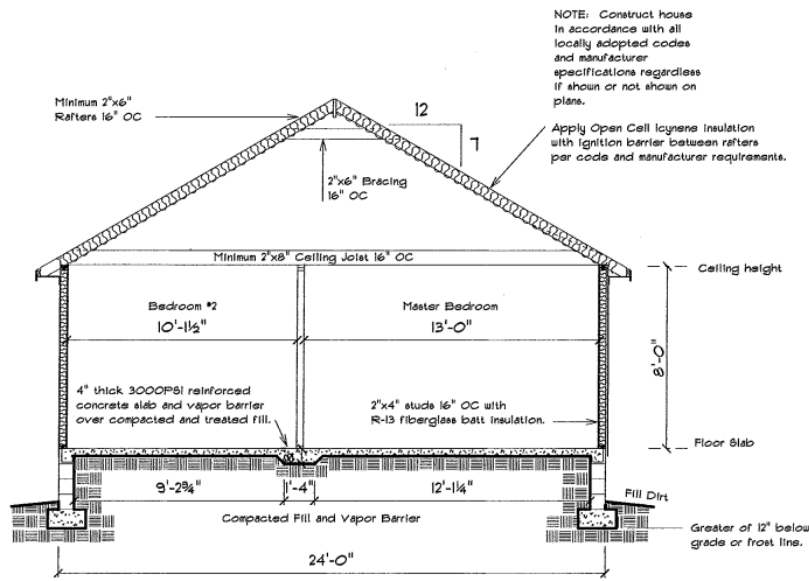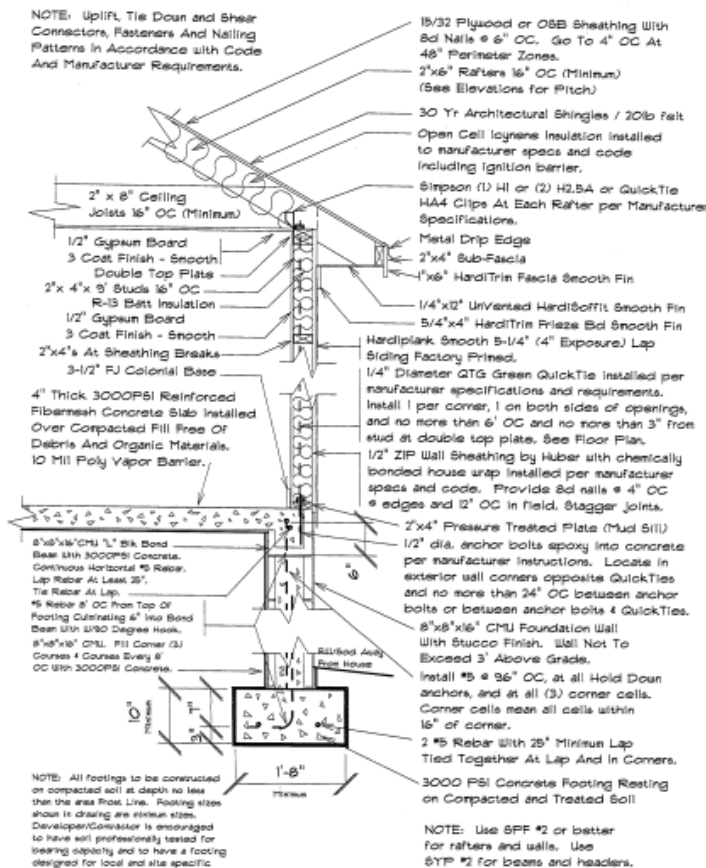Compacted Fill and Vapor Barrier

Greater of 12" below grade or frost line.

24'-0"

CROSS SECTION DIAGRAM   C
PLAN 0.28.2W-1S-0705D-1178SF
1/4" = 1'-0"

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NOTE: Uplift, Tie Down and Shear Connectors, Fasteners And Nailing Patterns In Accordance with Code And Manufacturer Requirements.

15/32 Plywood or OSB Sheathing With 8d Nails @ 6" OC. Go To 4" OC At 48" Perimeter Zones.

2"x6" Rafters 16" OC (Minimum) (See Elevations for Pitch)

30 Yr Architectural Shingles / 20lb felt

Open Cell Icynene Insulation installed to manufacturer specs and code including ignition barrier.

2" x 8" Ceiling Joists 16" OC (Minimum)

Simpson (1) HI or (2) H2.5A or QuickTie HA4 Clips At Each Rafter per Manufacturer Specifications.

1/2" Gypsum Board
3 Coat Finish - Smooth
Double Top Plates
2"x 4"x 9' Studs 16" OC.
R-13 Batt Insulation
1/2" Gypsum Board
3 Coat Finish - Smooth
2"x4"s At Sheathing Breaks
3-1/2" FJ Colonial Base

Metal Drip Edge
2"x4" Sub-Fascia
1"x6" HardiTrim Fascia Smooth Fin

1/4"x12" UnVented HardiSoffit Smooth Fin
5/4"x4" HardiTrim Frieze Bd Smooth Fin
Hardiplank Smooth 5-1/4" (4" Exposure) Lap Siding Factory Primed.

1/4" Diameter QTG Green QuickTie installed per manufacturer specifications and requirements. Install 1 per corner, 1 on both sides of openings, and no more than 6' OC and no more than 3" from stud at double top plate. See Floor Plan.

1/2" ZIP Wall Sheathing by Huber with chemically bonded house wrap installed per manufacturer specs and code. Provide 8d nails @ 4" OC @ edges and 12" OC in field. Stagger Joints.

4" Thick 3000PSI Reinforced Fibermesh Concrete Slab Installed Over Compacted Fill Free Of Debris And Organic Materials. 10 Mil Poly Vapor Barrier.

2"x4" Pressure Treated Plate (Mud Sill)
1/2" dia. anchor bolts epoxy into concrete per manufacturer instructions. Locate in exterior wall corners opposite QuickTies and no more than 24" OC between anchor bolts or between anchor bolts & QuickTies.

8"x8"x16"CMU "L" Blk Bond Beam With 3000PSI Concrete. Continuous Horizontal #5 Rebar. Lap Rebar At Least 25". Tie Rebar At Lap. #5 Rebar 8' OC From Top Of Footing Culminating 6" Into Bond Beam With U90 Degree Hook. 8"x8"x16" CMU. Fill Corner (3) Courses 4 Courses Every 8' OC With 3000PSI Concrete.

8"x8"x16" CMU Foundation Wall With Stucco Finish. Wall Not To Exceed 3' Above Grade.

Install #5 @ 96" OC, at all Hold Down anchors, and at all (3) corner cells. Corner cells mean all cells within 16" of corner.

2 #5 Rebar With 25" Minimum Lap Tied Together At Lap And In Corners.

3000 PSI Concrete Footing Resting on Compacted and Treated Soil

Fill Bed Above Frost Plane

10"

1'-8"

NOTE: All footings to be constructed on compacted soil at depth no less than the area Frost Line. Footing sizes shown in drawing are minimum sizes. Developer/Contractor is encouraged to have soil professionally tested for bearing capacity and to have a footing designed for local and site specific conditions.

NOTE: Construct wall in accordance with all locally adopted codes and manufacturer specifications regardless if shown or not shown on plans. Recommend that wall details be reviewed by local structural engineer familiar with local construction codes, requirements, and conditions.

NOTE: Use SPF #2 or better for rafters and walls. Use SYP #2 for beams and headers.

Typical Wall Section
Concrete Slab Floor & Rafters
1" = 1'-0"
Revised 7-31-14