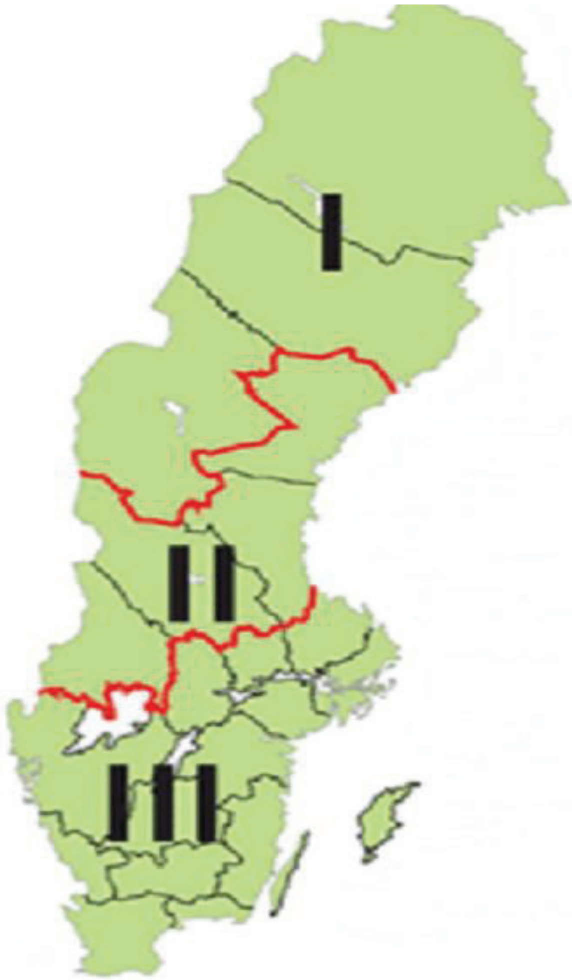

The three climate zones in Sweden as defined by Boverket's building regulations 2012.

Bottom-up description of the Swedish non-residential building stock

Archetype buildings and energy demand

Master of Science Thesis

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover:The three climate zones into which Sweden is divided as defined by Boverket in its building regulations, BBR 19. (Isover, 2012)

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Abstract

In Europe, the building stock occupies a large share of the energy consumed compared to other prevailing sectors. It is of great importance to monitor the energy patterns and trends within the building stocks, as well as it is of great interest to the European Union to intelligently manage the energy demand should the energy and climate targets set by the European Commission be met. A closer monitoring of the European building stocks is required if the retrofitting of existing buildings should give positive outcomes in terms of a decreased energy demand and to allow energy efficiency measures to be taken. The information regarding the building stocks in Europe, especially the non-residential ones, is limited and therefore it is an area in need of investigation, and this master thesis attempts to address this field.

This master thesis is a part of a larger project, which aims at modeling the building stocks in the European countries with the largest building stocks. A methodology is used to model the energy demand of the Swedish non-residential building stock. The same methodology has been applied to the building stocks of Germany, France and Spain as well as to the residential building stock in Sweden. The methodology follows a bottom-up approach in which the Swedish non-residential stock is described by using archetype buildings. The archetype buildings are characterized by numerous parameters and are quantified. These buildings, together with their characterization and quantification, are used as input parameters in the simulation model – Energy, Carbon and Cost Assessment for Building Stocks (ECCABS).

The Swedish non-residential building stock amounted to 336 archetype buildings consisting of 14 building types, 8 periods of construction and 3 climate zones. The results obtained with the ECCABS model for the final energy demand in the non-residential building stock was 41.09 TWh/yr compared to 33.7 TWh/yr presented by the Swedish Energy Agency and 46.64 TWh/yr presented in ODYSSEE's database. The final energy demand modeled by the simulation process was 21.9 % higher than the Swedish Energy Agency's statistics and 11.9 % lower than the statistics presented by ODYSSEE. Possible reasons for this deviation are discussed in this report.

Keywords: Swedish non-residential, building stock, energy demand, archetype buildings, bottom-up description

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Abbreviations

ADEME	Agence de l'Environnement et de la Maîtrise de l'Energie (French Environmental and Energy Management Agency)
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BBR	Boverket's Building Regulations
BETSI	The Building's Energy, Technical Status and Indoor environment, a study conducted by Boverket
CAV	Constant Air Volume
DHS	District heating system
ECCABS	Energy, Carbon and Cost Assessment of Building Stocks
ESA	European Standard Accounts
FTX	Mechanical ventilation system of exhaust and supply air with heat recovery
GAINS	Greenhouse gas and Air pollution Interactions and Synergies
IEE	Intelligent Energy Europe
ODYSSEE	Energy efficiency database in Europe
OECD	Organisation for Economic Co-operation and Development
PCB	Polychlorinated biphenyl
SBN	Svensk Bygg Norm (Swedish building standards) by Statens Planverk (contemporary Boverket)
SCB	Statistiska Centralbyrån (Sweden Statistics)
SFP	Specific Fan Power
SNA	System of National Accounts
STEM	Statens Energimyndighet (Swedish Energy Agency)
STIL2	"Förbättrad statistik i lokaler" (Improved statistics in non-residential premises), a series of studies conducted by the Swedish Energy Agency
VAV	Variable Air Volume

1. Introduction

1.1 Background

Our modern society is founded upon the need for energy and is incredibly dependent on receiving a steady supply of energy in its various forms. The diversity of sectors maintained with energy ranges from the transport sector to the agricultural sector, with the building sector being no exception in its dependence on energy. For instance, in the European Union, the building sector is responsible for 40 % of the energy consumption and is guilty of emitting 36 % of the CO_2 emissions. (Borghi, 2012)

In figure 1, the shares of the final energy consumption by the different sectors within the EU are shown in order to place the building sector's energy consumption in perspective. From this overview one can see that the building sector (households together with the tertiary sector) holds the largest share. As the building sector contributes significantly to the consumption of final energy, it impacts the use of resources and climate change substantially. Therefore, this sector is a central focus point for energy efficiency improvements in order to minimise its energy use and environmental impacts.

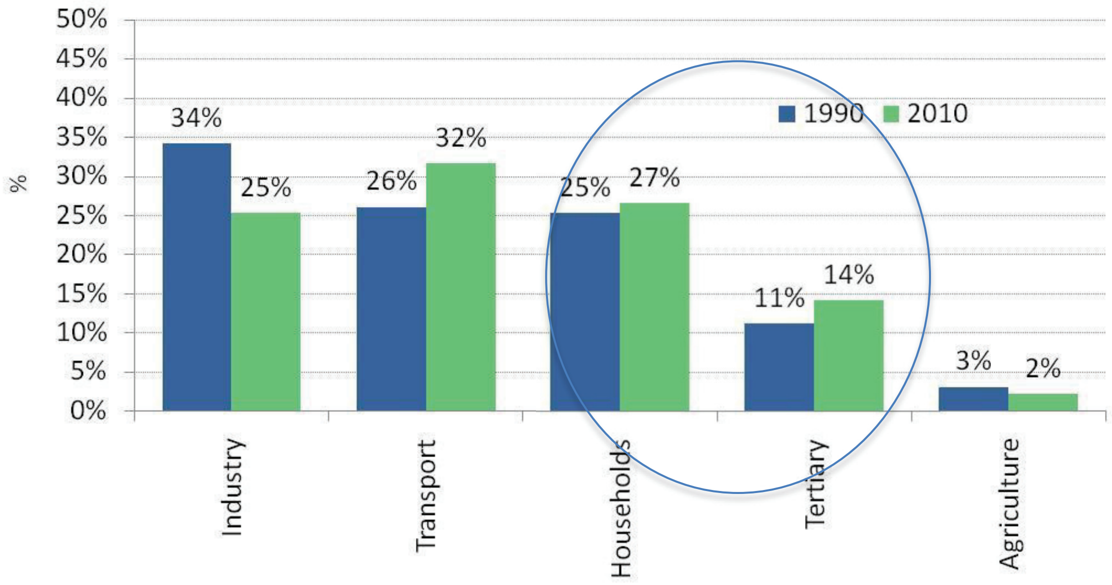


Figure 1. The final energy consumption by sector in percent in the EU in 1990 and 2010 Source: ODYSSEE-MURE, 2012

Under the European Union's growth strategy (Europe 2020), so-called *20-20-20 targets* have been set concerning the climate and energy consumption in the EU. These targets aim at achieving a 20 % reduction in greenhouse gas emissions, a 20 % share of renewable energy forms and an increased efficiency of 20 % by the year 2020. (European Commission, 2012) Moreover, the building sector is subject to several policies and regulations in order to increase the energy efficiency of the sector, one of these being the EU directive on the energy performance of buildings. In this directive, the need for adopting a methodology for calculating the energy demand associated with the typical uses of buildings is included and the directive aims at monitoring the building sector's energy use more rigorously. (EUR-Lex, 2010). This project highlights the importance of finding ways to measure energy consumption in the building sector.

Pathways to Sustainable European Energy Systems is an on-going project within the EU of which this master thesis is a part. The Pathways project focuses on the energy system of heat and power in Europe and aims to suggest and evaluate different pathways for the present energy system to meet a sustainable future. It includes examining the energy demand for 2050 in the EU 27 building stock by modelling the building stock's efficiency of energy end-uses in three different scenarios. In the project, European member states with the largest building stocks, representing 70 % of the energy use in the building sector, will be studied. So far, the building stocks of Spain, France, Germany, Sweden and the UK have been characterized. Both the residential and non-residential building stocks have been described for some countries, while other building stocks have been described by either one or the other.

This master thesis will contribute to the *Pathways* project by describing the Swedish non-residential building stock and validating the bottom-up modelling used in this project, the ECCABS model, against the Swedish non-residential building stock.

1.2 Aim of the thesis

The aim of this master thesis is to apply a derived methodology for characterising a building stock to the non-residential building stock in Sweden. Furthermore, the thesis work will serve as a basis for testing the suitability of the building energy simulation model – Energy, Carbon and Cost Assessment of Building Stocks (ECCABS) – to the non-residential building stock in Sweden.

The non-residential building stock in this case is meant to include a certain number of archetype buildings that are identified in the segmentation section in the methodology used. The archetype buildings do not include industrial nor agricultural buildings.

1.3 Structure

The master thesis' structure is such that it begins with a description of the major sources consulted throughout the work and which have been indispensable to the gathering of information on the non-residential building stock. Defining the Swedish non-residential building stock has been an important next step in this thesis in order to comprehend and include its complexity, as well as to clearly identify and state the system boundaries of the study.

These first sections are followed by a brief summary of how other EU countries have described their non-residential building stock and the applied typologies. Following this summary, the methodology of how the Swedish non-residential building sector has been described along with a description of the ECCABS model, with which the non-residential building sector's energy demand has been anticipated.

A presentation of the results obtained from the application of the ECCABS model follows the methodology. Finally, the report ends with the conclusions that can be drawn as well as a discussion of the results. Points for future work have also been mentioned.

2. Data sources

Throughout this master thesis a number of sources have been consulted, both national and international. National sources have given information on specific requirements for non-residential premises of the Swedish building stock as well as statistical data, on-going projects within the country and regulations concerning and forming the building stock. International sources have also been used within this work to give a broader perspective on the topic that is dealt with. They have given a view of the work being done outside of the Swedish boundaries, especially in the EU. These sources have been in the form of databases and international statistics organisations and even the many legislative aspects and directives have provided information on where the rest of the world is headed with respect to a more energy-efficient society, nonetheless in the building sector.

2.1 International Sources

International sources have been mainly in the form of databases on energy efficiency data such as ODYSSEE and GAINS in order to compare the values obtained from the simulation process as well as providing definitions for a non-residential building.

- ODYSSEE – *Energy Efficiency Database for Europe*
  The ODYSSEE database contains data on the end-use energy consumption by different themes as well as different energy efficiency and CO_2 related indicators. It is a project under the name of ODYSSEE-MURE that is coordinated by the energy network, ADEME, and supported by the Intelligent Energy Europe Programme of the European Commission. Data on energy efficiency and indicators are gathered from the 27 EU member states as well as from Norway and Croatia. The purpose of the project is to monitor the energy efficiency trends and policy measures in Europe. (ODYSSEE, 2012)

- GAINS – *Greenhouse Gas and Air Pollution Interactions and Synergies*
  GAINS is a model that estimates emissions, the potential for mitigation and costs for the major air pollutants and greenhouse gases. The model is used to assist in policy negotiations and to improve the overall air quality. (GAINS, 2012)

- Eurostat
  Eurostat is the European statistical office. It provides statistics on different statistical themes in the 27 EU countries with the aim of enabling comparisons between the member countries and regions. (Eurostat, 2012)

2.2 National Sources

The following national sources have been indispensable along the whole process of this master thesis:

- The Swedish National Board of Housing, Building and Planning (*Boverket*)
  Boverket has provided essential data not only concerning the regulations and guidelines for already existing buildings, the construction of new buildings and renovations of old buildings, but also in the many projects and reports performed and published.

    - The project BETSI has been an important source when obtaining information on the technical status of the building stock. The BETSI project was conducted on behalf of the Swedish government in order to monitor the energy status of the total building stock and to improve the overall energy efficiency.
    - Boverket's building regulations (BBR) have also provided information on different requirements concerning the rational use of energy in buildings.
    - Another project that has been of interest and essential to the collection of data has been the STIL2 project. In this project, different types of non-residential buildings have been inventoried with respect to their energy demand during a period of years. It started in 2005 with the investigation of energy use in offices and continued with one new building category for each in following year. The aim of this project is to improve the national energy statistics and the monitoring of the non-residential building stock in Sweden.

- Sweden Statistics (*Statistiska Centralbyrån*, SCB)
  Sweden Statistics have worked in collaboration with the Swedish Energy Agency (STEM) in the quest of mapping the energy use in the building stock, both in the residential and non-residential fields. Together with STEM, statistics on the energy use in the building stock have been presented on an annual basis improving the coverage of the energy status.

- The Swedish Energy Agency (*Energimyndigheten*, STEM)
  As mentioned before, statistics on the building stock's energy status has been monitored by the Swedish Energy Agency in association with Sweden Statistics. STEM has published a series of reports under the collective name of STIL2 in which inventories of the energy use in various non-residential premises have been done. The STIL2 series started in 2005 with an inventory of offices which continued with one new inventory each year up until the year 2010; these inventories treated schools, healthcare premises, sport centres, commercial premises and hotels and restaurants. Also, annual statistics concerning the energy use in the building stock has been monitored and collected annually since 1977, which has been of great help in collecting crucial data concerning the non-residential building stock in Sweden.

3. The non-residential building stock in literature

The total building stock of a country comprises of both the residential and the non-residential buildings. The non-residential building stock varies significantly to the residential building stock in several ways. The most obvious is that residential buildings have a common purpose of accommodating its residents, while the other part of the building stock may have numerable different purposes apart from dwelling that may vary greatly in nature.

The non-residential building stock has several different types of buildings that in turn may vary a great deal within the specific building types. Throughout the work, it has also been noticed that the residential building stock is much more rigorously investigated and monitored compared to the non-residential building stock. Accurate statistical data is collected from year to year as well as numerous reports being conducted on the residential side. Nonetheless, there exists information and data on the non-residential building stock, however modest in comparison. Compiling records and data on this part of the building stock is a work in progress and is important in improving the overall energy performance of buildings within the EU.

When investigating the energy efficiency potential of the non-residential building stock, defining it becomes a fundamental first step in the process. Included in the definition of a non-residential building should be the availability and the practicability of the statistical data.

3.1 Definitions of a non-residential building

Defining a non-residential building is an essential step in the study in order to give a clear understanding on what type of buildings to include in the study and which data should be collected. Existing definitions of the term “non-residential” vary slightly depending on the sources chosen. In the following text, some of these definitions are presented and an attempt at most suitably defining “non-residential”, given these definitions and from statistical data, is made.

3.1.1 Definitions from international sources

The definitions of non-residential buildings stated from four international statistical organisations – United Nations, European Standard Accounts (ESA), System of National Accounts (SNA) and Eurostat - have been looked upon. Also, definitions stated by the two databases Odyssee and GAINS have also been included in the search of an international definition.

The ESA definition of non-residential buildings is stated as follows:

- “Non-residential buildings consist of buildings other than dwellings, including fixtures, facilities and equipment that are integral parts of the structures and costs of site clearance and preparation. Historic monuments identified primarily as non-residential buildings are also included. Examples include warehouse and industrial buildings, commercial buildings, buildings for public entertainment, hotels, restaurants, educational buildings, health buildings, etc." (ESA, 1995)

The definition used by the SNA is almost identical to the first part of the definition used by ESA. Non-residential buildings are defined as the buildings, excluding dwellings that include

- "Fixtures, facilities and equipment that are integral parts of the structures and costs of site clearance and preparation." (United Nations Statistics Division, 2012)

However, these two definitions are rather difficult to comprehend. The ESA definition simplifies one's understanding of the definition slightly by providing examples of the type of buildings that are included in the definition. The SNA definition, on the other hand, is vague. Also, there is an uncertainty as to the types of buildings that are meant to be included by words such as fixtures, facilities and structures.

The Eurostat definition is as follows:

- "Non-residential buildings are constructions which are mainly used or intended for non-residential purposes. If at least half of the overall useful floor area is used for residential purposes, the building is classified as a residential building." (Eurostat, 1997)

The useful floor area does not include construction areas, ancillary areas (areas used for heating and cooling installations or power generators) or passageways such as stairwells, lifts etc.

The UN has defined non-residential buildings similarly to how Eurostat defines the term. The UN definition is as follows:

- "A building is regarded as a non-residential building when the minor part of the building (i.e. less than half of its gross floor area) is used for dwelling purposes." Non-residential buildings comprise industrial, commercial, educational, health and other buildings. (OECD, 2001)

The differences between the four definitions may perhaps depend on the purpose of the statistics in which they are to be applied and therefore are adjusted accordingly. The definitions stated by ESA and SNA are phrased almost identically. This may be due to the fact that both definitions describe statistics within the same category of national accounts. The UN and Eurostat have similar definitions as well because they both correspond to the statistical category of industry and services. Both these definitions concentrate on the share of the floor area used for non-residential purposes. The major difference in the four definitions is how specific they are in stating how many categories the non-residential buildings are divided into. In ESA's definition, the categories are more specific whereas in the UN's definition, the categories are more general and less specified such as the 'other'-category. In the Eurostat and SNA definitions, examples of building categories are not even mentioned.

The definition used by the ODYSSEE database is more focussed on the type of sector with which the buildings are associated, in this case the service sector.

- “Compared to residential buildings, non-residential buildings are more heterogeneous and refer here to the buildings in the service or tertiary sector. They are usually classified by type and by branch of activity according to the following categories: offices (private and public offices), health sector, education, hotels and restaurants, wholesale and retail trade and other types of buildings.” (Lapillone et al., n.d.)

The indicators used by the ODYSSEE database in the calculations of energy demand do not incorporate this non-specified category, called “others”, as the application of data to this category is considered too uncertain. The non-specified category can include activities that are not included elsewhere, for example small and medium-sized enterprises or military uses. (Lapillone et al., n.d.) The service or tertiary sector that is mentioned in the ODYSSEE definition above is in turn defined to comprise of; hotels and catering, health and education services, wholesale and retail trade, offices and public administration. (DECC, 2012)

To summarize the previously mentioned definitions into a single one, an international definition of a non-residential building can be formulated for use in this report when considering data from international sources. Such a definition is stated as being a building where more than half of the gross floor area is used for public or non-residential purposes other than dwelling.

3.1.2 Definitions from national sources

In order to obtain a better understanding of which type of buildings are included in the non-residential building stock in Sweden, the definition used by the Swedish statistical organisation need to be investigated, keeping the definitions of the international organisations in mind. Unlike the international statistics organisations, the national statistics organisations did not have an official definition of non-residential buildings listed in a glossary. The definitions were rather found in various reports, giving a more specific definition of the term according to the aim of the report.

In two reports by Göransson (2005) and Dalenbäck et al. (2005), the term “lokalbyggnad” annotates a non-residential building. In these reports, the following definition for a non-residential building is used:

- Buildings used for commercial and public purposes such as offices, stores, hotels, health and educational facilities, cultural and sport centres, etc. that have a larger non-residential area than the gross floor area used for residential purposes. Industrial buildings are not included. (Göransson, 2005)

A so-called “non-residential building” may have several different non-residential purposes within the building, for instance an office building may also contain some stores or dwellings, but different criteria in the definition of a non-residential building have been set up in order to facilitate classification. For instance, a certain percentage of the floor area of the non-residential building must consist of offices if the building has different types of non-residential premises in order to be classified as an office building. (Göransson, 2005)

In the report published by the Swedish Energy Agency (Statens Energimyndighet, STEM) *Föredömliga offentliga byggnader* (Exemplary public buildings), the aim is to investigate the measures that ensure that public buildings set examples for the use of renewable energy sources. The non-residential buildings are defined as

- Those buildings that are principally used for public purposes and activities. It further classifies the public buildings, referred to as "lokaler", according to the nature of the buildings' ownership, i.e. whether the building is owned by the state or is privately owned.

This criterion is not included in the definitions stated in the reports by Göransson (2005) and Dalenbäck et al. (2005) mentioned before but it is relevant in that report as it helps in proving the report's aim. Including the type of ownerships in the different non-residential buildings gives information on the possibilities for the buildings to fulfil the EU-directives on energy use, i.e. buildings that are owned by the state have stronger means to implement renewable energy sources in their usage than privately-owned buildings.

The descriptive report, *Energy statistics for non-residential premises 2010 - Description of the Statistics*, has played the most decisive role in choosing a suitable definition for the Swedish non-residential buildings in this work. In these statistical investigations, the non-residential buildings comprise the buildings having principally non-residential purposes and are classified as "lokaler" (non-residential premises) according to their building type codes. Further delimitations have been that the buildings should have a non-residential area of at least 200 m^2 and should be heated to a minimum of 10°C during 90 days. (STEM, 2011a) Industrial and agricultural buildings are not included. The non-residential building stock in this master thesis is subsequently equivalent to these non-residential premises due to the availability of data and statistics concerning this part of the building stock.

In order to obtain a clear overview of the different definitions and what type of buildings are included therein, lists of the building subtypes are given in table 3.1. For the following work, a definition of the non-residential buildings is established as being the buildings that are used for commercial and public purposes, where the non-residential area comprises a greater share than the gross floor area of the building. Examples of buildings that are included in this definition are buildings used for education, culture, sport activities, commerce, hotels, restaurants, health buildings etc.

Table 3.1. The type of buildings included in the definitions given by the different sources mentioned

SOURCES	ESA (1995)	OECD (2001)	ODYSSEE	THIS WORK
SUB-TYPES	Warehouses and industrial	Industrial	-	-
	Commercial	Commercial	Commercial	Commercial
	Educational	Educational	Educational	Educational
	Health	Health	Health	Health
	Hotels	-	Hotels	Hotels
	Restaurants	-	Restaurants	Restaurants
	Entertainment	-	Offices (private and public)	Cultural/Entertain-ment
		Other	Other	Other
				Sport centres
				Religion
				Garages
				Offices/ Administrative
				Dwellings

3.2 Examples of some European building stock typologies

The complexity of establishing a typology similar to the one that exists for residential buildings is acknowledged and perhaps is one of the reasons for the lack of information on the non-residential building sector. Work has commenced in order to deal with this issue in the form of a project supported by Intelligent Energy Europe (IEE), which goes by the name of TABULA. The TABULA project focuses on creating a unified typology for the residential building stock in Europe so that each national typology will consist of a set of representative buildings together with their energy performance properties. (TABULA, 2012) Even though the project has its main focus on residential buildings, it extends beyond this and has begun looking at a typology for non-residential buildings in four of its partner countries - Austria, Germany, Greece and Poland.

The different typologies for the non-residential building stocks used in the four countries are displayed in table 3.2.

Austria

The national statistics organization in Austria does not provide enough information on non-residential buildings; however two databases concerned with energy performance certificates (EPC) do contain such data sets. The available building types in these databases are operational buildings (factories/services buildings), conditioned non-residential buildings, schools, trade buildings, event centres, offices, hotels and hospitals. There exists also a database related to a project called Ecofacility that is a benchmarking database of the Austrian climate, which assists commercial building consultants in performing rough estimations of the buildings' energy efficiency. (Amtmann et al., 2012)

Germany

The building activity statistics collected by the Federal Statistical Office cover the demolitions, constructions and the status of different construction projects annually and have been doing so since 1993. Types of non-residential buildings are included in these statistics but not enough physical properties required for calculating energy demands are presented. Apart from these statistics, documents have been published dealing with the regulations for acquiring and using data as well as energy consumption values and benchmarks for non-residential buildings.

Four main parameters have been identified as important in the process of setting up a typology for the non-residential buildings – utilization, construction year, compactness/ size of the building and the technical building equipment. Through the different studies, building categories have been made according to the main purposes of the buildings in question. 11 categories have been identified together with 4 different construction year classes. The classes for the year of construction have been chosen by considering special architectural characteristics and building materials typical of the construction periods. (Amtmann et al. 2012)

Greece

The data found concerning the non-residential buildings in Greece were limited and the data originated from studies aimed at investigating the energy conservation measures and studies for aiding in the energy performance certification process.

The main categories of the non-residential buildings in Greece are formed according to their end uses such as offices/ commercial buildings, schools, hotels, hospitals and other non-residential buildings such as churches, factories, sports facilities, storage areas and parking buildings/ garages. A typology for the Greek non-residential building stock should be based on three parameters; building utilization, construction year period and climate.

The three construction year classes that have been selected are done so according to when the national Thermal Insulation Regulation was first implemented then adapted and finally fully implemented into the Greek building stock. The climate zones are defined on the basis of the number of heating days in each zone. (Amtmann et al. 2012)

Poland

The data from statistics and reports in Poland is very poor and limited. A very small share of the buildings, both residential and non-residential, has energy certificates and the information found on the energy performance of the buildings stems from energy audits performed for the Thermomodernisation Fund. Some data has also been collected throughout the participation in certain EU-projects.

The data found concerns mainly the building types of schools and hospitals, which have been chosen as a first draft typology for the non-residential buildings. Data on industrial buildings and offices have not been found. The construction year classes are divided into four such groups; pre 1945, 1946 – 1985, 1986 – 2000 and post 2000.

Heating systems have also been looked upon and included in an eventual typology and two systems – central DHS and local gas boilers – are used. (Amtmann et al. 2012)

Table 3.2. Segmentation criteria for the non-residential building stocks in Austria, Germany, Greece and Poland

Country	Criteria for segmentation			
	Period of Construction Years	Types of Buildings	Possible Supply Systems	Climate Zones
Austria	- 1918	Operational buildings	Oil	-
	1919-1979	Schools	Natural gas	
	1980-1999	Trade buildings	District heating	
	2000-2010			
Germany	- 1918	Public Facilities	-	-
	1919-1977	Education and Research		
	1978-2002	Schools		
	2003 -	Hotel, Accommodation		
		Public houses/ Restaurants		
		Events & Cultural buildings		
		Sport facilities		
		Retail & Services		
		Health Care		
		Transport infrastructure		
		Offices		
Greece	- 1980	Offices/ Commercial		A
	1981-2000	Hotels		B
	2001-2010	Hospitals		C
		Schools		D
Poland		Hospitals	Central DHS	
		Schools	Local gas boilers	

4. Methodology

The methodology adopted in this master thesis is the simulation of the non-residential building stock's energy demand using the ECCABS model. This is described in section 4.1. In order to provide a bottom-up description of the non-residential building sector, which is presented in section 4.2, a literature study was performed to collect information. A thorough research of the parameters necessary for the characterisation of the building stock was also conducted prior to simulation attempts.

4.1 The ECCABS Model

The model that is used to calculate the energy demand of the non-residential building stock is the ECCABS model (Energy, Carbon and Cost Assessment for Building Stocks). The model was developed in 2009 at the Division of Building Technology in cooperation with the Division of Energy Technology and the Department of Energy and Environment at Chalmers on behalf of the Swedish National Board of Housing, Building and Planning (Boverket) for their field study, the BETSI programme[1]. The ECCABS model is a bottom-up model in the form of a simulation program developed in the programming language MATLAB and requires a Simulink toolbox. It enables estimations of the effects of various efficiency measures to be done on entire building stocks. The building stock in question is required to be limited to a number of parameters and the buildings are therefore simplified to the basic features of their energy use. (Mata & Sasic Kalagasidis, 2009) The parameters that are included in the input files are given in table 4.1.The main purpose of the model is to calculate the energy demand required for the building stock according to these inputs. The energy savings due to the measures applied are plotted by comparison to the baseline energy demand.

Table 4.1 Inputs of the ECCABS model and the description of each input

NOTATION	DESCRIPTION	UNIT
A	Heated floor area	m^2
Ac	Average constant consumption of the appliances	W/m^2
HRec_Eff	Efficiency of the heat recovery system	%
Hw	Hot water demand	W/m^2
HyP	Consumption of the hydro pumps	W/m^2
Lc	Average constant lighting load in the building	W/m^2
Oc	Average constant gain due to people in the building	W/m^2
Pfh	Heat losses of the fan	W/m^2
Ph	Heating system's response capacity	
S	Total external surfaces of the building	m^2
SFP	Specific Fan Power	$W/l/m^2$
Sh	Maximum hourly capacity of the heating system	W
Sw	Total surface of the windows of the building	m^2
T0	Initial indoor temperature	°C

[1] The BETSI programme studied the status of the building stock with respect to the energy use, technology status, indoor air quality, damages and maintenance.

TC	Effective heat capacity of the building	J/K
Trmin	Minimum indoor temperature	°C
Ts	Coefficient of the window's solar transmission	%
Tv	Set point temperature for natural ventilation	°C
U	Building's mean U-value	W/m^2 °C
Vc	Sanitary ventilation rate	$l/s/m^2$
Vcn	Natural ventilation rate	$l/s/m^2$
Wc	Window's shading coefficient	%
Weight	Coefficient to scale up to the building stock	
Wf	Frame coefficient of the window	%

These input parameters are described in more detail in section 4.2.2 concerned with the characterisation of the non-residential building stock.

4.2 Bottom-up description of the building stock

A bottom-up method of processing the information collected was used in this report in order to describe the Swedish non-residential building stock. With a bottom-up description of a large system such as a country's building stock, original sub-systems are used to describe the grander system. The original, smaller sub-systems take the form of archetype buildings here in order to complete the picture of the grander non-residential building stock. The other type of method to tackle systems of complex character is a top-down method in which the grander system is decomposed into smaller sub-systems as opposed to a bottom-up model.

The bottom-up description of the non-residential building stock resulted in the segmentation of the non-residential building stock into different archetype buildings, which were then characterised according to different parameters and quantified by both number and heated area. These segmented, characterised and quantified archetype buildings served as input values to the ECCABS model. All of these steps are included in the methodology of how the work was carried out and are explained in more detail in the following sections.

4.2.1 Segmentation

The chosen segmentation type is a three-dimensional one based on the building type, period of construction and climate zone. The segmentation process simplifies the non-residential building stock somewhat and provides the basis for the boundaries of the smaller sub-systems that later will amount to the grander system of the non-residential building stock.

4.2.1.1 Building types

The reference buildings making up the archetypes of the non-residential building stock follow the same definition as those buildings stated and included in the energy statistics mentioned in section 2.2, National Sources. The building types that are included in this work are shown in 4.2 and amount to 14 categories.

Table 4.2. The building types included in the segmentation

Type of Building	Description
1. Dwellings	Apartment buildings where the majority of the area is used for non-residential purposes
2. Hotels, Boarding houses	-
3. Restaurants	-
4. Offices, Administrative	Private and public offices
5. Food commerce	Food trade, grocery stores
6. Other commercial buildings	Commerce, retail, shops
7. Healthcare 24/7	Hospitals, emergency units
8. Other healthcare centres	Healthcare centres with specific opening hours
9. Educational	Kindergarten to universities
10. Sport centres	Swimming halls, athletic centres, stadiums
11. Religious	Chapels, churches
12. Cultural	Theatres, concert halls, cinemas
13. Garages	Garages that are heated
14. Other	No information found as to what exactly is included therein

4.2.1.2 Periods of Construction

The period of construction is a variable that is important when considering the energy consumption in different buildings. Often, the buildings of a certain time periods are typical of that time and are characterized by similar building techniques influenced by contemporary building regulation codes and also by the choice of materials for facades, windows, roofs and other building features.

For example, buildings constructed up until 1940 have high ceilings with large windows but have less adequate climate envelopes. Between 1941-1960 and 1961-1970, the buildings have lower ceiling height than those constructed before 1940. These buildings are characterized by problematic indoor climates caused by moisture and mould as well as the use of, at the time, new and untested materials such as radon and PCBs. (Andersson et al., 2007)

The periods of construction in the segmentation of the non-residential building stock, seen in table 4.3, has been divided into 8 different classes spanning from before 1940 up until 2010. The last period labelled *data unavailable* is a period in which the buildings where the construction year is unknown are included.

Table 4.3. The 8 periods of construction considered in this work

	PERIODS OF CONSTRUCTION
1	- 1940
2	1941-1960
3	1961-1970
4	1971-1980
5	1981-1990
6	1991-2000
7	2001-
8	Data unavailable

The oil crises in the late 70s set their marks on the global economy making no exception to the Swedish building sector. A remarkable difference can be seen between the buildings constructed before and after 1980. (STEM, 2011b) This can be explained by the implementation of a building code, SBN 1980, which implied that the manner in which the construction of buildings was significantly altered. The alteration mainly focused upon regulating the isolation of the buildings. After the implementation of the SBN 1980 code, other codes have been introduced which did not exist in precedent building regulations. These newer codes regarded, for instance, the regulation of the maximum energy consumption of buildings when renovating old buildings or when constructing new ones. The implementation of these codes together with a growing concern for energy efficiency has led to the diminished energy consumption in the building stock that is seen in later years.

4.2.1.3 Climate zones

Sweden is Europe's fifth largest country with a total area of 449 964 km^2 and where 410 934 km^2 is covered by land. (NE, 2012) The length of Sweden dominates over its width that contributes to the characterization of the country's climate and the significant difference in climate between the northern and southern regions. The Swedish climate has been divided into three different zones by the Building Regulations (BBR) published by the Swedish National Board of Housing, Building and Planning (Boverket), which can be seen in figure 2. (Boverket, 2011) This division of Sweden into three climate zones has been done county-wise in order to set requirements on the buildings' energy use that are well adjusted to the temperature conditions that prevail in specific regions. Three climate zones have been considered sufficient to fulfil the minimum requirements.

Figure 2. The three climate zones according to BBR 19
Source: Rockwool, 2012

The first climate zone comprises three counties – Norrbotten, Västerbotten and Jämtland. The second zone refers to the counties of Västernorrland, Gävleborg, Dalarna and Värmland and the third climate zone includes the counties Västra Götaland, Kronoberg, Jönköping, Kalmar, Östergötland, Södermanland, Uppsala, Örebro, Stockholm, Västmanlands, Skåne, Halland, Blekinge and Gotland.

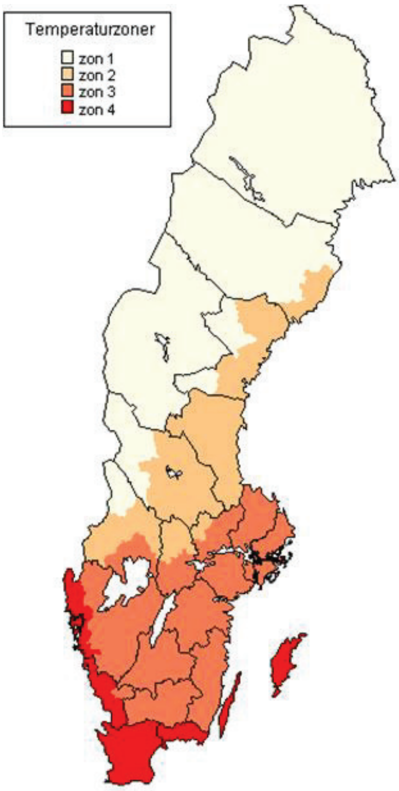


Figure 3. The four temperature zones of Sweden originally defined by Statens Planverk. Source: STEM, 2011a

Another division of the Swedish climate was made by Statens Planverk (present-day Boverket) in 1981. (Boverket, 2009a) In this division, Sweden is divided into four temperature zones and these zones follow the municipality boundaries instead of the county boundaries as in BBR's zone division. These four zones are based on the average annual temperature for the municipalities and were first presented in the purpose of setting standards for building isolation. These four temperature zones, displayed in figure 3, are used in the Swedish Energy Agency's annual reports about the energy use in the building stock and these zones are meant to homogenize the building stock with respect to certain factors of the building, such as its energy use.

In order for the segmentation of the non-residential building stock to be done as accurately as possible, the climate zones need to be properly defined with respect to the specific aim of this thesis. Deciding on which of the two different classifications of climate zones is most appropriate to use, one needs to consider the reasoning behind the two cases.

The climate zones that are defined in Boverket's building regulations (BBR 19) are aimed at setting up regulations for different properties of the buildings so as to provide a basis for comparing property values. Regulations describe what should be met in the building stock rather than what actually is in the real case. The other distribution of the climate zones is aimed more at attempting to provide a uniform view of how the different buildings are adapted to the prevailing temperatures in the region in question, with respect to the buildings' isolation properties. The latter division of the climate zones is found to be more relevant to this thesis work because it is thought to depict a more realistic image of the building stock with respect to the climate. However, obstacles have been encountered when collecting the necessary data in the segmentation process and data have been inadequately supplied in terms of these four climate zones. The practicability and availability of data is another aspect that also has to be considered and is just as important as and perhaps even more decisive than the relevance of the reasoning behind the choice of climate zones.

The climate zones that have been chosen for this master thesis follow the distribution presented by Boverket's building regulations. The main reason for this choice is that the three different temperature zones shown in figure 2 allows the possibility of collecting more accurate data on the physical properties of the buildings selected. This is because a large amount of the data recorded by the Swedish Energy Agency is presented according to the different counties that define the three climate zones.

In order to investigate the characteristics of these climate zones in terms of typical temperature values during the different seasons, the most populated city in each climate zone has been used to represent the climatic features for the whole zone. The reference cities chosen are presented in table 4.4. The use of such a reference city simplifies the real situation in the different climate zones but facilitates the collection of data for the mean seasonal temperatures. Moreover, the building stock is often most dense in the most populated cities and therefore is a good reference point when attempting the segmentation of the building stock. The weather data that is used in the simulation process is taken from the weather files for each city found in the database Meteonorm.

Table 4.4. The three reference cities representing each climate zone and their corresponding population in 2011(SCB, 2012)

Climate Zone	Reference City	Population 2011
Zone 1	Umeå	116 465
Zone 2	Sundsvall	96 113
Zone 3	Stockholm	864 324

4.2.2 Characterisation

A characterisation of the non-residential buildings is done by determining the physical parameters that are distinctive of the different types of buildings and assigning values to these parameters. The parameters that are investigated are presented in table 4.1 in section 4.1, which serve as the input variables in the simulation process with the ECCABS model.

These parameters affect the energy consumption of the buildings and are concerned with the properties of the materials used, construction techniques and also reflect the different building regulations that exist in Sweden. The parameters have been determined by using different approaches: 1) values set by building regulations and requirements, 2) values collected from various sources, and 3) values from calculations and assumptions.

4.2.2.1 Temperature

In Boverket's project BETSI, the average temperature that was used for single-dwelling buildings was 21.2°C and for multi-dwelling buildings was 22.2°C but the indoor temperature for non-residential buildings was not recorded. (Boverket, 2009b) In the set of building regulations compiled by Boverket, the minimum indoor temperature is set to 18°C in working places as well as in residences and 20°C in healthcare premises and other premises where children sojourn, such as schools. The minimum temperature of the floor is set to 16°C and for healthcare premises and other premises where children sojourn, a minimum floor temperature of 18 °C is recommended. (Boverket, 2011)

Arbetsmiljöverket, the Swedish agency that supervises working environments and conditions, has stated in their regulations that an acceptable temperature for working places where physical activity is minimal should be at least 20 °C and for places where physical activity is commonplace, the temperature should be at least 14-15°C. (Arbetsmiljöverket, 2009) A summary of the indoor temperatures recommended by these different authorities are presented in table 4.5

Table 4.5. Temperatures defined by various sources for different types of buildings

	Sources		
	BETSI	**BBR**	**Arbetsmiljöverket**
Temperature (°C)	S-D buildings: 21.2 M-D buildings: 22.2	Work/ residences: 18 Health/ schools: 20	Min activity: 20 Activity: 14-15

Based on this information, typical temperatures for the different non-residential building types have been chosen for this thesis and are presented in table 4.6.

Table 4.6. The minimum temperature of the different building types that have been decided upon after consulting the various sources

Type of Building	Temperature (°C)
Dwellings	21
Hotels, Restaurants, Boarding houses	20
Restaurants	20
Offices, Administrative	20
Food commerce	20
Other commercial buildings	20
Healthcare 24/7	20
Other healthcare centres	20
Educational	20
Sport centres	14.5
Religious	18
Cultural	20
Garages	14.5
Other	19.1

4.2.2.2 Hot water demand, H_w

The hot water demand has been calculated using equation 1 in order to convert the amount of hot water in litres to the power demand

$$Q = m \cdot c_p \cdot \Delta T = V \cdot \rho \cdot c_p \cdot \Delta T \qquad \text{Equation 1}$$

where

V is the volume of water in m^3
ρ is the density of water taken as 1000 kg/m^3
c_p is the specific heat capacity of water taken as 4.18 kJ/kg·K
ΔT is the temperature difference of the water with the surrounding as it is being heated.

The volume of the water used to calculate H_w is given in Energy statistics for non-residential premises (2011b) as the total use of water in 2010 for the different building types in the different periods of construction. Table 4.7 shows the hot water demand in the non-residential building stock and the calculations behind these values are presented in appendix D.

The temperature difference that is used in equation 1 is the difference between the temperature that the hot water is heated up to and the ambient temperature, which is assumed to be 25°C. The temperature of the hot water is heated up to at most 60°C in the hot water boilers, and this temperature is used in the calculations. (Boverket, 2011)

Table 4.7. The hot water demand in the non-residential building stock in W/m^2

TYPE OF NON RESIDENTIAL BUILDING	PERIOD OF CONSTRUCTION							
	-1940	1941-1960	1961-1970	1971-1980	1981-1990	1991-2000	2001-	DATA UNAV.
Dwellings	7.90	3.94	4.33	5.11	5.00	4.27	6.06	2.92
Hotels, boarding houses	4.97	4.52	21.70	47.33	11.25	3.87	4.08	12.50
Restaurants	5.84	3.12	8.87	11.22	4.12	5.39	4.10	12.17
Offices/ Administrative	2.78	2.29	2.07	1.95	2.05	1.73	1.94	2.17
Food commerce	3.66	3.89	1.60	2.06	2.66	1.76	1.05	5.44
Other commercial	4.11	1.85	1.80	2.02	2.56	1.17	1.54	2.36
Healthcare 24/7	3.83	3.74	3.76	4.14	5.33	4.65	5.38	3.48
Other healthcare	3.23	3.31	2.43	4.05	3.23	5.30	2.70	4.50
Educational	1.86	2.10	2.02	2.40	3.03	2.33	2.18	2.48
Sport centres	9.77	5.31	3.29	6.17	14.80	7.17	6.68	9.94
Religious	0.66	1.01	1.27	1.16	1.07	1.45	3.27	1.72
Cultural	2.30	1.83	2.69	1.80	3.92	2.07	2.98	1.48
Garages	2.17	2.99	2.93	3.07	1.86	1.29	2.88	1.75
Other	1.82	2.02	4.85	2.07	2.02	3.15	2.32	2.53

4.2.2.3 Consumption of the hydronic pumps, HyP

The electrical consumption of the hydronic pumps has been set to 0.36 W/m^2. (Mata, 2011)

4.2.2.4 Specific heat gains from occupants, appliances and lighting load (O_c, A_c, L_c)

The different heat gains from occupants, appliances and lighting loads are considered in this section. The heat gains from these three different sources fluctuate during the hours of a day according to the occupancy and activity level. In order to visualize this variation more clearly, profiles of the three different heat gains are presented in an hourly basis in figures 4, 5 and 6. However, these heat gain profiles are not included in the model during the simulation stages in this study but could prove useful for future reference.

The heat gain profiles illustrated herein are typical of those load profiles for office buildings. Heat gain profiles for different non-residential building types exist and differ from the ones representing a typical office building. Despite the differences in the load profiles from one building type to another, there are similarities. These similarities depend on the everyday routines and activities taking place within the specific building and the normal occupational period in the building (for example, the working or open hours in an office or store respectively).

Occupancy

The heat gain from occupants is a somewhat special case compared to the other two sources of heat gain. The heat energy that is emitted by one human being is considered to deviate only slightly to that of another individual; therefore a standardized value for the heat gain of an occupant is used. The heat gain of occupants varies depending on what type of physical activity is being performed at a specific time. The activity level in different building types is also accounted for when looking at the heat gains from occupants in order to make the collection of data as realistic as possible. (BEPAN, 2003)

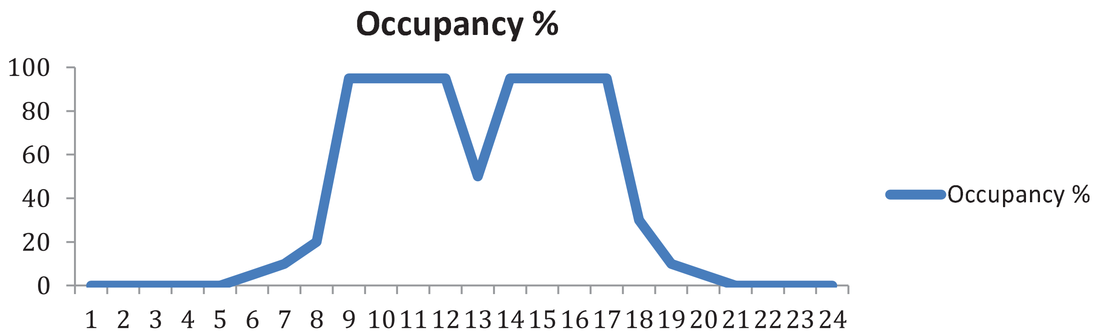


Figure 4. Hourly internal heat gain profile of the occupancy rate for an office building
Source: BEPAN, 2003

According to ASHRAE Handbook-fundamentals (2009) as cited by SVEBY (2010), the amount of heat energy emitted from one person is 108 W. The working space for one person at an office is assumed to be between 17 and 22 m^2 per person. (SVEBY, 2010) Different standardized values for sensible heat gain of occupants are presented for a variety of activities in table 4.8.

Table 4.8. Typical sensible heat gain per person with respect to different activities and different building types (BEMBook, 2012)

ACTIVITY	TYPE OF BUILDING	SENSIBLE HEAT GAIN/ PERSON (W)
Seated at rest	Cultural	67.5
Seated, light work	Office/ Admin., Hotels, Dwellings	70
Moderate office work	Office/ Admin., Hotels, Dwellings	75
Standing, walking slowly	Commercial Offices/ Admin.	75
Sedentary work	Restaurant	80
Light movement	Cultural, sport centres	90-170
Athletics	Sport centres	170-210

In table 4.9, a summary of the internal heat gain from occupants (O_c), which is used in the input file, is displayed. The O_c-values have been calculated from the values of the sensible heat gain per person, also given in table 4.9. In the case where some building types have several characteristic sensible heat gain values, the average value of the sensible heat gains has been calculated and assigned to that specific building type.

Table 4.9. Summary of the occupant heat gain O_c used in the input file

Type of building	Sensible heat gain/ person (W)	O_c (W/m^2)
Dwellings	72.5	3.72
Hotels, Boarding houses	72.5	3.72
Restaurants	80	4.1
Offices/ Administrative	73.3	3.76
Food commerce	75	3.85
Other commercial	75	3.85
Healthcare 24/7	72.5	3.72
Other healthcare	72.5	3.72
Educational	72.5	3.72
Sport centres	156.67	8.03
Religious	67.5	3.46
Cultural	109.17	5.60
Garages	9.75	0.5
Other	77.6	3.98

Lighting

The lighting is the major space cooling load component and it is often a complicated task to calculate because the instantaneous cooling load from lighting is not necessarily equivalent to the heat supplied by power due to heat storage. (ASHRAE, 2009) However, in the case of this master thesis, the lighting load is calculated from the total building electricity that is not used for heating and hot water purposes, shown in table 4.10.

Table 4.10. Use of electricity for other purposes than space heating and hot water in GWh

Building type	Electricity use (GWh)
Dwellings	269
Hotels, Boarding houses	967
Restaurants	250
Offices/ Administrative	2502
Food commerce	766
Commercial	1129
Healthcare 24/7	1959
Other healthcare	300
Educational	3544
Sport centres	675
Religious	163
Cultural	290
Garages	213
Other	1182
Total	13958

The lighting load, L_c, is calculated by distributing the electricity shown in table 4.10 to the different periods of construction. The electricity is divided by the heated area for each category in order to obtain the specific lighting load. An assumption that one fourth of a non-residential building's operational electricity and that one fifth of the operational electricity for the dwellings-category is consumed by lighting. (Persson, 2002) In so doing, the internal heat gain from lighting can be obtained. The lighting loads for the different building categories and periods of construction are shown in table 4.11.

Table 4.11. The lighting load, L_c, for each of the buildings in the different construction periods in W/m^2

Type of non-residential building	Period of construction -1940	1941-1960	1961-1970	1971-1980	1981-1990	1991-2000	2001-	Data unavailable
Dwelllings	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98
Hotels, Boarding houses	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78
Restaurants	5.55	5.55	5.55	5.55	5.55	5.55	5.55	5.55
Offices, Administrative	2.54	2.54	2.54	2.54	2.54	2.54	2.54	2.54
Food commerce	5.08	5.08	5.08	5.08	5.08	5.08	5.08	5.08
Other commercial	3.10	3.10	3.10	3.10	3.10	3.10	3.10	3.10
Healthcare 24/7	4.27	4.27	4.27	4.27	4.27	4.27	4.27	4.27
Other healthcare	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20
Educational	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
Sport centres	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78
Religious	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33
Cultural	3.60	3.60	3.60	3.60	3.60	3.60	3.60	3.60
Garages	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80
Other	2.58	2.58	2.58	2.58	2.58	2.58	2.58	2.58

The lighting loads have a specific profile depending on the usage and the on-going activities within the building type in question. An example of how the load profile for lighting may look like in an office building is shown in figure 5. It can be seen that the lighting load increases during the working hours and is more or less constant during the most normal working hours of the day.

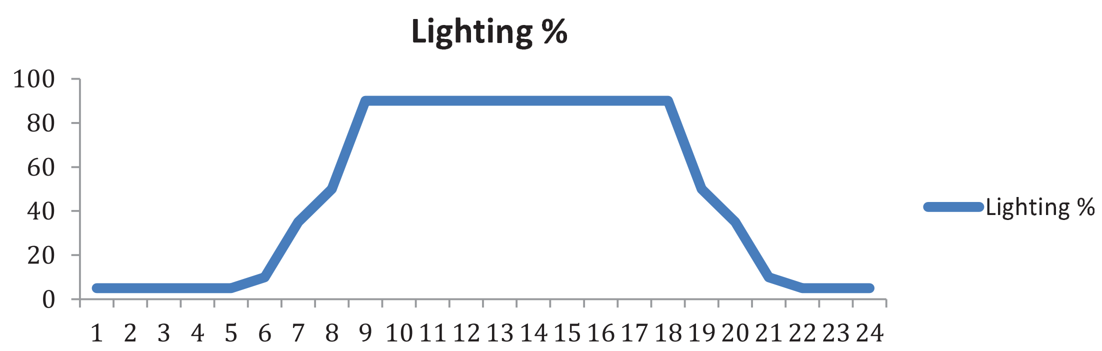


Figure 5. Hourly internal heat gain profile of the lighting load for an office building
Source: BEPAN, 2003

Appliances

The internal heat gain profile for the use of appliances in a typical office or other workplace is depicted by the profile shown in figure 6. From the figure it can be seen that the maximum usage of appliances is reached and maintained steadily during the most common working hours between 08 and 17 hours, quite similarly to the load profile shown in *Figure* .

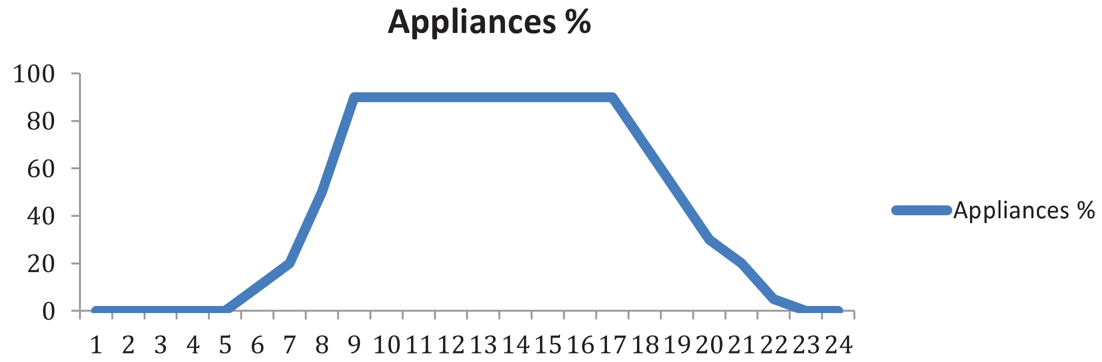


*Figure 6.*Hourly internal heat gain profile of the percentage of appliance use
Source: BEPAN, 2003

The different types of appliances that are used in the different building types are shown in table 4.12. The reports within the STIL2 study give a detailed description of the different appliances and their respective energy use. This information is interesting to keep track of but is not used further in the simulation process in this report.

Table 4.12. The specific electricity use for different purposes and appliances in the different building categories

Electricity Consumption (W/m2)	Building types									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11, 12**
Electrical heat	0	0	0	0.7	1.4	0.8	1.5	5	2.0	1.3	0
Heat pumps	0	0	0							0.6	0
Comfort cooling	0	0.3	1	0	0.4	1.5	0	0	0	0.5	0.2
Pumps	0	0.6	0.8	0.6	1.3	1.2	0.8	0.5	0.4	1.8	0.5
Fans	0	3.1	6.8	2	2.7	4.9	5.6	3.2	2.3	3.5	1.8
Dehumidifier	0	0	0	0	0	0	0	0	0	0.5	0
Other building electricity	0.9	0.3	0.5	0.2	1	0.8	0.1	1.03	0.03	0.1	0.14
Cooling machines	1.7	0	0	1.2	17	1.1	0.5	0.3	0	3.1	0
Office equipment	0	0.2	0.1	3.3	0	0	0.6	0.37	0.3	0.0	0.4
Kitchen	0.9	4.1	24	0.3	0	0	1.2	0.5	1.1	0.2	0.4
Laundry	0.8	0.2	0.2	0	0	0	0.8	0.3	0.2	0	0
Sauna	0	0	0	0	0	0	0	0	0.01	1.18	0
Medical operational electricity	0	0	0	0	0	0	0.6	0.4	0	0	0
Other operational electricity	1.2	1.1	1.5	0.2	2.3	2.6	0.8	0.5	0.1	0.3	0.4
Residual	0	0	0	0.8	0.8	0.9	0.7	0.4	0.5	0.3	0
Total	5.6	9.3	34	8.8	25	13	12	11	6.5	12	3.3

The internal heat gains from appliances that are used as input parameters for the ECCABS model are presented in table 4.12. The appliance loads are calculated similarly to the lighting loads except for two assumptions. The assumptions used are that appliances consume 75 % and 80 % of the electricity used (table 4.10) in non-residential buildings (excluding any dwelling) and dwellings-category respectively. (Persson, 2012)

Table 4.12. The internal heat gain load for appliances, A_c, for each of the buildings in the different construction periods in W/m^2

Type of non-residential building	Period of construction -1940	1941-1960	1961-1970	1971-1980	1981-1990	1991-2000	2001-	Data unavailable
Dwelllings	7.92	7.92	7.92	7.92	7.92	7.92	7.92	7.92
Hotels, Boarding houses	11.34	11.34	11.34	11.34	11.34	11.34	11.34	11.34
Restaurants	16.65	16.65	16.65	16.65	16.65	16.65	16.65	16.65
Offices, Administrative	7.62	7.62	7.62	7.62	7.62	7.62	7.62	7.62
Food commerce	15.25	15.25	15.25	15.25	15.25	15.25	15.25	15.25
Other commercial	9.29	9.29	9.29	9.29	9.29	9.29	9.29	9.29
Healthcare 24/7	12.80	12.80	12.80	12.80	12.80	12.80	12.80	12.80
Other healthcare	6.59	6.59	6.59	6.59	6.59	6.59	6.59	6.59
Educational	7.49	7.49	7.49	7.49	7.49	7.49	7.49	7.49
Sport centres	11.33	11.33	11.33	11.33	11.33	11.33	11.33	11.33
Religious	6.98	6.98	6.98	6.98	6.98	6.98	6.98	6.98
Cultural	10.80	10.80	10.80	10.80	10.80	10.80	10.80	10.80
Garages	11.40	11.40	11.40	11.40	11.40	11.40	11.40	11.40
Other	7.73	7.73	7.73	7.73	7.73	7.73	7.73	7.73

4.2.2.5 U-values

A building's thermal resistance is given as a U-value measured in W/m^2 K or W/m^2 °C. The U-value indicates how much of the heat inside the building is lost to the surroundings through different elements in the building's envelope. The lower the U-value of a specific building element, the lesser the amount of heat lost to the surroundings. (Ekstrand-Tobin & Olsson-Jonsson, 2011)

In the series of reports included in STIL 2 published by the Swedish Energy Agency, the U-values of the buildings are presented in the thermal properties of the building envelope. These values have been measured for the sample buildings that have been included in the studies of STIL2 and the average values of all the U-value measurements are presented in table 4.14 and table 4.15. There is no information about the different climate zones that correspond to the given U-values in the reports. Moreover, the regulation for U-values in the three climate zones should not exceed an average value of 0.6 W/m^2K. (Boverket, 2011) According to this data, it is assumed that there is no evident difference from zone to zone.

Table 4.14 The average U-values of walls, roofs and windows (in W/m^2 K) for three types of non-residential buildings - commercial, hotels/ restaurants and sport centres

Type of Buildings	Walls	Roofs	Windows	Average
Commercial	0.34	0.29	1.63	0.7533
Hotels, Restaurants	0.61	0.46	1.92	0.9967
Sport centres	0.31	0.28	1.66	0.75

For the educational and healthcare buildings, the average U-values have been presented differently to the other categories by dividing them into 7 periods of construction (*Data unavailable* period was lacking) seen in table 4.15.

Table 4.15. The average U-values of walls, roofs and windows (in W/m^2°C) in 7 periods of construction for educational (E) and healthcare (H) buildings

Period of Construction	Walls		Roofs		Windows	
	E	H	E	H	E	H
-1940	0.79	0.87	0.45	0.58	2.24	2.17
1941-1960	0.63	0.58	0.39	0.48	2.07	2.19
1961-1970	0.43	0.51	0.33	0.37	2.02	1.96
1971-1980	0.34	0.39	0.25	0.23	1.85	1.66
1981-1990	0.23	0.25	0.17	0.17	1.44	1.32
1991-2000	0.22	0.22	0.15	0.15	1.30	1.25
2001-	0.21	0.20	0.15	0.17	1.20	1.10

In table 4.16, a summary of the U-values for all the building categories (numbered 1-14 according to table 4.2 in section 4.2.1) are given and these values are used in one of the input files. The U-values that were lacking in the STIL2 reports are those of dwellings, offices and others. For dwellings and offices, the U-values have been obtained from sources other than the STIL2 reports (see notes below the table). Also, the categories of religious and cultural buildings have been assigned the same values as the hotels and restaurants-categories, as they are included in one of the categories in the specific STIL2 report. (STEM, 2011c) The U-values presented in the *Data unavailable*-column are the average values of the U-values in all the other periods of construction since these values were also lacking. The U-values of the last building category of *Other* are the average U-values of the other building categories' values in each period of construction.

Table 4.16 A summary of the U-values used in the input file

Type of building	-1940	1941-1960	1961-1970	1971-1980	1981-1990	1991-2000	2001-	Data unavailable
1	0.411*	0.411	0.411	0.411	0.411	0.411	0.411	0.411
2	0.997	0.997	0.997	0.997	0.997	0.997	0.997	0.997
3	0.997	0.997	0.997	0.997	0.997	0.997	0.997	0.997
4	0.540**	0.540	0.540	0.540	0.540	0.540	0.540	0.540
5	0.753	0.753	0.753	0.753	0.753	0.753	0.753	0.753
6	0.753	0.753	0.753	0.753	0.753	0.753	0.753	0.753
7	1.207	1.083	0.947	0.76	0.62	0.54	0.49	0.801
8	1.207	1.083	0.947	0.76	0.62	0.54	0.49	0.801
9	1.16	1.03	0.927	0.813	0.613	0.557	0.52	0.803
10	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750
11	0.997	0.997	0.997	0.997	0.997	0.997	0.997	0.997
12	0.997	0.997	0.997	0.997	0.997	0.997	0.997	0.997
13	0.753	0.753	0.753	0.753	0.753	0.753	0.753	0.753
14	0.886	0.857	0.828	0.791	0.748	0.737	0.727	0.796

*Value of multi-family dwellings(Boverket, 2009b)
** Boverket, 2010

4.2.2.6 Total external surfaces of the building, S

The expressions used to obtain the total external surfaces of the buildings are taken from a previous master thesis done in the Pathways Project (Benejam, 2011). The total external surface is defined by Equation 2.

$$S = S_{walls} + S_{roof} + S_{floor} + S_w \qquad \text{Equation 2}$$

The surface of the walls has been calculated based on information given in Boverket's report *Energi i bebygglesen - tekniska egenskaper och beräkningar (2010)*, which is a more in-depth report that followed through the results of the BETSI project. In this report, the non-residential energy use was covered but not for all the different types of non-residential buildings that are included in the typology of this thesis. The categories in the report were divided into three different ones - offices/administrative buildings, healthcare centres and lastly, public buildings (included in this are the categories of sport centres, cultural, religious and commercial buildings, hotels/ restaurants and garages). The category that is not included is educational buildings. On behalf of the non-residential sector, a total of 47 000 buildings constituted the results of this report.

The total area of external walls that was accounted for was 32.9 million m^2. (Boverket, 2010) Assuming that this area is divided evenly amongst the 47 000 buildings, an area of 700 m^2 per building of external walls is obtained. Using this assumption, one can calculate the area of the external walls in the total non-residential building stock including the category of educational buildings. The non-residential building stock included in the Swedish Energy Agency's statistics amounts to an average number of buildings of 84 508. (STEM, 2011) A total area of external walls is calculated to estimate 59.2 million m^2.

Another assumption that is necessary to make in order to get the external surface of the walls for each period of construction, building type and in each climate zone is that the areas of the external walls are distributed in the same proportion as the total average heated area in each of the three segmentation criteria. See appendix B.

According to the *French Environmental and Energy Management Agency (ADEME)*, the surface area of S_{roof} and S_{floor} are assumed to be equal and equivalent to the expression as shown in equation 3.

$$\boldsymbol{S_{roof} = S_{floor} = \sqrt{\frac{A}{levels}}} \qquad \text{Equation 3}$$

The area of the floor is also calculated in a similar fashion starting with a surface area of 30.3 million m^2 for the 47 000 non-residential buildings.

Total surface of the windows of the buildings, S_w

The total surface area of the windows for all of the non-residential building types has been calculated from data provided in the report *Energi i bebygglesen - tekniska egenskaper och beräkningar (2010)*. The total surface area of the windows in this report amounts to 7.8 million m^2, which only includes three building types mentioned above. Using the same assumptions as the ones used for calculating the surface area of the external walls, the average surface area of the windows for each building is approximately 166 m^2 per building, taking the number of non-residential buildings to be 47 000. Using these figures, the total average surface area of the windows would amount to an approximate 14 million m^2 for 84 508 non-residential buildings.

These calculations are used to provide an estimate of the surface area of the windows in the non-residential building stock according to building type, period of construction and in the different periods of construction.

Levels

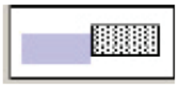
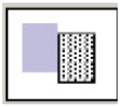
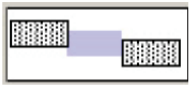
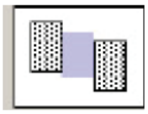
The number of levels in each non-residential building category has not been found in the research that has been made in the national sources. However, the levels of the buildings are calculated from equation 4 which is used in the 3-CL method. The 3-CL method is used by the ADEME in its calculations of end-use energy consumption in dwellings

$$\boldsymbol{S_{walls} = ATT \cdot Form \cdot \sqrt{\frac{A}{levels}} \cdot Levels \cdot HR - S_w} \qquad \text{Equation 4}$$

where:

ATT	is the attached character of the building
Form	is the form coefficient of the building
A	is the heated floor area
Levels	is the number of levels
HR	is the height under the roof which is assigned a value of 2.7 m
S_w	is the surface area of the windows.

The attached character of the building takes certain values and these values are given below:

Attachment character		Value
Independent building body		1
Attached on one small side		0.8
Attached on one large or 2 small sides	 or 	0.7
Attached on one large and a small side		0.5
Attached on 2 large sides		0.35

The non-residential buildings' attached characters have been assigned different values based on what is thought to be the most common type of character for the building category in question, seen in table 4.17.

Table 4.17. The attached character and form values of the different building categories according to the 3-CL method used by the French ADEME

Building category	Attached Character		Form	
	Values	Average	Values	Average
Dwellings	1, 0.8, 0.7, 0.5	0.75	4.12, 4.81	4.47
Hotels, Restaurants, Boarding houses	1, 0.8, 0.7, 0.5, 0.35	0.67	4.12, 4.81	4.47
Restaurants	0.8, 0.7, 0.5, 0.35	0.59	4.12, 4.81	4.47
Offices/ Administrative	0.8, 0.7, 0.5, 0.35	0.59	4.12, 4.81, 5.71	4.88
Food Commerce	1, 0.8	0.9	4.12	-
Other commercial	0.7, 0.5, 0.35	0.52	4.12, 4.81	4.47
Healthcare 24/7	1, 0.8	0.9	4.81, 5.71	5.26
Other healthcare	1, 0.8	0.9	4.12, 4.81	4.47
Educational	1, 0.8, 0.7	0.83	4.12, 4.81	4.47
Sport centres	1, 0.8, 0.7	0.83	4.12, 4.81	4.47
Religious	1, 0.8	0.9	4.12	-
Cultural	1, 0.8	0.9	4.12, 4.81	4.47
Garages	1, 0.8, 0.7, 0.5	0.75	4.12	-
Other	1, 0.8, 0.7, 0.5, 0.35	0.67	4.12, 4.81, 5.71	4.88

The form coefficient is also important to decide before one is able to find the average number of levels in each building category. The ADEME has also defined different coefficients for buildings' shapes and configurations for use in the 3-CL method and these are given in the following table. Even here, the form values have been chosen so as to represent the different building categories that represent the most likely structure of that particular building category. These values are shown below.

CONFIGURATION		VALUE
Compact		4.12
Elongated		4.81
Developed		5.71

4.2.2.7 Windows' shading and frame coefficient (W_c, W_f)

A window's shading coefficient is a measure of how effective the window is at blocking solar heat. It can depend on the type of glass that the window is made up of or what type of shading devices that are used. The lower the shading coefficient of a window is, the better it is at diverting solar heat from the building which means a lower impact on the building's cooling load. (APS,1999) Standard values for some typical window types in Sweden are presented in table 4.18.

Table 4.18. Typical shading coefficents for different types of windows (Girdo, Höglund & Troedsson, 1984)

WINDOW TYPE	SHADING COEFFICIENT
Single-pane, clear glass	1
Double-pane, clear glass	0.9
Double-pane, tinted with reflective, metallic coating	0.2-0.5
Triple-pane, clear glass	0.81
Triple-pane, tinted with reflective, metallic coating	0.15-0.4

In Sweden, the most common types of windows up until the 1970s were windows that were double-glazed. In the 1970s, it became more common with triple-glazed windows in order to save energy and this trend has continued up until today's window manufacturing. This is the basis for the calculations of the shading coefficients chosen for the non-residential building stock, which can be seen in table 4.19. The windows were framed with wood in older buildings and are still the leading material of window frames, as this raw material is abundant in Sweden. Nonetheless, slight modifications have been carried out on the window frames of modern buildings by adding a metal (often in aluminium or steel) or plastic (however, plastic frames, such as PVC, are not as common as metal) covering on the wooden frame. (Ekstrand-Tobin &Olsson-Jonsson, 2011)

In table 4.19, the shading coefficients for the chosen typology are shown. The shading coefficients have been assumed to be the same for all the building subtypes but vary with respect to the period of construction. The values for the first three periods of construction have been taken as the average of the shading coefficients of double-pane windows in table 4.18. Similarly, the coefficients for the periods of construction after 1970 are the average values of the shading coefficients for triple-pane windows taken from table 4.18. The shading coefficient for the data unavailable period is the average value of all the periods of construction's coefficients.

Table 4.19. The shading coefficients chosen for all subtypes in the different periods of construction

PERIOD OF CONSTRUCTION	SHADING COEFFICIENT, WC
-1940	0.625
1941-1960	0.625
1961-1970	0.625
1971-1980	0.5425
1981-1990	0.5425
1991-2000	0.5425
2001-	0.5425
Data unavailable	0.578

A frame coefficient, W_f, of 0.71 is taken to be a standard value for the windows in Sweden. (SVEBY, 2010). This value is used for all the building categories included in the typology.

4.2.2.8 Coefficient of the solar transmission of the window T_s

The solar transmission of the windows is, like the shading coefficient, dependent on the window glass' properties, which is often provided by the manufacturers of the window glass. There are some standard values for the solar transmissions of different types of windows and these are shown in table 4.20.

Table 4.20. Standard solar transmission values for some types of windows (SVEBY, 2010)

TYPE OF WINDOW	COEFFICIENT OF SOLAR TRANSMISSION
Double-pane	0.76
Triple-pane	0.68

4.2.2.9 Effective heat capacity of the building, TC

The effective heat capacity of the building represents the building's thermal inertia and is determined by equation 5. The equation is the sum of the volumetric heat capacities of the layers in direct contact with the internal air, such as internal layers of exterior walls, internal walls and middle floors.

$$TC = \sum \rho_i \cdot c_{pi} \cdot S_i \cdot d_i \qquad \text{Equation 5}$$

where:

ρ_i is the density of the layer (kg/m^3),
c_{pi} is the specific heat capacity of the layer (J/kg K),
S_i is the area of the layer (m^2), and
d_i is the thickness of the layer (m).

The maximum thickness according to the EN ISO 13790 is either 10 cm or the middle of the building element depending on whichever comes first. The layers that are included in the equation are all the layers starting from the internal surface and stopping at the first insulating layer. The effective heat capacity values for each of the building categories are shown in table 4.21.

Table 4.21. TC values of the different building types in the periods of construction in MJ/K

TC	PERIOD OF CONSTRUCTION							
	-1940	1941-1960	1961-1970	1971-1980	1981-1990	1991-2000	2001-	Data unav.
Dwellings	18.2	13.0	10.4	7.8	7.8	10.4	2.6	7.8
Zone 3	6.4	17.6	3.7	2.7	2.7	3.7	0.9	2.7
Zone 2	0.9	5.0	0.5	0.4	0.4	0.5	0.1	0.4
Zone 1	0.6	3.8	0.3	0.2	0.2	0.3	0.1	0.2
Hotels, Boarding houses	13.6	4.5	11.3	14.7	19.2	11.3	4.5	2.3
Zone 3	11.0	3.7	9.1	11.9	15.5	9.1	3.7	1.8
Zone 2	1.5	0.5	1.3	1.6	2.1	1.3	0.5	0.3
Zone 1	1.0	0.3	0.8	1.0	1.4	0.8	0.3	0.2
Restaurants	4.5	2.3	3.4	3.4	4.5	2.3	1.1	3.1
Zone 3	3.7	1.8	2.7	2.7	3.7	1.8	0.9	2.5
Zone 2	0.5	0.3	0.4	0.4	0.5	0.3	0.1	0.3
Zone 1	0.3	0.2	0.2	0.2	0.3	0.2	0.1	0.2
Offices, Administrative	58.8	33.9	46.4	50.9	60.0	27.1	27.1	11.3
Zone 3	47.5	27.4	37.5	41.1	48.4	21.9	21.9	9.1
Zone 2	6.5	3.8	5.1	5.7	6.7	3.0	3.0	1.3
Zone 1	4.2	2.4	3.3	3.6	4.2	1.9	1.9	0.8
Food commerce	1.1	1.1	14.7	11.3	7.9	3.4	9.0	6.9
Zone 3	0.9	0.9	11.9	9.1	6.4	2.7	7.3	5.6
Zone 2	0.1	0.1	1.6	1.3	0.9	0.4	1.0	0.8
Zone 1	0.1	0.1	1.0	0.8	0.6	0.2	0.6	0.5
Other commercial	10.2	9.0	19.2	27.1	17.0	12.4	20.4	2.3
Zone 3	8.2	7.3	15.5	21.9	13.7	10.0	16.4	1.8
Zone 2	1.1	1.0	2.1	3.0	1.9	1.4	2.3	0.3
Zone 1	0.7	0.6	1.4	1.9	1.2	0.9	1.4	0.2
Healthcare 24/7	13.6	18.1	40.7	33.9	14.7	11.3	6.8	7.9
Zone 3	11.0	14.6	32.9	27.4	11.9	9.1	5.5	6.4
Zone 2	1.5	2.0	4.5	3.8	1.6	1.3	0.8	0.9

Zone 1	1.0	1.3	2.9	2.4	1.0	0.8	0.5	0.6
Other healthcare	3.4	5.7	11.3	7.9	10.2	1.1	2.3	1.1
Zone 3	2.7	4.6	9.1	6.4	8.2	0.9	1.8	0.9
Zone 2	0.4	0.6	1.3	0.9	1.1	0.1	0.3	0.1
Zone 1	0.2	0.4	0.8	0.6	0.7	0.1	0.2	0.1
Educational	45.2	74.7	110.9	69.0	21.5	20.4	12.4	104.1
Zone 3	36.5	60.3	89.5	55.7	17.4	16.4	10.0	84.0
Zone 2	5.0	8.3	12.3	7.7	2.4	2.3	1.4	11.6
Zone 1	3.2	5.3	7.8	4.9	1.5	1.4	0.9	7.4
Sport centres	2.3	5.7	17.0	6.8	12.4	2.3	5.7	5.7
Zone 3	1.8	4.6	13.7	5.5	10.0	1.8	4.6	4.6
Zone 2	0.3	0.6	1.9	0.8	1.4	0.3	0.6	0.6
Zone 1	0.2	0.4	1.2	0.5	0.9	0.2	0.4	0.4
Religious	11.3	2.3	1.1	3.4	2.3	3.2	1.1	1.1
Zone 3	9.1	1.8	0.9	2.7	1.8	2.6	0.9	0.9
Zone 2	1.3	0.3	0.1	0.4	0.3	0.4	0.1	0.1
Zone 1	0.8	0.2	0.1	0.2	0.2	0.2	0.1	0.1
Cultural	7.9	2.3	3.4	4.5	2.3	1.1	2.3	3.4
Zone 3	6.4	1.8	2.7	3.7	1.8	0.9	1.8	2.7
Zone 2	0.9	0.3	0.4	0.5	0.3	0.1	0.3	0.4
Zone 1	0.6	0.2	0.2	0.3	0.2	0.1	0.2	0.2
Garages	1.1	3.4	4.5	2.3	3.4	1.1	1.1	2.4
Zone 3	0.9	2.7	3.7	1.8	2.7	0.9	0.9	2.0
Zone 2	0.1	0.4	0.5	0.3	0.4	0.1	0.1	0.3
Zone 1	0.1	0.2	0.3	0.2	0.2	0.1	0.1	0.2
Other	21.5	12.4	22.6	24.9	27.1	6.8	11.3	22.6
Zone 3	17.4	10.0	18.3	20.1	21.9	5.5	9.1	18.3
Zone 2	2.4	1.4	2.5	2.8	3.0	0.8	1.3	2.5
Zone 1	1.5	0.9	1.6	1.8	1.9	0.5	0.8	1.6

4.2.2.10 Efficiency of heat recovery system

The efficiency of the heat recovery system is a value between 0 and 1. For the Swedish non-residential building stock, the efficiency of the heat recovery systems is set to 0.5. (Andreasson, Borgström & Werner, 2009)

4.2.2.11 Ventilation

The input parameters that are concerned with ventilation in the ECCABS model are the sanitary and natural ventilation rates (V_c and V_{cn}), the set point temperature for natural ventilation (T_v) and the Specific Fan Power (SFP), shown in table 4.22. The values for V_c and the SFP have been collected from the series of studies conducted by the Swedish Energy Agency under the collective name of STIL2. The set point temperature for natural ventilation is defined as the temperature that exceeds a comfortable indoor temperature and is assumed to be 24°C. (Boverket, 2011)

Table 4.22. Input parameters concerned with ventilation

Type of building	Vc (l/s/m²)	Tv (°C)	SFP (kW/m³/s)
Dwellings	0.37*	24	1.5*
Hotels, boarding houses	2.75	24	2.4
Restaurants	5	24	2.4
Offices/Administrative	1.48	24	2.75
Food commerce	1.9	24	2.1
Other commercial	1.85	24	2.5
Healthcare 24/7	1.9	24	2.67
Other healthcare	2.2	24	2.1
Educational	1.73**	24	2.4
Sport centres	1.96	24	2.3
Religious	1.5	24	2.4
Cultural	1.5	24	2.4
Garages	1.8**	24	2.45
Others	2.0	24	2.34

* Boverket, 2010
** V_c-values have been calculated using a minimum room height of 2.7 m from given air turnovers.
*** Martin, 2001

Natural ventilation is defined as the exchange of air caused by differences in air pressure between the outdoor surroundings of a building and its indoor environment. This natural ventilation is brought about by natural means without using a mechanical system or a fan, and may be brought about simply by opening a window. (GBTech, n.d.) The natural ventilation rate (table 4.23) has been calculated for the Swedish non-residential building stock using the surface area of the floor, room height and based on the assumption that there is a ventilation rate of 1.6 air changes per hour for a window opening of 10 % with internal temperatures below 25°C. (Arnold, 2007) The calculations were done by following equation 6.

$$V_{cn} = \frac{r_v \cdot h_{room}}{S_{floor}} \qquad \text{Equation 6}$$

Table 4.23. The calculated values for natural ventilation for the non-residential buildings

Vcn	Period of year of completion							
	-1940	1941-1960	1961-1970	1971-1980	1981-1990	1991-2000	2001-	Data unav.
Dwellings								
Zone 3	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
Zone 2	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
Zone 1	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
Hotels, Boarding houses								
Zone 3	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
Zone 2	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
Zone 1	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
Restaurants								
Zone 3	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Zone 2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Zone 1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Offices, Administrative								

Zone 3	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
Zone 2	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
Zone 1	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
Food commerce								
Zone 3	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Zone 2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Zone 1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Other commercial								
Zone 3	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Zone 2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Zone 1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Healthcare 24/7								
Zone 3	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Zone 2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Zone 1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Other healthcare								
Zone 3	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Zone 2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Zone 1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Educational								
Zone 3	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
Zone 2	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
Zone 1	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
Sport centres								
Zone 3	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Zone 2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Zone 1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Religious								
Zone 3	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Zone 2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Zone 1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Cultural								
Zone 3	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Zone 2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Zone 1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Garages								
Zone 3	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Zone 2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Zone 1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Other								
Zone 3	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Zone 2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Zone 1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2

The STIL2 study inventoried the type of ventilation systems in the different non-residential buildings that were included in the different reports; the results are seen in table 4.24.The most common ventilation system used in all the different types of non-residential buildings was the mechanical ventilation system of exhaust and supply air with heat recovery (FTX) with constant air volume (CAV) followed by FTX system with variable air volume (VAV).

Table 4.24. The share of the different types of ventilation systems in the different building categories

	Percentage of buildings					
Type of ventilation system	Comme-rcial	Offices, Admin.	Health	Sport	Educat-ional	Hotels, Restaurants
FTX (CAV)	78	75	85	74	87	76
FTX (VAV)	20	13	8,8	8	3	19
Exhaust & supply air	4	11	3,5	4	7	0
Exhaust air	0	0	2,1	0	3	3
Natural- draught	0	0	-	0	1	-
Other	0	0	0,5	14	0	1

4.2.2.12 Maximum heating/cooling power of heating/ cooling system (S_h, S_c)

The maximum heating and cooling power were assumed to be high enough to ensure that the building's energy demand was satisfied at all times by the heating and cooling systems.

4.2.2.13 Response capacity of heating/ cooling system (P_h, P_c)

The response capacity of the heating/ cooling systems of the buildings was assumed to be capable of responding to any changes in the energy demand. Therfore, the response capacities were set high enough so as to ensure this assumption.

4.2.3 Quantification

4.2.3.1 Quantification of the number of buildings in the non-residential building stock

The quantification of the non-residential building stock is done according to the building types, the periods of construction and the climate zones presented in the segmentation section. The statistical data presented by the Swedish Energy Agency (Energimyndigheten) in their annual energy statistics give the number of buildings only according to the different building types but no information on how many buildings are included in the periods of construction or in the three different climate zones. The number of buildings has been calculated in order to provide this information and the calculation process is explained in the following text.

Statistical data that were displayed in the energy statistics of 2010 show the average heated area of the different building types categorised by the periods of construction. The share of the heated area for each building type in each period of construction was calculated and later multiplied by the total number of buildings in that specific building type. Equation 7 summarises this step.

$$n_{i,j} = n_{i,tot} \cdot \frac{A_{i,j}}{A_{i,tot}}, \qquad \text{Equation 7}$$

$i = 1, 2, 3, \ldots 14$ and $j = 1, 2, 3, \ldots 7$

where
$n_{i,j}$ is the number of buildings in building type, i, and in period of construction, j
$n_{i,tot}$ is the total number of buildings in building type i
$A_{i,j}$ is the average heated are of building type, i in period of construction j
and $A_{i,tot}$ is the total average heated area of the building type, i.

The share of the heated area in each of Sweden's 20 counties was also provided in the data so together with the number of buildings in each period of construction, the number of buildings in each climate zone was also possible to calculate. The calculations of the number of buildings in the climate zones are based upon the assumptions that the share of the heated area in the counties is the same for each building type and is constant for each period of construction.

The number of buildings in each climate zone for each building type and period of construction have been calculated by using the equation 8.

$$\boldsymbol{n_{i,j,k} = n_{i,j} \cdot x_k}, \; k = 1, 2, 3, \ldots 20 \qquad \text{Equation 8}$$

where
$n_{i,j,k}$ is the number of buildings in building type i, in the period of construction of j and in the county k
x_k is the share of the heated area in each county, k.

The number of buildings in each zone is then calculated by summing up the number of buildings in each of the counties that are included in the three different zones. The results obtained from this quantification is given in table 4.25.

Table 4.25. The number of buildings for each building type, construction period and climate zone

NUMBER OF NON-RESIDENTIAL PREMISES IN 2010	PERIOD OF CONSTRUCTION								
	-1940	1941-1960	1961-1970	1971-1980	1981-1990	1991-2000	2001-	Data unav.	Total
Dwellings	1379	985	788	591	591	788	197	591	6109
Zone 3	1104	788	631	473	473	631	158	473	4730
Zone 2	166	119	95	71	71	95	24	71	711
Zone 1	63	45	36	27	27	36	9	27	272
Total	1333	952	762	571	571	762	190	571	
Hotels, Boarding houses	1098	366	915	1190	1556	915	366	183	6682
Zone 3	879	293	732	952	1245	732	293	146	5272
Zone 2	73	24	60	79	103	60	24	12	435
Zone 1	185	62	154	200	262	154	62	31	1108
Total	1136	379	947	1231	1609	947	379	189	
Restaurants	892	446	669	669	892	446	223	605	4014
Zone 3	714	357	535	535	714	357	178	484	3874
Zone 2	392	196	294	294	392	196	98	266	2130
Zone 1	53	26	39	39	53	26	13	36	285
Total	1159	579	869	869	1159	579	290	786	
Offices, Administrative buildings	2970	1714	2342	2570	3027	1371	1371	571	16051
Zone 3	2376	1371	1874	2056	2422	1097	1097	457	12749
Zone 2	69	40	54	60	70	32	32	13	369
Zone 1	93	54	74	81	95	43	43	18	501
Total	2538	1464	2001	2197	2587	1172	1172	488	
Food commerce	79	79	1022	786	550	236	629	483	3379
Zone 3	63	63	817	629	440	189	503	386	3089
Zone 2	18	18	240	184	129	55	148	113	906
Zone 1	5	5	67	51	36	15	41	32	253
Total	86	86	1124	865	605	259	692	531	
Other commercial buildings	624	554	1178	1663	1040	762	1248	139	7208
Zone 3	499	444	943	1331	832	610	998	111	5766
Zone 2	30	27	57	80	50	37	60	7	348
Zone 1	18	11	34	47	30	22	35	4	200
Total	547	482	1033	1458	911	668	1094	122	
Healthcare 24/7	290	386	869	724	314	241	145	169	3161
Zone 3	232	309	695	579	251	193	116	135	2509
Zone 2	30	39	89	74	32	25	15	17	320
Zone 1	113	150	338	281	122	94	56	66	1219
Total	374	498	1121	934	405	311	187	218	
Other healthcare buildings	225	375	751	526	676	75	150	75	2928
Zone 3	195	324	648	454	584	65	130	65	2464
Zone 2	25	41	83	58	74	8	17	8	314
Zone 1	95	158	315	221	284	32	63	32	1197

Total	314	523	1046	732	941	105	209	105	
Educational	1734	2860	4247	2644	823	780	477	3987	17553
Zone 3	231	382	567	353	110	104	64	532	2342
Zone 2	191	315	467	291	91	86	52	439	1931
Zone 1	21	34	50	31	10	9	6	47	208
Total	443	730	1084	675	210	199	122	1018	
Swimming and sport centres	117	291	874	350	641	117	291	291	2973
Zone 3	551	1377	4130	1652	3029	551	1377	1377	14042
Zone 2	13	32	96	38	71	13	32	32	327
Zone 1	10	25	76	30	56	10	25	25	258
Total	574	1434	4302	1721	3155	574	1434	1434	
Religious	1845	369	184	553	369	527	184	184	3689
Zone 3	1189	238	119	357	238	340	119	119	2718
Zone 2	203	41	20	61	41	58	20	20	464
Zone 1	113	23	11	34	23	32	11	11	257
Total	1505	301	150	451	301	430	150	150	
Cultural	979	280	420	560	280	140	280	420	3218
Zone 3	898	257	385	513	257	128	257	385	3080
Zone 2	108	31	46	62	31	15	31	46	369
Zone 1	56	16	24	32	16	8	16	24	192
Total	1062	303	455	607	303	152	303	455	
Garages	164	492	656	328	492	164	164	351	2624
Zone 3	161	483	644	322	483	161	161	345	2758
Zone 2	18	54	72	36	54	18	18	39	309
Zone 1	39	117	156	78	117	39	39	84	670
Total	218	654	872	436	654	218	218	467	
Other	1295	750	1364	1500	1636	409	682	1364	8932
Zone 3	304	176	320	353	385	96	160	320	2115
Zone 2	143	83	150	165	180	45	75	150	990
Zone 1	858	497	903	993	1084	271	452	903	5961
Total	1305	755	1374	1511	1648	412	687	1374	
Total	11042	9975	17002	14430	11167	5772	5960	9222	84508
Total (summed)	12592	9142	17140	14258	15061	6787	7126	7908	90016

4.2.3.2 Quantification of the heated area of the non-residential building stock

To quantify the heated area of the non-residential building stock so that it is in correspondence to the segmentation of the stock, similar calculations and assumptions, as the ones made in the quantification in terms of the number of buildings, are made. The data used as an outpost in the calculations shows the distribution of the heated area of the non-residential buildings in the different periods of construction by type of building. A further segmentation into the three climate zones is necessary and the following process enables this.

An assumption is made such that the share of the heated area in each county relative to the total heated area in the country can be thought to be constant in each period of construction and is the same for each of the building types. Using this assumption, the heated area of the different building types in the different periods of construction can be calculated for each county. Equation 9 is applied to obtain the heated area in each county according to building type and construction period.

$$\boldsymbol{A_{i,j,k} = A_{i,j} \cdot x_k} \qquad \text{Equation 9}$$

where
$A_{i,j,k}$ is the average heated area of each building type, i, in each period of construction, j and in each county, k
$A_{i,j}$ is the average heated area of each building type, i in each period of construction, j and x_k is the share of the average heated area in each county, k.

Similarly, the average heated area in each climate zone divided by type of building and construction period is obtained by summing the average heated area of each county in the corresponding building types and construction periods. The results obtained are shown in table 4.26Table .

Table 4.26. Results of the quantification of the heated area of the non-residential building stock by building type, period of construction and climate zone

AVERAGE HEATED AREA OF NON-RESIDENTIAL PREMISES IN 2010 BY TYPE (MILLION M2)	PERIOD OF YEAR OF COMPLETION								
	-1940	1941-1960	1961-1970	1971-1980	1981-1990	1991-2000	2001-	Data unav.	Total
Dwellings	0.70	0.50	0.40	0.30	0.30	0.40	0.10	0.30	3.10
Zone 3	0.56	0.40	0.32	0.24	0.24	0.32	0.08	0.24	2.40
Zone 2	0.08	0.06	0.04	0.03	0.03	0.04	0.01	0.03	0.33
Zone 1	0.05	0.04	0.03	0.02	0.02	0.03	0.01	0.02	0.21
Hotels, Boarding houses	1.20	0.40	1.00	1.30	1.70	1.00	0.40	0.20	7.30
Zone 3	0.96	0.32	0.80	1.04	1.36	0.80	0.32	0.16	5.76
Zone 2	0.13	0.04	0.11	0.14	0.19	0.11	0.04	0.02	0.79
Zone 1	0.08	0.03	0.07	0.09	0.12	0.07	0.03	0.01	0.50
Restaurants	0.40	0.20	0.30	0.30	0.40	0.20	0.10	0.27	1.80
Zone 3	0.32	0.16	0.24	0.24	0.32	0.16	0.08	0.22	1.74
Zone 2	0.04	0.02	0.03	0.03	0.04	0.02	0.01	0.03	0.24
Zone 1	0.03	0.01	0.02	0.02	0.03	0.01	0.01	0.02	0.15
Offices,	5.20	3.00	4.10	4.50	5.30	2.40	2.40	1.00	28.1

Administrative									
Zone 3	4.16	2.40	3.28	3.60	4.24	1.92	1.92	0.80	22.3
Zone 2	0.57	0.33	0.45	0.50	0.58	0.26	0.26	0.11	3.07
Zone 1	0.36	0.21	0.29	0.32	0.37	0.17	0.17	0.07	1.95
Food commerce	0.10	0.10	1.30	1.00	0.70	0.30	0.80	0.61	4.30
Zone 3	0.08	0.08	1.04	0.80	0.56	0.24	0.64	0.49	3.93
Zone 2	0.01	0.01	0.14	0.11	0.08	0.03	0.09	0.07	0.54
Zone 1	0.01	0.01	0.09	0.07	0.05	0.02	0.06	0.04	0.34
Other commercial	0.90	0.80	1.70	2.40	1.50	1.10	1.80	0.20	10.4
Zone 3	0.72	0.64	1.36	1.92	1.20	0.88	1.44	0.16	8.32
Zone 2	0.10	0.09	0.19	0.26	0.17	0.12	0.20	0.02	1.14
Zone 1	0.06	0.06	0.12	0.17	0.11	0.08	0.13	0.01	0.73
Healthcare 24/7	1.20	1.60	3.60	3.00	1.30	1.00	0.60	0.70	13.1
Zone 3	0.96	1.28	2.88	2.40	1.04	0.80	0.48	0.56	10.4
Zone 2	0.13	0.18	0.40	0.33	0.14	0.11	0.07	0.08	1.43
Zone 1	0.08	0.11	0.25	0.21	0.09	0.07	0.04	0.05	0.91
Other healthcare	0.30	0.50	1.00	0.70	0.90	0.10	0.20	0.10	3.90
Zone 3	0.24	0.40	0.80	0.56	0.72	0.08	0.16	0.08	3.04
Zone 2	0.03	0.06	0.11	0.08	0.10	0.01	0.02	0.01	0.42
Zone 1	0.02	0.04	0.07	0.05	0.06	0.01	0.01	0.01	0.27
Educational	4.00	6.60	9.80	6.10	1.90	1.80	1.10	9.20	40.5
Zone 3	3.20	5.28	7.84	4.88	1.52	1.44	0.88	7.36	32.4
Zone 2	0.44	0.73	1.08	0.67	0.21	0.20	0.12	1.01	4.46
Zone 1	0.28	0.46	0.69	0.43	0.13	0.13	0.08	0.64	2.84
Sport centres	0.20	0.50	1.50	0.60	1.10	0.20	0.50	0.50	5.10
Zone 3	0.16	0.40	1.20	0.48	0.88	0.16	0.40	0.40	4.08
Zone 2	0.02	0.06	0.17	0.07	0.12	0.02	0.06	0.06	0.56
Zone 1	0.01	0.04	0.11	0.04	0.08	0.01	0.04	0.04	0.36
Religious	1.00	0.20	0.10	0.30	0.20	0.29	0.10	0.10	2.00
Zone 3	0.80	0.16	0.08	0.24	0.16	0.23	0.08	0.08	1.83
Zone 2	0.11	0.02	0.01	0.03	0.02	0.03	0.01	0.01	0.25
Zone 1	0.07	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.16
Cultural	0.70	0.20	0.30	0.40	0.20	0.10	0.20	0.30	2.30
Zone 3	0.56	0.16	0.24	0.32	0.16	0.08	0.16	0.24	1.92
Zone 2	0.08	0.02	0.03	0.04	0.02	0.01	0.02	0.03	0.26
Zone 1	0.05	0.01	0.02	0.03	0.01	0.01	0.01	0.02	0.17
Garages	0.10	0.30	0.40	0.20	0.30	0.10	0.10	0.21	1.60
Zone 3	0.08	0.24	0.32	0.16	0.24	0.08	0.08	0.17	1.37
Zone 2	0.01	0.03	0.04	0.02	0.03	0.01	0.01	0.02	0.19
Zone 1	0.01	0.02	0.03	0.01	0.02	0.01	0.01	0.02	0.12
Other	1.90	1.10	2.00	2.20	2.40	0.60	1.00	2.00	13.1
Zone 3	1.52	0.88	1.60	1.76	1.92	0.48	0.80	1.60	10.6
Zone 2	0.21	0.12	0.22	0.24	0.26	0.07	0.11	0.22	1.45
Zone 1	0.13	0.08	0.14	0.15	0.17	0.04	0.07	0.14	0.92
Total	17.6	15.9	27.1	23.0	17.8	9.20	9.50	14.7	134.7

5. Results

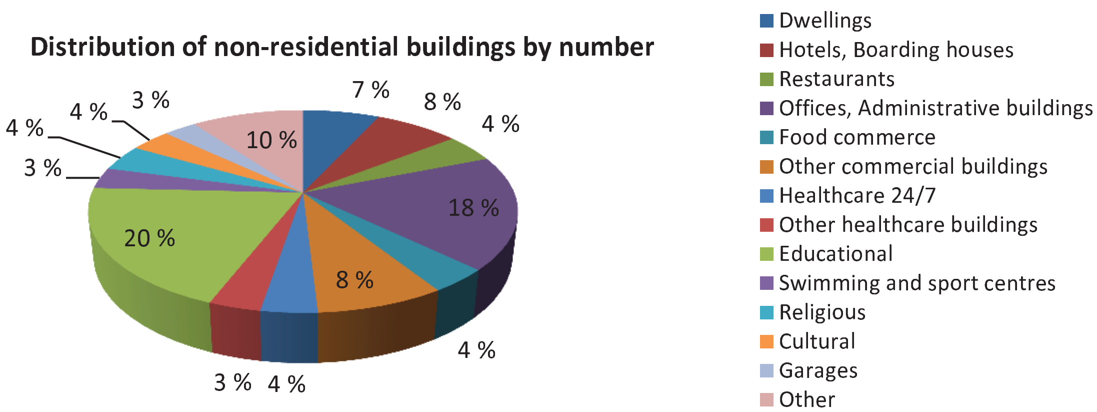
5.1 Results of the characterization of the Swedish non-residential building stock

In this section, the results of the bottom-up characterization of the Swedish non-residential sector are presented. The results are shown according to the different steps within the methodology used to describe the non-residential building stock. They are presented in order to give an overview of how the non-residential building stock is distributed with respect to the different parameters included in the typology.

5.1.1 Segmentation

Building types

The non-residential building stock in Sweden is distributed amongst the 14 building types mentioned in section 4.2.1. In figure 7 and figure 8, the distribution of the different types is shown, both in terms of the number of buildings and the heated area respectively.



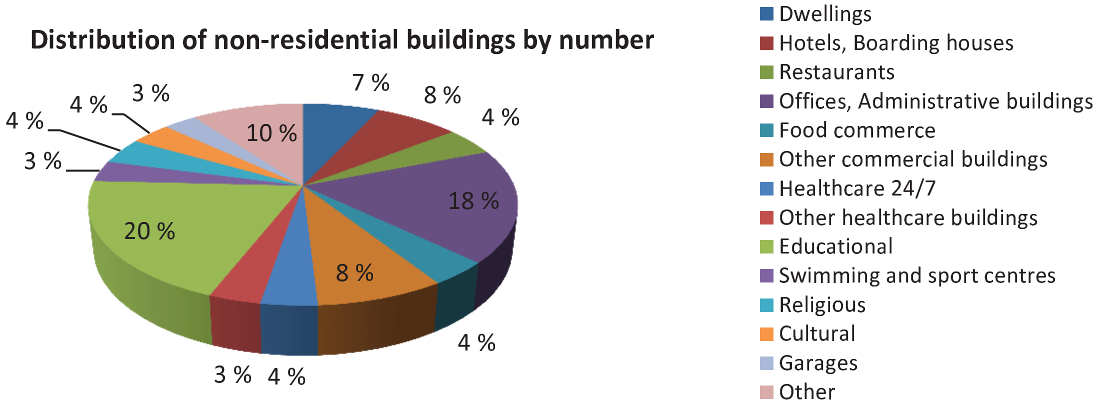


Figure7. The distribution of the non-residential buildings according to number

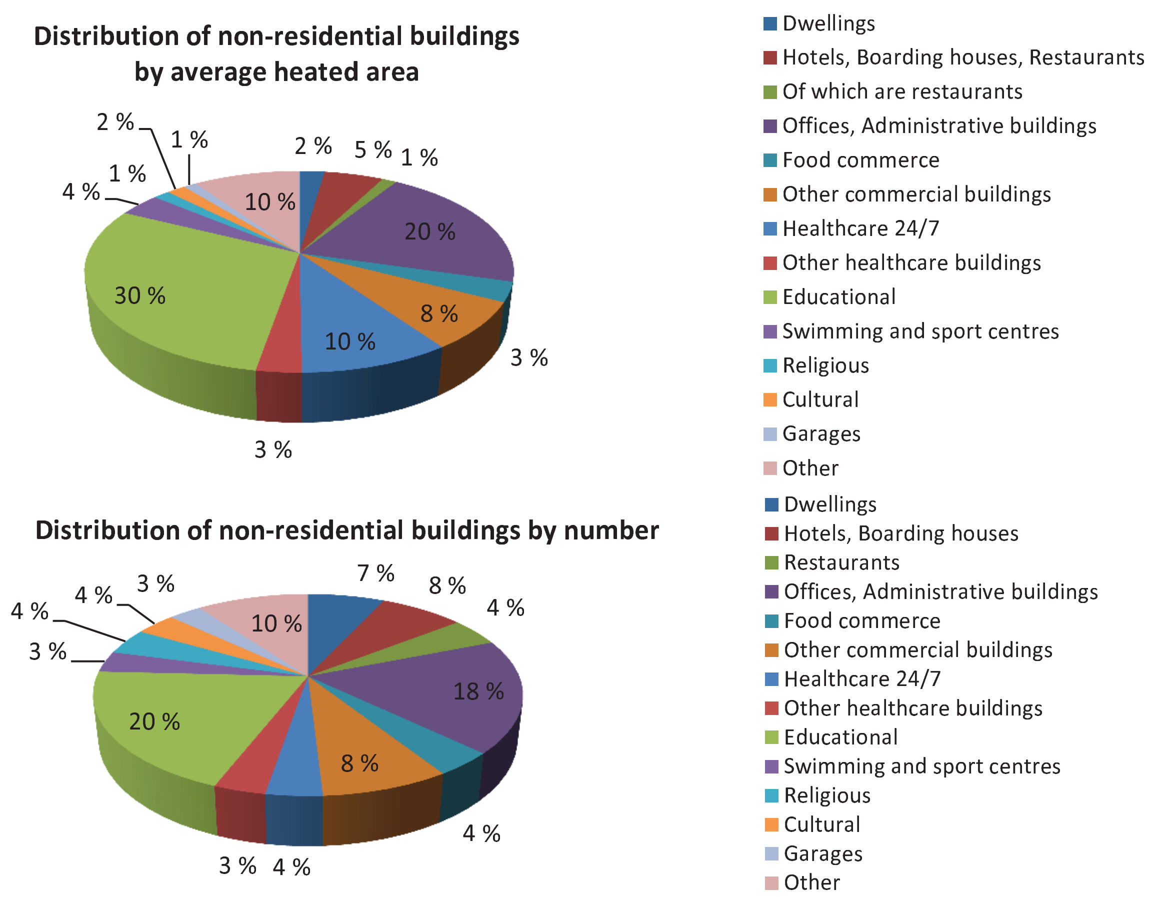


Figure 8. The distribution of the non-residential buildings according to heated area

From figure 7, it is evident that the category of educational buildings holds the largest share by number (20 %) in the entire non-residential building stock. It is followed closely by the category of offices and administrative buildings (18 %). Also, the educational buildings-category possesses a dominating share of the non-residential building stock in terms of the heated area and is, again, followed closely by the category of offices and administrative buildings, as can be seen by figure 8.

Periods of construction

The building types have been segmented into 8 different periods of construction as stated in section 4.2.2. In figure 9 and figure 10, the distribution of the buildings by number and heated area respectively, is shown according to each period of construction.

The majority of the non-residential buildings were completed in the period between 1961 and 1970 while the following decade takes the second place. Not many of the buildings that are included in the non-residential archetypes were constructed in the past two decades.

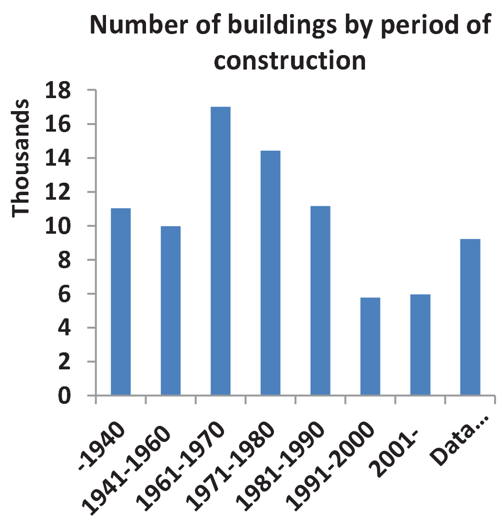


Figure 9. The non-residential building stock distributed by periods of construction in number (thousands of buildings)

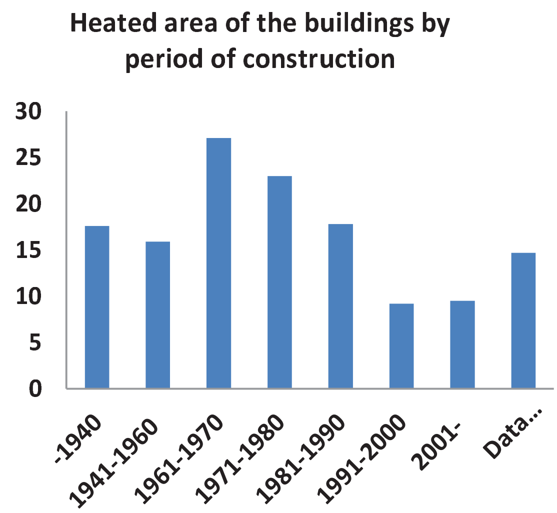


Figure 10. The non-residential building stock distributed by periods of constructiob in heated area (million m^2)

Climate zones

The non-residential building stock in the three different climate zones is shown in figure 11 according to number and figure 12 according to the heated area.

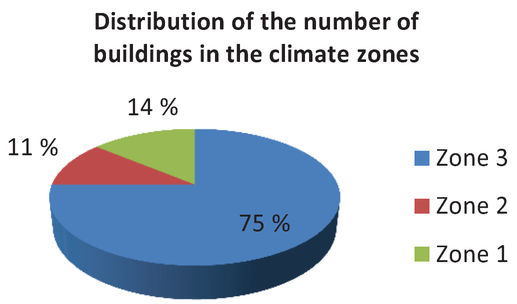


Figure 11. Distribution of the number of buildings in the climate zones

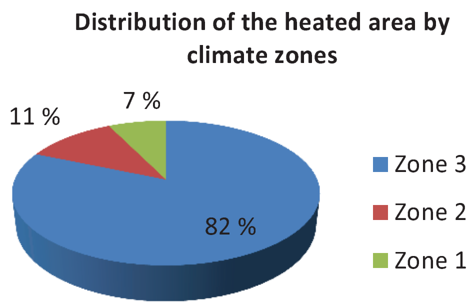


Figure 12. Distribution of the heated area of the buildings in the climate zones

The distribution of the non-residential buildings is denser, both in terms of number and heated area, in the southernmost climate zone, number 3, and more sparsely distributed in the northerly climate zones 1 and 2. However, the distribution of the number of buildings is greater in zone 1 compared to in zone 2 which could be explained by the larger area in climate zone 1. With regards to the heated area, it is larger in zone 2 compared to zone 1, which could be explained by the larger population size in zone 2 than in zone 1.

5.1.2 Quantification

The results of the quantification of the non-residential building stock have been calculated based on the assumptions and the method presented in section 4.4. The details of the calculation results can be seen in Appendix C. Figures 13-16 show the quantification results with respect to the construction years as well as the climate zones in terms of heated area and number.

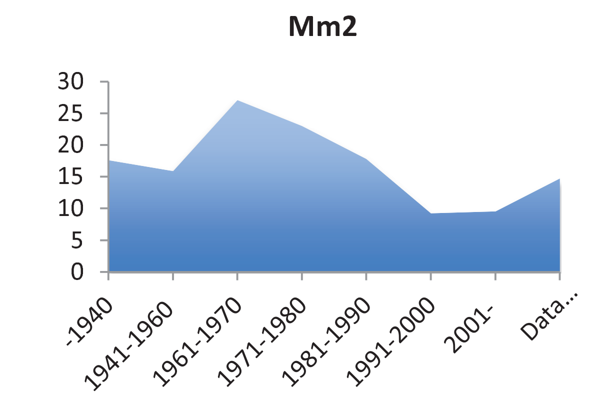


Figure 13. The distribution of the non-residential buildings by heated area in million m^2 and according to the periods of construction

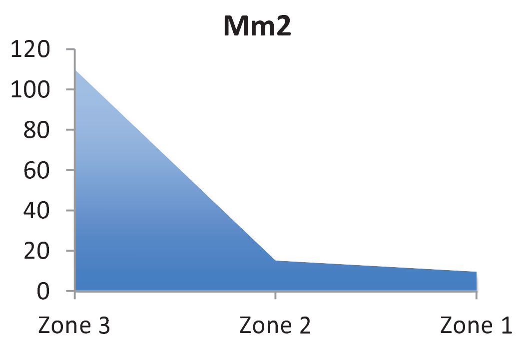


Figure 14. The distribution of the non-residential buildings by heated area in million m^2 and according to the 3 climate zones

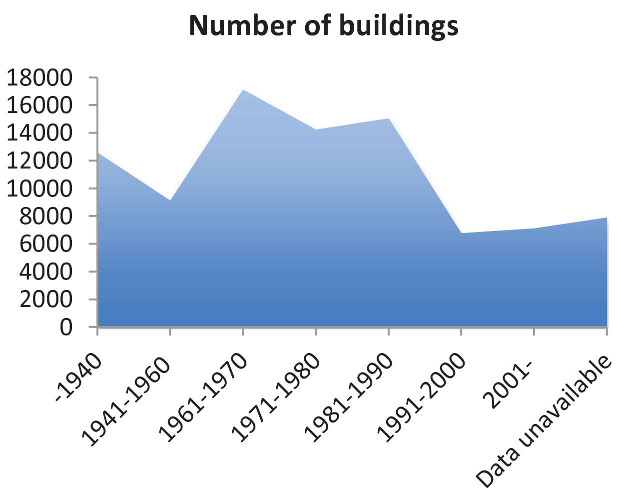


Figure 15. The distribution of the non-residential buildings by number and by periods of construction

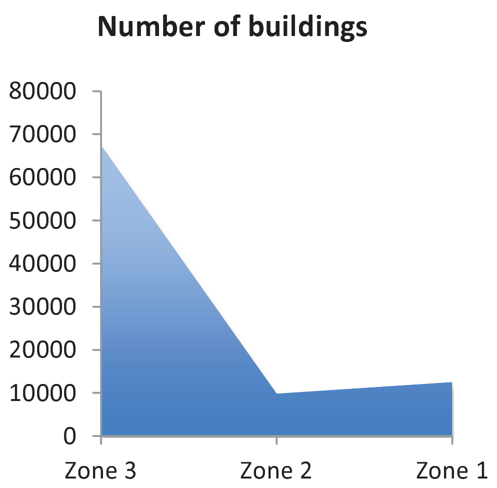


Figure 16. The distribution of the non-residential buildings by number and by climate zones

The non-residential building stock in Sweden is most abundant between the period of construction between 1961 and 1990 and in the third climate zone where most Swedish cities are situated. This is the case for both the amount of buildings and the heated area.

5.2 Results and validation of the ECCABS-model simulation

The energy demand was calculated with the help of the ECCABS model. The 14 archetype buildings that were characterized and quantified served as the input data for the model in the year 2010. The same year of 2010 was set for validating the model with statistics from the reference databases of GAINS, ODYSSEE and STEM. The output data obtained from the model gives the final energy demand disaggregated by fuel types, as well as by end-use where it is disaggregated by space heating, hot water and electricity. The useful energy is also given in a disaggregated form, but only by end-use for space heating, hot water and electricity and not by fuel types. The output data for the useful and final energy demands can be seen in table 5.1.

Table 5.1. The useful and final energy demands for the non-residential building stock disaggregated by end-use – space heating, hot water, electricity – for the year 2010 in TWh

END-USE	FINAL ENERGY	USEFUL ENERGY
Space heating	17.09	16.01
Hot water	4.08	4.16
Electricity	19.91	19.91
Total	41.09	40.07

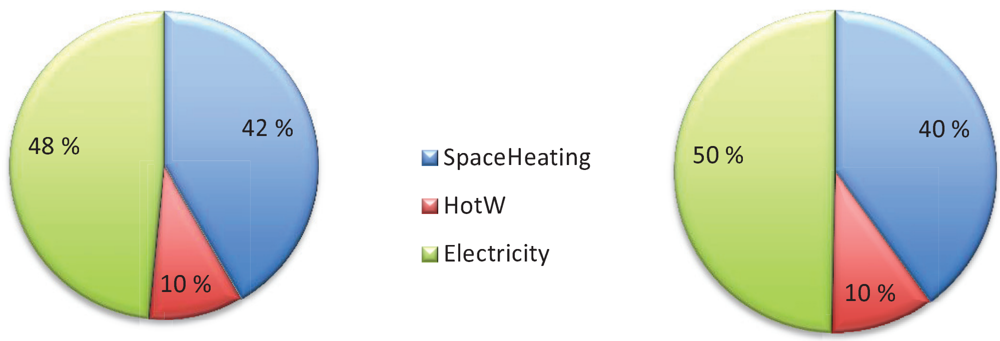


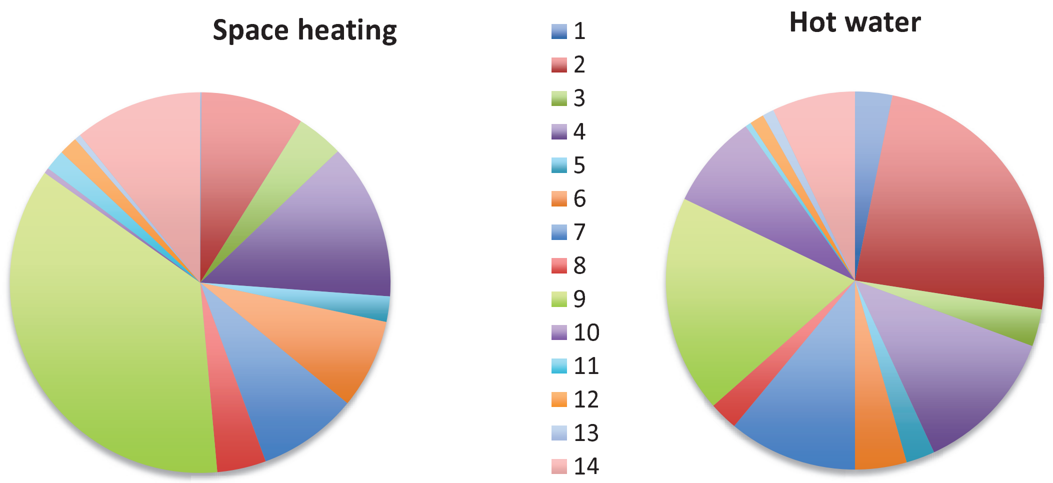
Figure 17. The distribution of the energy demand disaggregated by end-use, final energy demand shown on the left and useful energy on the right

Figure 17 shows the distribution of the final and useful energy demands disaggregated by end-use and from these pie charts, the largest share of energy consumption is held by electricity and the second-largest share is accounted for by space heating.

The results from the ECCABS model are also disaggregated by the non-residential building types for both the useful and final energy demands, which are shown in table 5.2.

Table 5.2. The useful and final energy demands of the non-residential building stock disaggregated by building type and by end-use for the year 2010 in TWh

Building type	Space heating		Hot water		Electricity	
	Final Energy	Useful Energy	Final Energy	Useful Energy	Final Energy	Useful Energy
Dwellings	0.02	0.01	0.13	0.13	0.28	0.28
Hotels, boarding houses	1.5	1.4	0.99	1.01	1.36	1.36
Restaurants	0.68	0.64	0.13	0.13	0.64	0.64
Offices/ Administrative	2.27	2.13	0.51	0.52	3.5	3.5
Food commerce	0.37	0.34	0.1	0.1	1.04	1.04
Other commercial	1.3	1.22	0.18	0.18	1.55	1.55
Healthcare 24/7	1.45	1.36	0.45	0.46	2.51	2.51
Other healthcare	0.71	0.67	0.1	0.11	0.45	0.45
Educational	6.19	5.79	0.76	0.78	5.04	5.04
Sport centres	0.08	0.08	0.33	0.34	0.87	0.87
Religious	0.3	0.28	0.02	0.02	0.26	0.26
Cultural	0.27	0.26	0.05	0.05	0.38	0.38
Garages	0.09	0.09	0.04	0.04	0.29	0.29
Other	1.86	1.74	0.29	0.29	1.74	1.74



Electricity

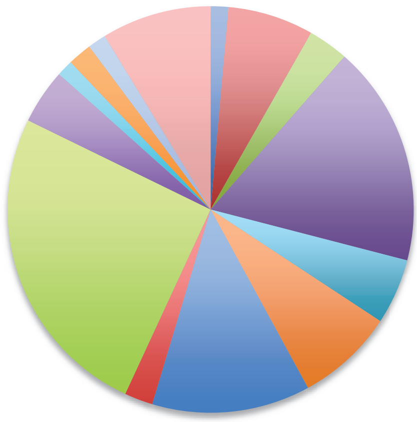


Figure 18. The final energy use for each end-use disaggregated by building types numbered 1-14.

In figure 18, the three charts show the disaggregated final energy demands for each end-use. Each end-use's final energy demand is disaggregated by the different building types, labeled 1-14. Educational buildings (labeled number 9) consume most of the final energy for space heating purposes and electricity, followed by offices and administrative buildings. The final energy consumption for hot water purposes is greatest for the building category of 'other healthcare' followed by educational and offices and administrative buildings in that order respectively.

Furthermore, the energy demands from the simulation process need to be validated against reference databases in order to verify the model as being applicable on the non-residential building stock. The results are validated against the statistics presented by the Swedish Energy Agency (STEM), GAINS and ODYSSEE. The statistics that are most compatible for a comparison with the modeling results are those of the Swedish Energy Agency while ODYSSEE and GAINS are less compatible. ODYSSEE and GAINS have different reference frames when calculating the energy demands of the non-residential building stock compared to the system boundaries defined in this thesis work. For instance, GAINS data on the energy consumption includes more aspects of the tertiary sector than only the non-residential buildings such as agriculture, transportation and residential buildings (GAINS, 2010) GAINS is the least compatible database to compare the results and is therefore not included in the comparisons. Most weight will be placed on the comparison of the results of this work to data provided by STEM.

The data from STEM and ODYSSEE, which are used to compare the results obtained with the ECCABS model, are given in the following tables. The data from ODYSSEE does not include the same segmentation of the non-residential building stock in terms of building types. Nonetheless, it is used as a reference bearing in mind the differences between the system boundaries of this work and their statistics.

Table 5.3. The final energy consumption in TWh for the non-residential buildings included in the services sector from ODYSSEE's database

Building type	Electricity	Total
Hotels, Restaurants	1.63	2.33
Health, social action sector	2.91	5.00
Education/ research	2.56	8.14
Trade (wholesale/ retail)	5.82	6.16
Public & private offices	5.23	8.26

From data in both ODYSSEE's database and the statistics published by STEM, the final energy consumption has been disaggregated by fuel types. The ECCABS model also presents its output data of the final energy demand disaggregated by fuel types. These data are summarized in table 5.4.

Table 5.4. The final energy demands from the three different sources – ECCABS model, ODYSSEE and STEM – disaggregated by fuel types in TWh

Fuel types	ECCABS	ODYSSEE	STEM
Coal	0	0	0
Oil	1.08	2.33	0.77
Gas	0.4	1.16	0.31
District heating	16.73	18.49	15.96
Biomass	1.47	0.47	0.47
Electricity	21.3	26.17	16.15
Total	41.09	46.64 (48.61)[1]	33.7

[1]Without climatic corrections

The summary of the final energy demand disaggregated by fuel types shows that there is a deviation between the totals. The total obtained with the ECCABS model amounts to 41.09 TWh/yr, which is 21.9 % higher than the total provided by STEM and 11.9 % lower than the total given in the database of ODYSSEE. However, looking at the distributions of the fuel shares there is a slight difference between STEM and the ECCABS model, with the exception of a few. The shares of the fuels taken in the same order as that presented in table 5.4 are 0 %, 2.63 %, 0.97, 40.7 %, %, 3.58 % and 51.8 % for the ECCABS model and 0 %, 2.28 %, 0.92 %, 47.4 % , 1.39 % and 47.9 % for the data in STEM. The exceptions that are noticed are the fuel shares of district heating, biomass and electricity that deviate more than the other fuel shares. Possible reasons for these deviations are suggested and explained in further detail in section 6 where a discussion of the overall results will be given.

6. Discussion

Possible reasons for the deviation in the results obtained in the simulation performed and the statistics used as references are explained in the following section.

Firstly, there are some uncertainties in certain assumptions that were made in the steps within the methodology before the simulation process.

- Some parameters were lacking information on the variation between climate zones or for the different periods of construction for the typical buildings. In these cases, it was assumed that these parameters were the same for all the climate zones or the periods of construction. For example, the internal heat gain from lighting is one of these parameters. The lighting load was assumed to consume 25 % of the total use of electricity for other purposes than heating and hot water for the whole country. The lighting load in the north of Sweden would generally be higher than the lighting load in the buildings situated in the more southern climate zones due to the lesser number of light hours in the north of Sweden. In the collection of data and material regarding this parameter, no information as to how much the use of lighting in the north differs from the south was found. This is also the case for the internal heat gains from appliances where similar assumptions were made. Consequently, these assumptions would affect the share of electricity in the total final energy demand.

- Similarly, the consumption of the hydronic pumps was another parameter surrounded by uncertainty. The information of hydronic pumps in the Swedish non-residential building stock was lacking and was assumed to be the same for all the building categories in all the periods of construction as well as in all the climate zones. The consumption of hydronic pumps would differ from one building type to another. For example, the hydronic pumps of a warm garage compared to the hyrdonic pumps used in an office or dwelling would be quite different.

- Moreover, some parameters were difficult to manage in the different periods of construction. In these cases, they were assumed to be the same for all the periods of construction and some examples of such parameters are the V_c, SFP and U-values for some specific building types.

Secondly, the assumption made in the segmentation step of this work concerning the climate zones, and therefore affecting the temperature parameter, might have a large impact on the results and the values of the input data.

- In the segmentation process, the climate zones were defined by choosing a reference city that would represent the whole climate zone. These reference cities were in turn chosen by taking the city with the largest population of inhabitants within the specific climate zone’s boundaries. This was done as it is considered that the building stock is well represented by cities of this type, as the buildings are usually abundant in large cities. Even if it is considered a valid assumption for choosing the weather files associated with these reference cities, the three cities chosen to represent the climate zones are all coastal cities. The fact that they are all situated on the coast may not provide a fair overall representation of the climate zone as coastal climates are somewhat special and differ from inland climates. Perhaps choosing the cities with the three largest populations within the specific zone could improve the assumption made and in turn, improve the selection of weather files used in the model.

- The defining criteria for the climate zones would affect the choice of the weather files obtained from the database Meteonorm. These weather files used provide only data up until 1990 giving a data gap of more than 20 years. The non-residential buildings that are described and characterised in this report have been done so for the year 2010 while the corresponding weather files describe the temperatures only until 1990. This would result in deviations since the weather over 20 years may change significantly, especially considering the climate change patterns.

Further possibilities for the deviations between the results and the statistical references can be due to the uncertainties within the statistical values produced by STEM itself.

- Uncertain categories are included in the categorisation of buildings and periods of construction. These categories are the ones labelled others and data unavailable. No information as to what is included within theses categories is given and can be judged to be a source of uncertainty when assigning values to the input parameters concerning these categories.

- The statistics published by STEM are associated with uncertainty intervals for each value, sometimes with these intervals having a wide range of values. These uncertainty intervals were neglected in order to simplify the processing of the data to be used as input values for the ECCABS model. Perhaps accounting for these uncertainty values would minimise the deviations seen in the results. One way of accounting for these uncertainty values might be to use scenarios when performing the simulations of the energy demand within the non-residential building sector. For example, three such scenarios could be used where one considers the maximum, minimum and average values for different parameters. Certain parameters to consider in scenarios could be the areas and number of buildings, the different internal heat loads and the hot water demand.

The results of the final energy demand may also differ from the statistics used as reference databases because of different criteria for measuring and calculating the energy demand. A closer investigation of these exact criteria needs to be performed in order to provide a fairer comparison and reference frame. For example, it is not clear from ODYSSEE's 'heating' to represent electricity or district heating.

Additionally, the sources consulted in order to compile the input data have been of a heterogeneous nature. The series of reports included in the STIL2 project aim at improving the energy statistics, with a commencement of the project in 2005. For each year, one non-residential building category was studied according to that category's energy use and technical status of the buildings included. In 2005, offices and administrative buildings were studied and data regarding their energy consumption trends were collected continuing in 2006 with the study of educational buildings, and so on. The last building category to be investigated in this project was commercial buildings in 2010, so the range of data used as input data has a range of 5 years.

In 5 years' time, retrofitting of the existing buildings could have been performed, improving the buildings energy patterns. If the rate of retrofitting measures could be accounted for on an annual basis, which it is not in this work, it would result in the decrease of the total final energy demand. Also, the criteria for the different building categories included in the separate STIL2 do not correspond to the criteria used in the Swedish Energy Agency's statistics or the criteria used in this report according to the segmentation process. This is also a point needed to remark upon as it affects the precision of the modelling process.

The use of building regulations as a source for different parameters may also be a source of error. The building regulations used in this work are taken from the latest version of the regulations. These may not reflect the reality of what actually is found in the already existing buildings in the sense that these buildings may not have been retrofitted in an up-to-date fashion or not at all. Despite this possibility, the information provided by the building regulations has been used to characterize certain parameters.

The fuel shares with the largest deviation to the values presented in official statistics and which have been difficult to correct in the simulation process are the shares of district heating and electricity. The disaggregation of the final energy by fuel shares has been made in the official statistics but the way in which the disaggregation has been measured or calculated is not presented. The district heating could include direct or indirect electric heating. Some buildings also have their own heating supply, which may not be reported and would therefore not be included in the official statistics. Furthermore, the energy statistics were presented in a manner in which the energy for both space heating and hot water purposes were aggregated. This made the disaggregation of energy slightly awkward and it was assumed that the fuel shares for space heating were equivalent to those for hot water.

The amount of reports concerning the energy demand by non-residential building stock was limited compared to that available for the residential building stock. Furthermore, the level of detail concerning the parameters affecting the buildings' energy consumption was generally lower than that provided for residential buildings or completely lacking. From the literature study performed throughout this work, the monitoring of the non-residential building stock, both in Sweden and in Europe, is poorer than that of it residential counterpart. However, this fact is acknowledged by the EU member states and projects concerning the supervising of the non-residential stock are becoming numerous. The surveillance of the non-residential building stock's energy demand is a work in progress and there is room for improvements to be made concerning the energy statistics published.

7. Conclusions and Further work

Several conclusions can be drawn from this master thesis regarding the methodology used to describe the non-residential building stock and the ECCABS model used to simulate it.

Concerning the methodology:

- It was possible to define archetype buildings for the Swedish non-residential building stock following the methodology presented in the Pathways project. On the other hand, the three-dimensional segmentation resulted in 336 archetype buildings and it can be discussed if the segmentation dimension concerning building types can be revised in order to minimise the number of archetypes.

- In the segmentation process, it was assumed that the climate zones were represented by a single city chosen according to its population size. The climate zones could be chosen by a more accurate method, as in this case, the three cities chosen to represent the zones were situated along the coast.

- The characterisation process was time-consuming and it was difficult to obtain values for many of the parameters. Assumptions were made in order to obtain information on specific parameters where some of these parameters affected the model outcome significantly. Also, it was difficult to disaggregate the energy in terms of end-use since the data concerning this point was aggregated by end-use.

- The lack of detailed data concerning the non-residential building stock should be remarked and could be one of the sources for making the description of the non-residential building stock less accurate.

- A sensitivity analysis would be interesting to perform in order to identify the input parameters with a significant effect in the energy demand. However, the sensitivity analyses of other, similar master theses were used to give an idea of which parameters the model is most sensitive to.

Concerning the ECCABS model:

Further work is needed to research the specific input parameters that were uncertain in the model. Also, a closer look needs to be taken on some of the assumptions that were made and perhaps the use of scenarios mentioned in the discussion might be more appropriate to use in order to model the energy demand. A further example of such scenarios could consist of assuming 16 hours of no occupancy followed by 8 hours of occupancy at a specific work place (non-residential building). Using this type of scenario could modify the values of the input parameters and hence the energy consumption of the buildings. This might be interesting to investigate because such assumptions have a significant effect on the model. The statistics that were used were presented with uncertainty intervals as discussed previously and these intervals could be used to provide additional scenarios of a minimum and maximum energy demand.

The non-residential building stock of Sweden has been describes in this master thesis and further studies, outside the scope of this master thesis, could be made to investigate the effect of the implementation of energy efficiency measures to the building stock.

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Figure 2.

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Figure 3.

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