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Master Thesis

Estimation of Electric Energy Demand using 3D City Models

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Declaration

I, Camilo Alexander Leon Sanchez, matriculation number 3366228, hereby declare that I have written independently my Master's thesis on the subject

Estimation of Electric Energy Demand using 3D City Models

with no other help than the stated sources and aids which I have marked with proper citations as such.

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Estimation of Electric Energy Demand using 3D City Models

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Berlin, August 12, 2013

Camilo Alexander León Sánchez

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Abstract

In this master thesis, a methodology for the estimation of electrical energy demand of buildings using a 3D city model is presented. The idea of include that kind of data lies in the fact that nowadays those models are rich of geometric and semantical data, which could be useful in energy demand forecasting.

The first part of the document introduces the basic concepts of the Geographic Information Systems, the CityGML standard and the Web Map Services. As well as the introduction of basic concepts of energy and the presentation of several methods for the estimation of electrical energy demand. After the presentation of the different methodologies, the selection of the End-Use method is done, which is the one that better suits the scope of this master thesis. After the selection of the method to use, a better presentation of its characteristics is done.

Later the comprehensive tools for processing CityGML files are presented, giving a description of their characteristics and why are they considered. After this chapter the problem statement of the master thesis is done.

In the following chapter the methodology for the estimation of electrical energy demand is done, first from a theoretical perspective being detailed in every single step of the process at the end the chapter is concluded by the presentation of the work-flow diagram that better states the ideas presented. After this chapter the results of an area of study used in the implementation part of the master thesis are shown, in this section the methodology is evaluated and some adjustments to the initial idea are done.

The final chapter of this document is dedicated to the conclusions and the presentation of further researches that could take place after.

Zusammenfassung

In dieser Masterarbeit wird eine Methodik für die Prognose vom Strombedarf der Gebäude mit der Benützung eines 3D-Stadtmodell vorgestellt. Die Idee liegt um diese Art von Daten zu nutzen, dass heute diese Modelle reichen von geometrischen und semantische Daten, die nützlich sein in Energie Bedarfsprognose könnten.

Der erste Teil des Dokuments wird die grundlegenden Konzepte der Geographic Information Systems, der CityGML-Standard und den Web Map Services vorgestellt. Neben der Einführung der grundlegenden Konzepte von Energie und die Aufführung von verschiedene Methoden für die Prognose des Strombedarfs. Nach der Präsentation der verschiedenen Methoden, die Auswahl der End-Use-Methode durchgeführt wird, das ist der eine, die passt besser zu das Ziel dieser Masterarbeit. Nach der Auswahl der Methode zu verwenden, wird eine bessere Präsentation seiner Eigenschaften getan.

Im folgenden Kapitel wird die Methodik für die Prognose des Strombedarfs erfolgt, zunächst ist aus theoretischer Perspektive jeder einzelne Schritt des Prozesses detaillierte , und am Ender des Kapitels stellt die Präsentation der Work-Flow Diagramms, die besser den Prozess fest erklären.

Nach diesem Kapitel werden die Ergebnisse eines Test Region die in der Umsetzung Teil der Masterarbeit verwendet gezeigt, in diesem Abschnitt ist die Methodik ausgewertet und einige Anpassungen bei der ersten Idee sind fertig.

Das letzte Kapitel dieses Dokuments wird auf die Schlussfolgerungen und die Präsentation von weiteren Forschungsthemen fokussiert, die in kommenden Projekten könnten ausgebildet.

Acknowledgements

" I can do everything by the power of Christ.
He gives me strength"

Philippians 4:13

First of all I want to thank God for giving me the chance of making my dream come true, I could live and study in Berlin. I would like to thank Prof. Dr.-Ing. Frank Neitzel and Dipl.-Ing. Thomas Becker for being my tutors during my master thesis but most, for their cooperation during the last months. I would like to thank as well to the staff members of the Institute for Geodesy and Geoinformation Science who always are there ready to help us. Finally, to Prof. Dr. rer. nat. Thomas H. Kolbe for giving me the idea of working in this topic.

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Esto es por ti abuelito Efraín, siempre estarás en mi corazón.

1. Introduction

1.1. Motivation

At the present time, new technologies are developed every single day in such a variety of topics that could go from the wide popular internet and smart phones up to electric cars. Almost all of them share a factor in common, they need electrical energy. This incredible request for electrical energy and the increase in the concern for the environment lead the decision makers to demand a good knowledge of the electrical energy consumption of a place (city, region, country). For that reason, Several approaches have been developed for the estimation of energy consumption with different scopes such as energy forecasting or the influence of human behaviour to mention some.

It is likely that most of those studies took place on countries located on high latitudes where seasons entail a dramatic change of temperatures. These researches have considered different methodologies to obtain their results, such as econometric, trends, inventories, end-user models and so on, but at this moment in time, none of those that have been found and used as references for the elaboration of this document do include 3D city models as an input parameter for the estimation of electrical energy consumption.

1.2. Problem Statement

Chapters 2 and 3 of this Master Thesis give us the theoretical background from both the CityGML standard and the forecasting of Electrical Energy Demand. No matter what estimation method is used, this is a meticulous and rigorous process that requires detailed data, which must be included into the building simulation resulting in a more realistic assessment of energy demands (Yamaguchi, Fujimoto & Shimoda 2011, Lee, Yi & Malkawi 2011).

For this master thesis, the End-Use method is considered (section 3.1.5) because it focuses only on the impact of energy usage patterns of various devices and systems. This is called Energy Appliances (Mehra & Bharadwaj 2000) and involving factors such as number of devices, number of users, time of use and its energy consumption. None of those variables are external such as electrical energy prices, population income, social status, etc. Instead of that they are focused on facts that can be influenced by the building itself, for example the number of users of a microwave oven for a 1 person flat will differ from a 4 people house.

It is expected that a well defined and detailed, from both geometric and semantic perspectives, 3D building model will lead to a better analysis of the Electrical Energy Appliances of a residential unit. Knowing the spaces of a building or an apartment influences directly on equipment requirements leading to a better definition of the energy appliances database, i.e. a kitchen requires stoves, ovens, etc. For that reason this master thesis is developed, with the hope that the estimation the electrical energy consumption of a residential building can be done based on its 3D CityGML model.

2. Geographic Information Systems

The first Geographic Information System ***GIS*** appeared at late 1960's as an initiative of the Canadian Government to produce Land capability maps. Those maps were later analysed in order to obtain information of agricultural rehabilitation of marginal farms(Coppock & Rhind 1991), this system is known as the Canada Geographic Information System (CGIS). Since their origin, GISs have been used as computer based systems for geographic information that allows the user to process large amounts of data, which is spatially located in an specific place.

Evolution of technology have entailed a benefit for the GIS sector. Now it is possible to store massive amounts of data in a single computer. Data can be processed locally as well in a remote way over a local network or as nowadays over the cloud even with the use of portable devices such as mobile phones. Former time data was mostly available in 2D, the initial results of a GIS were printed maps or tables that were used by the decision makers to support their statements. This initial concept have changed by the time, the digital era offers multiple possibilities for the users to visualise and present their results, an additional alternative are Web services, such as Web Map Service (WMS). Based on dynamic user requests, the service returns a raster version of a map i.e. a png file (de la Beaujardiere 2006). A second possibility is a Web Feature Service (WFS), a type of service that from a user request returns the features or data itself that could even be modified locally by the user and after stored again of the server (Vretanos Panagiotis 2005).

Nowadays most of the data and information available is on 3D, with new paradigms of data acquisition and processing i.e. LIDAR, Digital Photogrammetry, Radar Satellite sensors. This kind of data contains not only x and y coordinates but also height values (z coordinate) so new possibilities have emerged so users not only represent the landscape with Digital Terrain Models (DTM) or Digital Elevation Models (DEM) but also to model human built structures like buildings, bridges, tunnels, etc., this kind of data has been modelled for many years using CAD software such as Autocad, Microstation or ArchiCAD. However new standards are requested so the data can be read, shared and used between multiple users. One of them is CityGML (section 2.1) its functionality is much wider than just semantical and geometrical 3D objects representation. The CityGML can also be used in projects like (Lee 2004), to model Human Activity by using 3D GIS or as as data source for indoor navigation purposes like in (Nagel, Becker, Kaden, Li, Lee & Kolbe 2010).

2.1. City Geography Markup Language

The City Geography Markup Language has been developed since 2002 as a part of the initiative Spatial Data Infrastructure Germany (GDI-DE), in 2008 version 1.0.0

was adopted as an Open Geospatial Consirtium (OGC) standard, being updated in 2012 by CityGML 2.0 a major revision of the model, which introduces a "substantial addition and new features to the thematic model of CityGML" (Kolbe, Gröger, Nagel & Häfele 2012). The standard was implemented as an application schema of the Geography Mark-up Language version 3.1.1 (GML3) based on the ISO 19107 model.

This standard models 3D vector data with their associated semantic information, (Kolbe et al. 2012) it also provides an extension mechanism to enrich the data with identifiable features under the preservation of semantic interoperability. CityGML presents a multi-scale model with 5 well-defined consecutive Levels of Detail (LOD), where objects are more detailed with increasing the LOD regarding both their geometry and thematic differentiation. A CityGML file can contain multiple representations and geometries for each object in different LOD simultaneously. Table 2.1 gives description of the different Levels of Detail.

	LOD0	**LOD1**	**LOD2**	**LOD3**	**LOD4**
Model scale description	regional, landscape	city, region	city, city districts, projects	city districts, architectural models (exterior), landmark	architectural models (interior), landmark
Class of accuracy	lowest	low	middle	high	very high
Absolute 3D point accuracy (position/height)	lower than LOD1	$5/5m$	$2/2m$	$0.5/0.5m$	$0.2/0.2m$
Generalisation	maximal generalisation	object blocks as generalised features; $> 6*6m/3m$	objects as generalised features; $> 4*4m/2m$	object as real features; $> 2*2m/1m$	constructive elements and openings are represented
Building installations	no	no	yes	representative exterior features	real object form
Roof structure/ representation	yes	flat	differentiated roof structures	real object form	real object form
Roof overhanging parts	yes	no	yes, if known	yes	yes
CityFurniture	no	important objects	prototypes, generalised objects	real object form	real object form
Solitary Vegetation Object	no	important objects	prototypes, higher 6m	prototypes, higher 2m	prototypes, real object form
Plant Cover	no	$> 50*50m$	$> 5*5m$	$< LOD2$	$< LOD2$

Table 2.1.: LOD 0-4 of CityGML with their proposed accuracy requirements

sources: (Kolbe et al. 2012)

A visual example of the Levels of Detail can be seen in figure 2.1.

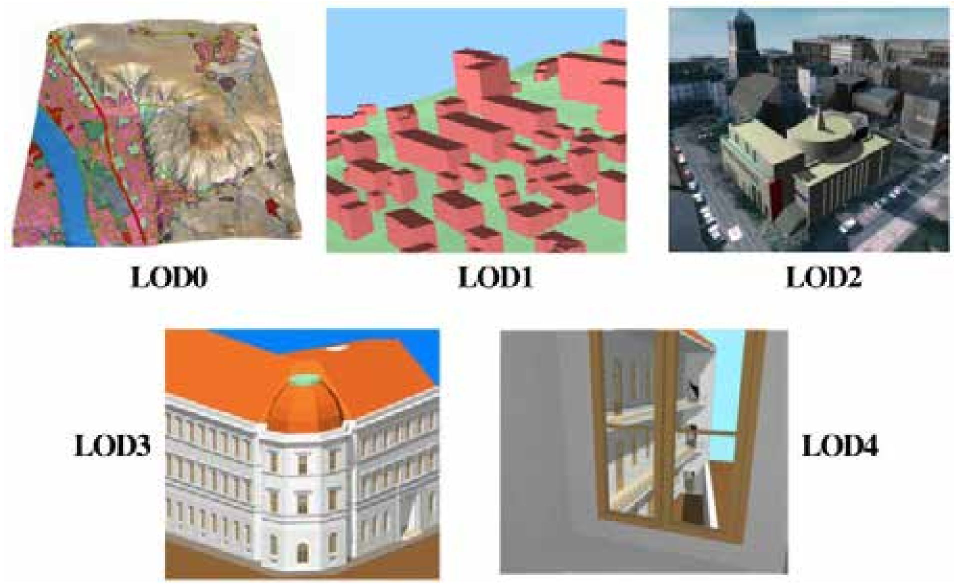


Figure 2.1.: The five levels of detail (LOD) defined by CityGML
source: OGC City Geography Markup Language (CityGML) Encoding Standard (Kolbe et al. 2012)

As mentioned at (Kolbe et al. 2012), CityGML includes both spatial and thematic models (Section 2.1.1). The spatial model allows the consistent and homogeneous definition of geometrical and topological properties of CityGML features, representing them as GML3's geometry model objects, involving the use of their geometric primitives. This means that the model is based on the standard ISO 19107 "Spatial Schema" representing 3D geometry according to the Boundary Representation model.

A further definition of the spatial model can be found in the CityGML specification document (Kolbe et al. 2012) section 8. The thematic model employs the geometry model for different thematic fields. Within this master thesis the Building Model, is of a special interest and it is explained at section 2.1.1. The standard offers also a possibility to model objects that are not explicitly modelled yet by using the concept of generic objects and attributes (section 2.1.2).

2.1.1. Thematic Model

The thematic model of CityGML allows an explicit modelling of certain type of objects in order to reach a high degree of semantic definition and interoperability between applications. Most of the classes are derived from the basic geometric classes _Feature and _FeatureCollection for the representation of the spatial objects. However features can also contain non-spatial attributes which are mapped to GML3 feature properties with their corresponding data types. This guarantees that attributes and data types will have a standardised interpretation.

The CityGML standard includes the following thematic extension modules: Appearance, Building, CityFurniture, CityObjectGroup, Generics, LandUse, Relief, Transportation, Vegetation, WaterBody, and TexturedSurface. Thematic extension modules **Bridge, Tunnel** are introduced in version 2.0 (Kolbe et al. 2012)

Building Model

According to (IGGS 2009a, Kolbe et al. 2012), this thematic model allows Buildings to be represented in all levels of detail (LoD0 to LoD4). It enables the representation of simple buildings that consist of only one component as well as the representation of complex relations between parts of a building, e.g. a building consisting of three parts a main house, a garage and an extension, those parts can again consist of parts.

An example of a simple and complex building can be seen in figure 2.2.

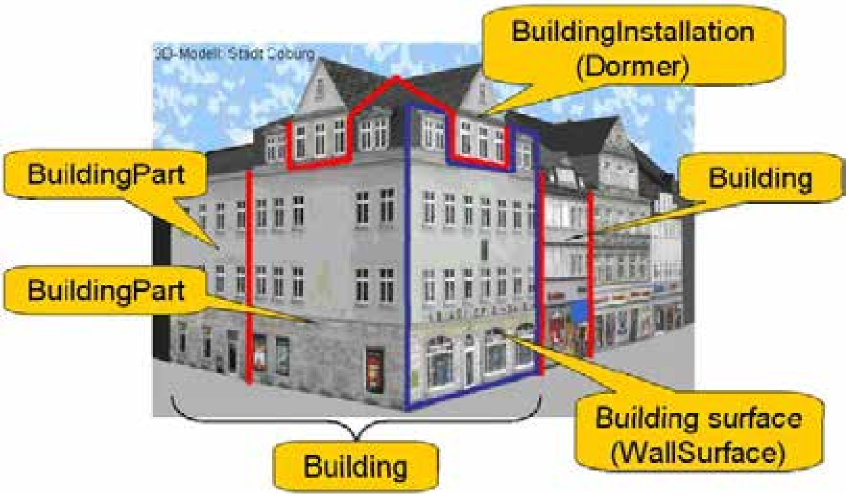


Figure 2.2.: Example of buildings consisting of building parts
source: 3D Geo Database for CityGML (IGGS 2009a)

The subclasses ≪Building≫ and ≪BuildingPart≫ of ≪AbstractBuilding≫ enable these modelling options. The first two subclasses inherit all properties from the latter one like its function, usage, year of construction, etc. (figure 2.3).

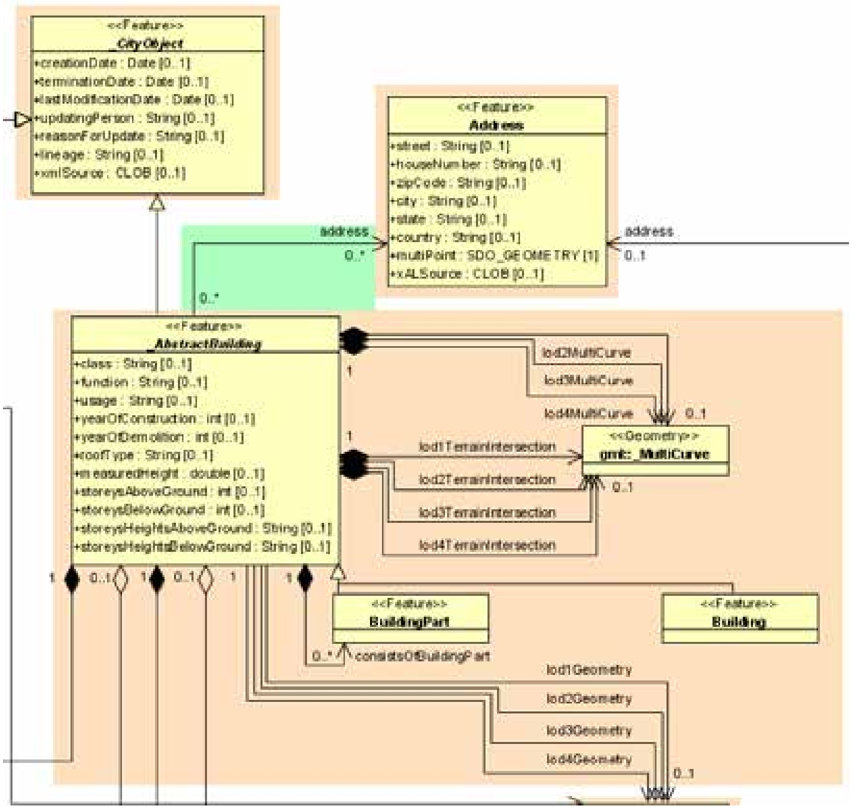


Figure 2.3.: Excerpt from the UML Diagram of the Thematic Building Model

source: 3D Geo Database for CityGML (IGGS 2009a)

Attribute values are generally filled in the lower hierarchy level, because basically every part can have its own construction year and function. However, the function can also be defined in the root of the hierarchy and therefore span over the whole building. It is important to mention that the individual Building Parts within a Building must not penetrate each other and must form a coherent object.

Figure 2.4 presents the different levels of details LoD of CityGML. In LoD0 the building is represented by horizontal surfaces describing the footprint and the roof edge. In LoD1, a building model consists of a geometric representation of the building volume. This geometric representation is refined in LoD2 by additional MultiSurface and MultiCurve geometries, used for modelling architectural details like a roof overhang, columns, or antennas. In LoD2 and higher LoDs the outer facade of a building can also be differentiated semantically. Closure surfaces can be used to virtually seal open buildings as for example hangars, allowing e.g. volume calculation.In LoD3, the openings in _BoundarySurface objects (doors and windows) can be represented as thematic objects. In LoD4, the highest level of resolution, also the interior of a building, composed of several rooms, is represented in the building model by the class Room.

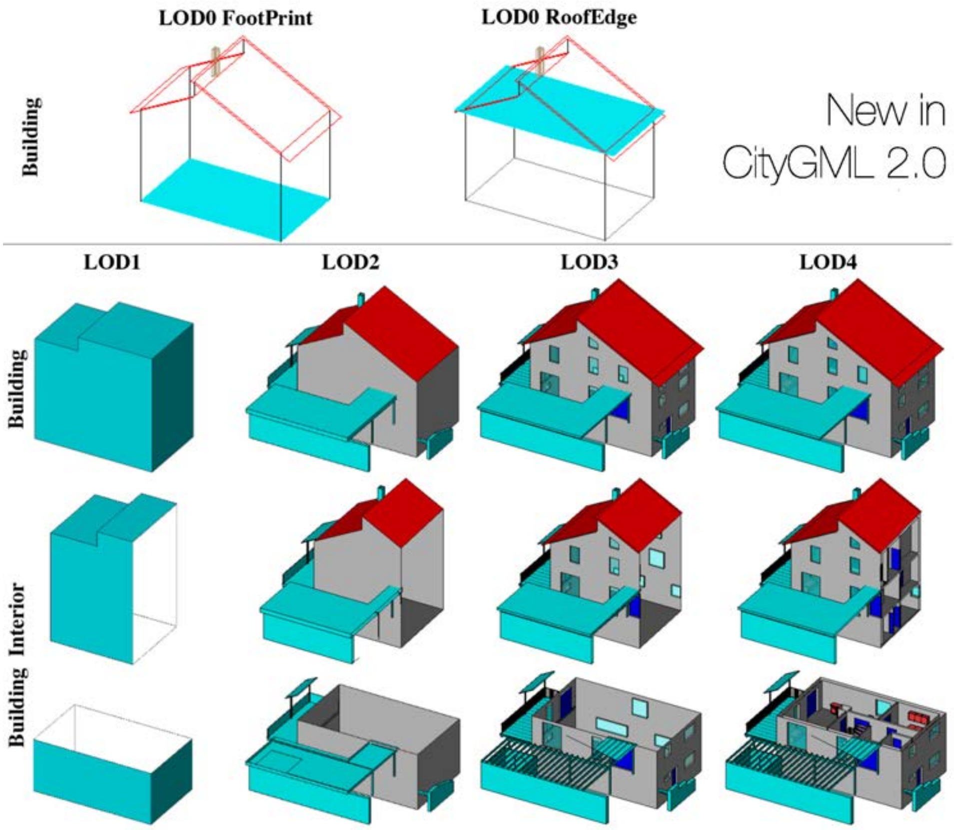


Figure 2.4.: Levels of Detail of the Building Model of CityGML
source: (Eicker, Nouvel, Schulte, Schumacher & Coors 2012, Kolbe et al. 2012)

2.1.2. Extending CityGML

The concept of generic objects and attributes allows for the extension of CityGML applications during runtime, i.e. any _CityObject may be augmented by additional attributes, whose names, data types, and values can be provided by a running application without any change of the CityGML XML schema. Similarly, features not represented by the predefined thematic classes of the CityGML data model may be modelled and exchanged using generic objects.

In addition, extensions to the CityGML data model applying to specific application fields can be realised using the Application Domain Extensions (ADE) (Kolbe et al. 2012). Such additions comprise the introduction of new properties to existing CityGML classes like e.g. the number of habitants of a building or the definition of new object types. The difference between ADEs and generic objects and attributes is, that an ADE has to be defined in an extra XML schema definition file with its own name space. This file has to explicitly import the XML Schema definition of the extended CityGML modules.

2.2. 3D-Geo-Database for CityGML

The Berlin 3D City Geodatabase was created on behalf of the Berlin Senate and Berlin Partner GmbH and funded by the European Union in the Period from November 2003 and December 2005. It was developed at the Institute of Geodesy and Geoinformation Science at the TU Berlin extending the work done at the Institute for Cartography and Geoinformation (IKG) of the University of Bonn and was implemented and evaluated in cooperation of Autodesk GmbH in Potsdam (IGGS 2009a). The database fulfils the CityGML standard model and was implemented in the DBMS Oracle 10G R2. In March 2012 a new version that fully supports the DBMS Oracle 11G was released (IGGS 2012). This database fulfils the CityGML standard for read and write files (versions 1.0.0 and 0.4.0.) and read (versions 0.3.0 and 0.3.1).

Being a compliant CityGML database means that it defines its classes and relations for topographic objects based on important properties like geometry, topology, semantic and appearance (IGGS 2011). This data model supports up to 5 Levels of Detail (LoD) for any geographical object (geo-object) meaning that when the LoD is increased, object obtain a more precise and finer geometry as well as its thematic refinement. In the case of DTMs, it supports several types of representation and could combine them when it is required. This also means spatial data types that are not explicitly modelled in CityGML (raster files), for that purpose and in order to manage orthophotos or aerial photographs, the Oracle 10G R2 GeoRaster functionality is used.

The database model supports the storage and management of any geo-object that is not already specified in CityGML. Nevertheless, it requires that those application systems that would use these data must be able to interpret those file formats and afterwards retrieve them back to the database. Those objects could have external references, which may help them to have a better definition or to extend the information about it e.g. a building with an id of a cadastre information system. There is also no restriction on the geometry of the 3D objects, they can be represented as the combination of solids and surfaces and an aggregation of these elements.

This is an Open Source project and the entire software development is freely accessible to the interesting public. (IGGS 2011, IGGS 2009a)

3. Energy

Generation and utilisation of energy involves a conversion from one energy form into another, which in several situations requires intermediate steps. Energy could be classified (FAO. 1991) in primary, secondary, final and useful. Table 3.1 presents this classification, as well as some technologies and examples.

Energy	**technology**	**examples**
Primary		coal, wood, hydro, dung, oil, etc.
	conversion	power plant, kiln, refinery, digester
Secondary		refined oil, electricity, biogas
	transport / transmission	trucks, pipes, wires
Final		diesel oil, charcoal, electricity, biogas
	conversion	motors, heaters, stoves
Useful		shaft power, heat

Table 3.1.: Energy flow

source: Energy for sustainable rural development projects - Vol.1: A reader(FAO. 1991)

Where:

- **Primary Energy:** is the energy as it is available in the natural environment, i.e. the primary source of energy.
- **Secondary Energy :** is the energy ready for transport or transmission.
- **Final Energy :** is the energy which the consumer buys or receives.
- **Useful Energy :** is the energy which is an input into an end-use application.

The electrical energy, which is of relevance for the scope of this master thesis, according to (Princenton University 2012) is defined as ”energy made available by the flow of electric charge through a conductor” and as such the higher the voltage the more electrical energy is made available. It has multiple users and purposes in the case of Domestic usage. It is employed for cooking, lighting, heating, ventilation and cooling (HAVC), communications, etc.

According to the SI (Organisation Intergouvernementale de la Convention du Mètre 2006), the measure unit for energy is the joule J, which can be expressed as the force of one Newton applied on a distance of one meter, as can be seen in equation 3.1:

$$J = \frac{kg * m^2}{s^2} = N * m \tag{3.1}$$

Where:

- J = Joule
- kg = kilogram
- m = meter
- s = second
- N = Newton

Power is the energy produced per unit of time (FAO. 1991), and electric power is the rate at which electric energy is transferred by an electric circuit. The SI unit of power is *watt*, which is a joule per second and is expressed by equation 3.2:

$$W = \frac{m^2 * kg}{s^3} = \frac{N * m}{s} = \frac{J}{s} \tag{3.2}$$

Energy consumption is measured by kilowatts per hour kWh which is the energy of one kilowatt power flowing for one hour(Silverman 2007), it can be expressed in terms of Joules as:

$$1(kWh) = 3.6 * 106J = 3.6 \text{ million Joules} \tag{3.3}$$

3.1. Methodologies used for Estimation of Electrical Energy Demand

There are several public and private establishments in the energy sector that do electricity forecasting as a fundamental part of their institutional mission. Estimations are done based on the data availability, scope or level of detail. In this section, some of the methods that have been used for forecasting are presented, followed by a evaluation of their pros and contras keeping in mind that the scope of this master thesis is to use a city 3D model as a main source of data. At the end of this section, the selected method is presented.

3.1.1. Trend Method

In this method, the variable to estimate is considered as a function of time (Cullen 1999, Mehra & Bharadwaj 2000), meaning that it determines the electricity demand as a trend of the historical sales of energy measured in kWh. Its basic approach considers the consumption of electricity for a sample year plus an additional amount for each year after the base one. The calculation of electricity forecasting is done using the equation (3.4) from (Mitchell, Ross, Park & Corporation 1986):

$$(class\ kWh)_{year} = a + b * (year - base\ year) \tag{3.4}$$

Where:

- a = estimate amount on a base year
- b = additional amount for each year after the base year

This was the leading method before 1970's, however at the present time it is mainly used to obtain a preliminary estimation of the forecasting or for short-term modelling. (Cullen 1999, Mitchell et al. 1986, Mehra & Bharadwaj 2000).

3.1.2. Time-Series Method

Other method that considers the variable as a function of time is the Time-Series Method, based on (Cryer & Chan 2008) time series analysis purpose is both model the stochastic mechanism of an observed series and to forecast their future values. This method forecasts energy demand based on the patterns and trends found on the data (Cullen 1999) which means that it requires electricity consumption values for at least 30 time periods, i.e. months or years. This prerequisite might be a big issue for regions with a lack of such a database as for example new developed areas in a city.

3.1.3. End-Use Method

A different practice can be done by the end use method, according to (Mitchell et al. 1986), this model is confined largely to forecasting residential loads, it surveys major electricity consuming residential equipment. Forecast is done by projecting quantity, energy efficiency and use of all electrical appliances used in a home. At the end, the final energy forecast results from the sum of all end-using activities (Mehra & Bharadwaj 2000). Equation 3.5 presents the estimation for electrical appliance.

$$\mathrm{ECA} = \mathrm{S} * N * P * H \tag{3.5}$$

Where:

- ECA = Energy consumption of an appliance in kWh
- S = Number of appliances per customer
- N = Number of customers
- P = Power required by the appliance in kWh
- H = Hours of appliance use

3.1.4. Econometric Method

"This approach combines economic theory with statistical methods to produce a system of equations for forecasting energy demand" (Mehra & Bharadwaj 2000). For each consumer class (residential, commercial, industrial, etc.) it estimates the energy demand by the inclusion of the relationship between consumption with several independent factors such as economic, environmental, demographic, policy change, technological, etc. (Shuvra, Rahman, Ali & Khan 2011). It can project future values for those factors and solve equations for future values of consumption, (Mitchell et al. 1986, Cullen 1999).

This is among the most complex forms of energy forecasting, and is used for all areas of service. In general, within this approach the estimation of energy demand could be expressed by the equation 3.6 as:

$$E = f\left(Y, P_i, P_j, POP, T\right) \tag{3.6}$$

Where:

- E =Electricity demand
- Y = Income per capita
- P_i = Price of energy
- P_j = Price of related fuels (alternative fuel sources of energy if that's the case)
- POP = Population
- T =Technology

Based on (Bhattacharyya & Timilsina 2009), "the following equations provide examples of specifications used in simple econometric analyses" (table 3.2).

Where EMP is employment of labour, a, b, c, d, e, f, - are coefficients to be determined through the estimation process, t is time period t while t-1 represents the time period before t.
(a) Linear relation between energy and income (GDP)
$E_t = a + bY_t$
This implies an (income) elasticity that tends asymptotically to unity as income increases. Note that b is not the elasticity in this specification, which has to be determined from the basic definition of elasticity.
(b) Log-linear specification of income and energy
$\ln E_t = \ln a + b \ln Y_t$
Here b represents the elasticity of demand, which is a constant by specification.
(c) Linear relation between energy and price and income variables
$E_t = a + bY_t + cP_t$
This is not a popular specification however.
(d) Log-linear specification of income, price and energy
$\ln E_t = \ln a + b \ln Y_t + c \ln P_t$
As with model (b), the short-run price and income elasticities are directly obtained here.
(e) Dynamic version of log-linear specification of energy with price and income variables
$\ln E_t = \ln a + b \ln Y_t + c \ln P_t + d \ln E_{t-1}$
The short run and long-run price and income elasticities are obtained here.
(f) log-linear model of price and other demographic variables
$\ln E_t = \ln a + b \ln P_t + c \ln EMP_t + d \ln POP_t$
(g) log-linear model of energy, price, income, fuel share and economic structure variables
$\ln E_t = \ln a + b \ln P_t + c \ln Y_t + d \ln F_t + e \ln S_t$
(h) dynamic version of the above model
$\ln E_t = \ln a + b \ln P_t + c \ln Y_t + d \ln F_t + e \ln S_t + f \ln(E_{t-1})$
(i) linear relation between per capita energy and income
$E_t/POP_t = a + bY_t/POP_t$
(j) Log linear relation between per capita energy and income
$\ln(E_t/POP_t) = \ln a + b \ln(Y_t/POP_t)$
(k) log-linear relation between energy intensity and other variables
$\ln(E_t/Y_t) = \ln a + b \ln P_t + c \ln F_t + d \ln S_t$
(l) Dynamic version of log-linear energy intensity relation
$\ln(E_t/Y_t) = \ln a + b \ln P_t + c \ln F_t + d \ln S_t + e \ln(E_{t-1}/Y_{t-1})$

Table 3.2.: Typical examples of single equation econometric models

source: (Bhattacharyya & Timilsina 2009)

3.1.5. Advantages and Disadvantages of the Mentioned Methods

Once the different forecasting methods are presented, it is necessary to discuss about their benefits and finally to take a decision of which could be used on the estimations that are going to take place during this master thesis. For that reason Table 3.3 is presented based on the consideration that a tabular presentation of their advantages and disadvantages helps on the decision making.

Method	Advantages	Disadvantages
Trend method	-Little skill required -Inexpensive and quick -Can be upgraded by adjusting data -Minimal data requirements	-Vulnerable to changes -No explicit audit for errors
Time-Series method	-Accurate for short term -Low cost -Minimal data requirements -Statistical evaluation of forecast uncertainty	-Requires a big historical dataset -Does not treat factors explicitly -Tough interpretation of errors -Difficult to allow for conservation or change
End-Use method	-Can trace true location of forecasting error -Intermediate technical and computer skills -Easy to explain results	-Requires large amount of detailed data -Data assembly costly and difficult -Technology must be explicitly specified -Requires knowledge of end-use technologies and practices
Econometric method	-Explicitly measures effect of underlying causes of trends and patterns -Provides statistical evaluation of forecast uncertainty -Combines economic and demographic information on service territory -Can incorporate other methods -Models can be readily re-estimated	-Requires skill and experience in econometrics and computer programs -Extensive data required for detailed disaggregated model -Costs can be relatively high

Table 3.3.: Advantages and disadvantages of the energy demand forecasting methods
sources: (Mehra & Bharadwaj 2000, Mitchell et al. 1986, Cullen 1999)

Based on the motivation of this master thesis (section 1.1), and the information presented in this section, the End-Use method is chose as the Energy forecasting method that will be use in this master thesis. This method neither requires information as income per capita, energy price like the econometric method (section 3.1.4, or does not require an historical data base of the consumption values like Time series method requires (section 3.1.2).

Based on the fact that End-Use method focuses on the electrical energy appliances for its estimation, basic data such as the total number of dwellings and the number of inhabitants per residential unit, must be available before the forecasting of the energy demand of a residential building. Without those values the forecast can not be done. Equation 3.5 presents that the number of users per appliance is one of its variables. Moreover the final value of the forecast of a dwelling is the sum of all electrical appliances that have been modelled and the final value of the building's forecast is again the sum of all dwellings values plus those appliances of the building itself like for example electric light for common areas such as corridors.

Notwithstanding, it is important to emphasise that this method requires a detailed database that includes as much appliances' data as possible (i.e. Number of TV's per house, energy requirements per TV, time that each TV is on per inhabitant, number of inhabitants of that dwelling place, and so on). This kind of data is strongly related to what will be called in this master thesis Occupancy influence, or what some authors (Page, Robinson & Scartezzini 2007, Shuvra et al. 2011, Santin, Itard & Visscher 2009) called Human Behaviour. This topic will be discussed in detail in section 3.2.

3.2. Occupancy Influence

Human behaviour has a huge impact on energy uses, it is relevant to energy use as mechanical parameters such as equipment and appliances (Santin et al. 2009) causing dramatic variations on energy consumption in similar dwellings with the identical characteristics (Branco, Lachal, Gallinelli & Weber 2004). For that reason it should not be undertaken during forecasting studies. Normally, it is included in energy demand models of buildings as occupancy patterns that represent an average user(Yamaguchi et al. 2011) or by operation schedules (Page et al. 2007, Lee et al. 2011). In case of the latter one, it is possible to assume that a continuous presence of people at that location (dwelling or office) increases the energy use in comparison to those scenarios where users either do not have a constant presence or have large periods of absence(Santin et al. 2009).

The electricity demand of a building (residential or offices) varies regarding to the number of people that lives or work in that specific place. An increase of the amount of users entails an increase of the energy demand in that location. Nevertheless this increase is not linear to the number of occupants(Haldi & Robinson 2010), and that happens because some electrical appliances are shared between users without involving a change on the energy consumption like the case of electrical lighting for a living room or cellular office. Some other appliances, which their use is shared most of the time, only increases their consumption on specific circumstances like a TV, one of the users wants to see an specific show that nobody else is interested in. However, this statement is only applicable when all the occupants use the same device at the same time. An additional TV or a washing machine, just to mention some devices, implies a high increase factor to the energy consumption of that specific appliance.

Another characteristic that has been distinguish in several approaches is users behaviour (Reinhart 2004, Wout, Dirk & Hugo 2010, Astrid, Udo, Aris & Sabine 2010), those authors consider that users could be classified in active or passive. This is done in order to model dynamic switching of appliances based on external influences like for example daylight can do to electrical lighting inside a building. Whereas a passive user will turn the lights on at arrival and turn them off at departure, the active one will be turning lights on and off during his stay according to daylight illuminance.

Due to the difficulty of modelling very dynamic and stochastic behaviours, some authors like(Clevenger & Haymaker 2006, Haldi & Robinson 2010) have included in their studies the human behaviour in extreme conditions, calling them as best and worse cases. The best case is related to a normal employment of the electrical appliances by the user. The latter one means that all users are using all appliances the at the same time and all the time. Based on the paradigm presented within this paragraph, several user profiles can be defined, which will be used as forecasting parameters in order to optimise results.

Figure 3.1 shows variability of normalised annual energy use for cold climates obtained by (Clevenger & Haymaker 2006), a study done to evaluate the impact of building occupant on energy modelling situations.

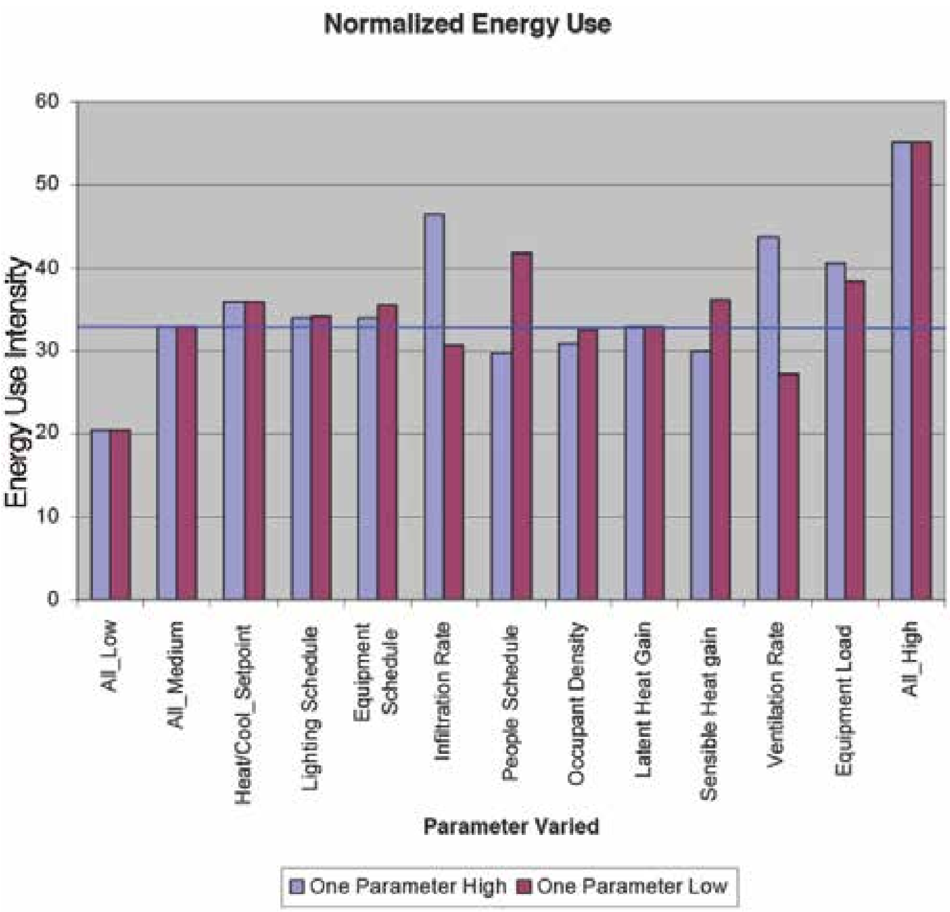


Figure 3.1.: Energy Results for Cold Climates. Example of Occupancy Influence
source: The Impact of the building occupant on energy modelling simulations (Clevenger & Haymaker 2006)

The blue line indicates the result obtained using the mean values of all parameters, variation of individual parameter values are presented in red (low use) or blue (high use). The different behavioural scenarios tested in that research lead to variations of more than 150% of the final energy use intensity.

3.3. Electrical Energy Appliances

After the presentation of several forecasting methods (see section 3.1), it is necessary to specify the different energy appliances that will be considered during this master thesis. However this method requires a big database in order to produce better results. At the end the electrical energy consumption of a dwelling can be expressed as the sum of its electrical appliances (equation 3.7).

$$DEC_i = \sum_{j=1}^{n} ECA_j + \epsilon_j \tag{3.7}$$

Where:

- DEC_i = Energy consumption for dwelling i as in equation 3.5
- ECA_{ij} = Energy consumption for end-use j, for dwelling i
- ϵ_j =Error term

There is an important consideration that must be include in equation 3.5. This is due to the fact that a increase of the number of users do not mean a linear increase of the energy consumption as it is expressed in (Haldi & Robinson 2010, Yamaguchi et al. 2011) and section 3.2. For that reason the number of users will be considered on the mentioned equation as it is stated in (KEMA-XENERGY 2004, KEMA, Inc. 2010) so:

$$ECA = S * U * P * H \tag{3.8}$$

Where:

- S = Number of appliances per customer
- $U = 1 + \log N$
- N = Number of users at that dwelling
- P = Power required by the appliance in kWh
- H = Hours of appliances use

By including the number of users just as its logarithm we are guaranteeing that energy consumption will increase for that energy appliance. It indicates that the increment will be proportional to the number of users. The End-Use Energy Group Appliances considered for this master thesis, which were defined based on (Meier, Rainer & Greenberg 1992, KEMA-XENERGY 2004, KEMA, Inc. 2010), are listed below.

- Food Preparation
- Laundry
- Electrical Lighting
- Entertainment and Technology
- Personal Computer and Home offices
- Miscellaneous

3.3.1. Food Preparation ($\mathbf{EC_{FP}}$)

This Appliance group include the following devices:

- Fridges and Freezers (ECFnF)
  A standard fridge/ freezer will be include per dwelling. This is one of the basic electric devices that a dwelling has. Its energy consumption is obtained from the specification document provided by the producer. This device will considered as on all the time. The energy consumption of these devices is obtained by the producer technical information sheets.

- Ranges, Ovens, Chimney hood, Microwave Ovens, Dishwasher (EC_{ROCMD})
  Similarly, those appliances will be included per dwelling. Their energy consumptions are extracted from the specification document provided by the producer.

  $$EC_{ROCMD} = U * P * H \tag{3.9}$$

  Equation 3.9 will be considered for each individual device. Finally, the electrical energy consumption of the Food Preparation section can be specified as:

  $$EC_{FP} = ECFnF + EC_R + EC_O + EC_{CH} + EC_{MO} + EC_D \tag{3.10}$$

It is assumed that a dwelling has only one device per appliance.

3.3.2. Laundry ($\mathbf{EC_{L}}$)

This group appliance includes Washing machines and Tumble dryers, their energy consumptions are obtained from the specification document provided by the producer. Due to their characteristics, they will be considered by their requirements on time and energy consumption per load.

$$EC_L = U * P * H \tag{3.11}$$

Equation 3.11 will be considered for each individual device. The electrical energy consumption of the Laundry appliance section can be specified as:

$$EC_L = EC_{WM} + EC_{TD} \tag{3.12}$$

It is assumed that a dwelling has only one device per appliance.

3.3.3. Electrical Lighting ($\mathbf{EC_{EL}}$)

Considering the statement that electrical lighting requirements in a space type (i.e. Kitchen, bedroom, toilet, living room, etc.) are fixed (USA, Energy Dept. 2002), the estimation of electrical energy consumption will be done considering the list below:

- lamps per room **LpR**
- Rooms per dwelling **RpD**

- Operating hours per room **HpR**
- Wattage per Lamp **WpL**

The number of users per dwelling will be considered as it is stated in equation 3.8 so the equation for the estimation of the Electrical Lighting per space type is:

$$EC_{EL} = LpR * RpD * HpR * WpL * U \tag{3.13}$$

3.3.4. Entertainment and Technology ($\mathbf{EC_{EnT}}$)

This group appliance include several devices such as Tv, video players (Blue Ray, DVD, VCR, etc.), Stereo, Home Theatre, Gaming Systems. Their energy consumptions are obtained from the specification document provided by the producer.

$$EC_{EnT} = U * P * H \tag{3.14}$$

Equation 3.14 will be considered for each individual device. Based on this, the electrical energy consumption of the Entertainment and Technology sector will be specified as:

$$EC_{EnT} = EC_{TV} + EC_{VP} + EC_S + EC_{HT} + EC_{GS} \tag{3.15}$$

It is assumed that a dwelling has only one device per appliance.

3.3.5. Personal Computer and Home offices ($\mathbf{EC_{PC}}$)

This group appliance involves the number of personal computers as well as their time of use. There are specific devices that are considered being on all the time such as modems and routers, they do not require an specification of the number of users because that's irrelevant for the equipment. A special case is printer devices or scanners due to the fact they have such a dynamic schedule, a standard short period of time will be considered. Their energy consumptions are obtained from the specification document provided by the producer.

$$EC_{PC} = U * P * H \tag{3.16}$$

Equation 3.16 states the estimation of electrical energy consumption for computers, printers, scanners, etc. in case of modems and routers it is not necessary to include the number of users for its estimation so as equation 3.17.

$$EC_{PC,MR} = S * P * H \tag{3.17}$$

It is assumed that a dwelling has only one device per appliance.

3.3.6. Miscellaneous (EC_M)

According to (Meier et al. 1992), Miscellaneous end use appliances are defined as electricity not consumed by familiar end uses such as those mentioned above. This group has a high variability and it is highly influenced by the launch of new technologies. Nowadays, mobile phones, tablets, docking stations, etc., can be included inside this category. Their energy consumptions are obtained from the specification document provided by the producer.

$$EC_M = U * P * H \tag{3.18}$$

Equation 3.18 will be considered for each individual device. It is assumed that a dwelling has only one device per appliance.

3.3.7. Summary of Electric Model

In summary, the final electric model is expressed as the following equation:

$$DEC = EC_{FP} + EC_L + EC_{EL} + EC_{EnT} + EC_{PC} + EC_{PC,MR} + EC_M \tag{3.19}$$

In my opinion, all estimation must be adjusted to specific time frames such as days, weeks or months, i.e. Laundry Appliances section 3.3.2 estimates its energy consumption per load, it is necessary to specify the number of loads per week/month so those values can be add to the estimation values obtained for other appliances with other type time specifications such as fridges/freezers or wifi routers with their daily consumption (they are 24/7 on) or TV sets and their time of use per day. It is important to state as well that the consumption of all energy appliances will be expressed in kW/h.

4. Comprehensive tools for Processing CityGML Files

The conceptual models that have been presented in the previous chapters, will help the author with the development of this master thesis. Furthermore, they require a physical implementation to take place and it will be done using a 3D City model, which is based on the CityGML standard. This require a complete implementation framework that involves the use of several technological tools. This will allow the develop and execute of the workflow of the master thesis and is described in chapter 5.

4.1. citygml4j 2.0ea

It is a Java class library and API for facilitating work with the City Geography Markup Language (CityGML) developed at the Technical University of Berlin. It allows to read, process, and write CityGML datasets, and to develop CityGML-aware software applications using Java (IGGS 2009b).

This master thesis employs this library for the estimation of energy consumption of residential buildings. First of all, basic geometric and semantic information from buildings is extracted including the estimation of the number of inhabitants. After this process the electrical energy demand is computed. Final results are stored as generic attributes of buildings in a new CityGML File.

4.2. JTS Topology Suite 1.13

According to (Tsusiat Software 2011), “the JTS Topology Suite is an API of spatial predicates and functions for processing geometry” using Java. It is a robust implementation for processing linear geometry on 2D. It is of special relevance for this master thesis because all geometric enquires are solved using the library methods and properties. GML geometries are converted into JTS geometries so properties or attributes of those geometries are easily to ask like for example the area of a polygon.

4.3. FME

The Feature Manipulation Engine developed by Safe Software is a collection of spatial ETL (Extract, transform and load) tools, which are useful in the process of transforming and manipulating spatial data (Carrión 2010). Based on their own words (Safe Software Inc. 2012), it allows the transformation of 275 spatial and non-spatial formats, it is very useful to restructure, reformat and integrate spatial data.

This platform will be used to convert the CityGML file generated as a result of the processes done by the citygml4j library into other formats so those values are easily readable and handle by other platforms. Format types like ESRI Geodatabase or Excel table sheets are examples of data types that are supported by this platform.

4.4. ArcGIS

ArcGIS is a Geographic Information Software from ESRI. This platform is used mainly for visualisation purposes in cases such as the presentation of the test area or to present the resulting database using either ArcScene or ArcMap as well as for result comparison purposes.

5. Estimation of Electrical Energy Demand using CityGML

This section presents the methodology done in this master thesis for the estimation of electrical energy demand of buildings using a 3D CityGML model. It presents the hypothesises and assumptions considered as well as and their theoretical justification. At the end of each main part, it is resumed with a diagram that presents the workflow that is followed. The estimation is split into three main parts, first one is the estimation of building parameters (including its number of inhabitants), the second part is energy appliances, it states which equipment are considered and the last one is human behaviour, which presents the life style model used.

5.1. Building Data Requirements

A detailed 3D semantic model of a building is fundamental for the scope of this master thesis, it can provide relevant information such as number of storeys of a building, quantity of dwellings and their rooms. The CityGML standard provides the right environment for those modelling purposes, table 5.1 shows the relation of the semantic themes that are available for the building model 2.1.1 and the level of detail representation.

Geometric / Semantic Theme	LOD0	LOD1	LOD2	LOD3	LOD4
Building footprint and roof edge	X				
Volume part of the Building shell		X	X	X	X
Surface Part of the Building Shell		X	X	X	X
Terrain Intersection Curve		X	X	X	X
Curve Part of the Building Shell			X	X	X
Building Parts		X	X	X	X
Boundary Surfaces			X	X	X
Other Building Installations			X	X	X
Openings				X	X
Rooms					X
Interior Building Installations					X

Table 5.1.: Semantic themes of the class _AbstractBuilding

source: OGC City Geography Markup Language (CityGML) Encoding Standard (Kolbe et al. 2012)

As the reader can see in table table 5.1, critical information such as volume, footprint or rooms are available when a building is modelled using this standard. Furthermore, table 5.2 presents the semantical attributes of a building that should be accessible from the CityGML file i.e. number of storeys, storey height.

≪Feature ≫ **_AbstractBuilding**
+class : gml::CodeType [0..1]
+function : gml::CodeType [0..*]
+usage : gml::CodeType [0..*]
+yearOfConstruction : xs::gYear [0..1]
+yearOfDemolition : xs::gYear [0..1]
+roofType : gml:CodeType [0..1]
+measuredHeight : gml::LengthType [0..1]
+storeysAboveGround : xs::nonNegativeInteger [0..1]
+storeysBelowGround : xs::nonNegativeInteger [0..1]
+storeyHeightsAboveGround : gml::MeasureOrNullListType [0..1]
+storeyHeightsBelowGround : gml::MeasureOrNullListType [0..1]

Table 5.2.: AbstractBuilding Class

source: OGC City Geography Markup Language (CityGML) Encoding Standard (Kolbe et al. 2012)

However not all that information is accessible from the dataset available for this master thesis, this is shown in table 5.3, which presents the attributes of a building.

Name	Type
EIG_KL_OV	gen:intAttribute
EIG_KL_PV	gen:intAttribute
ANZ_LOC	gen:intAttribute
EIG_KL_ST	gen:intAttribute
FOLIE	gen:stringAttribute
LFD	gen:stringAttribute
HNR	gen:stringAttribute
STR	gen:stringAttribute
GMDE	gen:stringAttribute
KREIS	gen:stringAttribute
RBEZ	gen:stringAttribute
LAND	gen:stringAttribute
Kachel	gen:stringAttribute
TexVersion	gen:intAttribute
H_Trauf_Max	gen:doubleAttribute
H_Trauf_Min	gen:doubleAttribute
H_First_Max	gen:doubleAttribute
H_First_Min	gen:doubleAttribute

Table 5.3.: Attributes available at the CityGML dataset of Berlin

source: CityGML dataset file of the Test Area

The reader can see in table 5.3, that the dataset contains no storey information as was stated by the _AbstractBuilding class in table 5.2. Nevertheless the data that is available is useful for the estimation of the missing information, which leads to additional computations of the building features that are available when such a detailed model is not present. This section presents the dataset of the area of study and those concepts that are taken into consideration for the estimation of the required data of buildings.

5.1.1. Test Area

A test area inside Berlin was defined for implementation purposes. The Import/Export tool of the 3D CityDB (section 2.2) is used to extract the data of that area into a single CityGML file, which contains a LOD2 geometric representation. This is the a fundamental task and so it can be seen what information is available from the 3D City Model. Figure 5.1 shows the chosen test area that is located in the district of Charlottenburg.

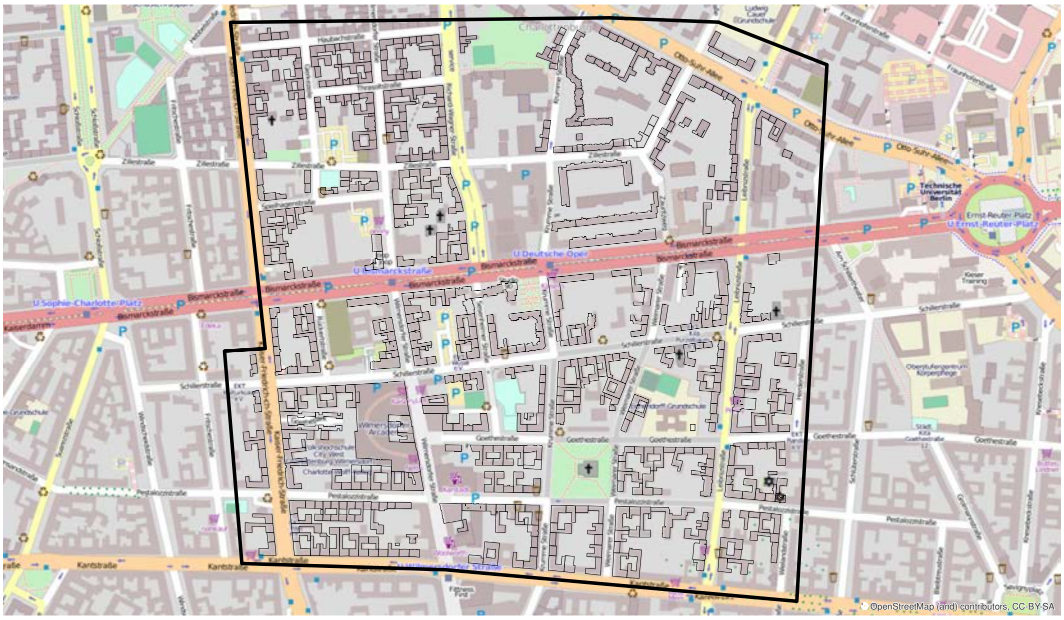


Figure 5.1.: Test Area

source: Own graph using ArcGIS and OpenStreetMap as base Layer

The dataset includes **833** building type features.

5.1.2. Building Type

As it is mentioned in the problem statement, section 1.2, the scope of this master thesis is estimate the electrical energy demand of residential buildings, which can be classified by the CityGML function attribute, which contains the purpose of the feature (IGGS 2009b). Due to the fact that we are focused on the Building Thematic Model, its function indicates whether it is either residential, public, industrial or commercial building. Within the city model of Berlin, this attribute includes a code according to the German cadastral information system (ALK) (Senatsverwaltung für Stadtentwicklung 2005). Table 5.4 shows the function values that were identified as relevant, buildings which mainly or uniquely use is residential.

Function	ALK Description
1210, 1211	**Wohnhaus in Reihe** Residential House in row
1220, 1221	**Freistehender Wohnblock** Free standing block of flats
1230, 1231	**Wohnblock in geschlossener Bauweise** Block of flats in a closed construction
1300, 1301	**Gebäude und Freifläche - Wohnen** Buildings and open space - Living
1310, 1311	**Einzelhaus** Detached house
1320, 1321	**Doppelhaus** Semi-detached house
1330, 1331	**Reihenhaus** Serial House
1340, 1341	**Gruppenhaus** Group home
1360, 1361	**Hochhaus** high-rise
1381	**Behelfsmäßiges Wohngebäude** Provisional residential building
1390	**Andere Wohnanlage** Other Condominium
1399	**Wohngebäude** Residential building
2100	**Gebäude- und Freifläche - Mischnutzung mit Wohnen** Buildings and open space - mixed use with housing
2110	**Wohnen mit öffentlich** Living with public
2120	**Wohnen mit Handel und Dienstleistungen** Living with trade and services
2130	**Wohnen mit Gewerbe und Industrie** Residential, commercial and industrial
2140	**Öffentlich mit Wohnen** Public building with housing
2150	**Handel und Dienstleistungen mit Wohnen** Trade and services with living
2710	**Wohnen** Residential
2711	**Landwirtschaftliches Wohngebäude** Farm house

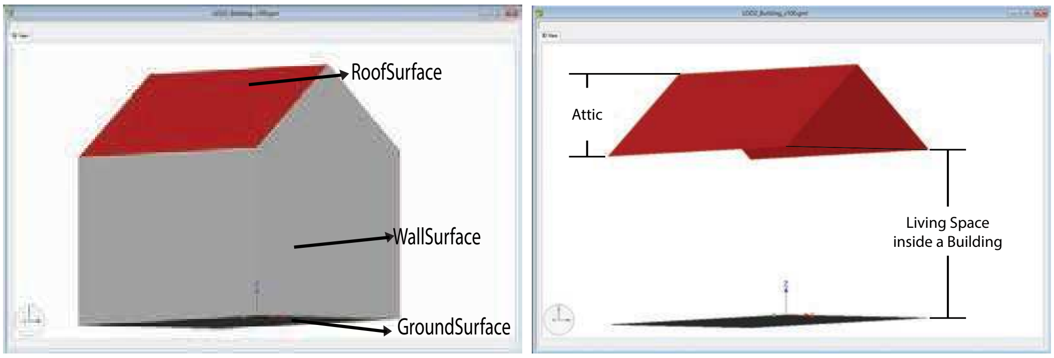
Table 5.4.: Classification of residential buildings in the city model of Berlin according to the ALK

After an initial filter to the dataset, the result is that **553** of those features have a function value that lies into the values presented on table 5.4.

5.1.3. Estimation of Number of Storeys

Table 5.3 indicates that the dataset do not have information regarding building storeys, nevertheless this section presents an approach that uses the building boundary surfaces for that estimation. Based on the fact that the LOD2 representation models only the features that defines a building, as can be seen in figure 5.2(a), it is stated that a building is delimited at its nadir and zenith by the GroundSurface and RoofSurface features respectively, as well as the GroundSurface is its footprint or better said, its constructed area.

The statement made in the previous paragraph is to justify my decision of considering only those parameters for the estimation of what I call the Living Space inside a Building, which is the space between the lower part of the Roof and the footprint of the building as it is shown in figure 5.2(b).



(a) (b)

Figure 5.2.: LOD2 Building, all boundary surfaces Figure (a), delimitation of Building's Living Space, Figure (b).
source: Own graph using FZKViewer-2.3 (KIT 2012)

For that reason it is necessary to extract the limits of the building, which are the extreme coordinates of both features, in the case of the Ground Surface just one value for the Z coordinate is obtained, this is because the footprint of a building is a plane. For the Roof Surface, only the minimum Z coordinate value is used at this step so the height of the Living Space of a Building can be calculated by equation 5.1.

$$BLS_h = RSz_{min} - GSz \tag{5.1}$$

The number of storeys of a Building can be estimated as the integer value of equation 5.2

$$NoS = BLS_h - SS_h \tag{5.2}$$

Where:

- NoS = Number of Storeys
- BLS_h = Building's Living Space height
- SS_h = Standard Storey height

Based on (Neufert, Brockhaus, Kister, Lohmann & Merkel 2005), the Standard Storey height considered for this master thesis is *2*,75m (figure 5.3). Nevertheless, it is important to state that the considerations and statements presented by the authors of that book, are based according to the norms and standards valid at that specific period of time, which means that the Storey's height can differ by the year of construction erection.

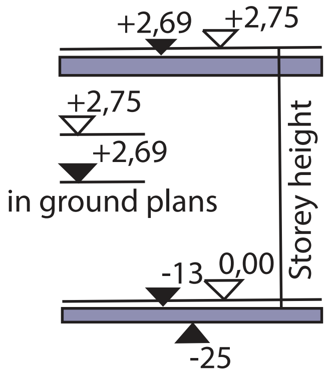


Figure 5.3.: Height dimension in Sections and Elevations

source:Wohnungsbau-Normen: Normen, Verordnungen, Richtlinien. 25.... (Neufert et al. 2005)

For that reason a classification of buildings is done with the aim to obtain better results of the number of storeys. However this information is not available in the dataset of the area of study (Table 5.3). A possibility to solve this issue is using one of the WMS that the Senate of Berlin has available on its FIS-Broker service ((Senatsverwaltung für Stadtentwicklung und Umwelt 2013)). That is the case of the *Gebäude alte 1992-1993* service, which shows a scan image of a map of Berlin with its buildings and their year of construction (figure 5.4).

(a) (b)

Figure 5.4.: WMS Berlin buildings' age, area of study figure (a) legend of the WMS figure (b)

source: Own graph using the FIS-Broker WMS (Senatsverwaltung für Stadtentwicklung und Umwelt 2013)

Notwithstanding this WMS presents a classification of buildings (figure 5.4(b)), which means that buildings must be classified on those categories and the information that is available of the building's storey height must be adjust to that classification. Table 5.5 presents the year of construction and their corresponding storey's height values.

Year	Height (m)	Special Considerations
<1900	3,20	
1900 - 1918	3,00	
1919 - 1932	3,00 2,50	1^{st} to 2^{nd} Floors
1933 - 1945	2,75 2,50	1^{st} to 2^{nd} Floors
1946 - 1961	2,70 2,50	1^{st} to 3^{rd} Floors
1962-1974	2,70	
>1975	2,80	

Table 5.5.: Height of Buildings based on the year of construction

Own table based on the FIS-Broker WMS (Senatsverwaltung für Stadtentwicklung und Umwelt 2013), (Architekten- und Ingenieur-Verein zu Berlin 1974) and (IGGS 2013)

These values are used as an input in the implementation, for every building that do not have year of construction data uses the standard value mention in this section *2*,75m. It is important to mention that height values do not include the space between storeys or the floor itself. This mean an additional *40 cm* per storey.

Data Acquisition

The result from a WMS is a image, so addi-tional steps are required to extract this data. Although there are many possibilities to that automatic using platforms like FME, ERDAS Image, ArcGIS, etc., I decided to do it manually due to the image resolution of the WMS and overlapping mismatch (figure 5.5).

Figure 5.5.: Overlapping mismatch of WMS and buildings' footprint

source: Own graph using ArcGIS

The results of building classification of the area of study can be seen in table 5.6.

Year	Number of buildings
<1900	239
1900 - 1918	82
1919 - 1932	0
1933 - 1945	1
1946 - 1961	127
1962 - 1974	71
1975	33

Table 5.6.: Classification of building age for the area of study

source: Own table

Roof Space

The last parameter that must be considered in this section is the roof space, there is no statement that says if the roof space is suitable for living or not. Notwithstanding at least in the case of Germany, several Federal Estates define on their legislation for buildings that those areas can only be considered as suitable for residential purposes if they have a height value of at least $2,30m$ as can be seen on (Bayerische Staatregierung 2007, Hamburg Senat 2005, Recht NRW 2000). For that reason I consider as an additional storey of the building if its roof has a height higher than $2,30m$ or better expressed.

$$Roof_h = RSz_{max} - WSz_{max} \tag{5.3}$$

Where:

- $Roof_h$ = Roof height
- RSz_{max} = max. Z coordinate of the Roof Surface Bounding Box
- WSz_{max} = max. Z coordinate of the Wall Surfaces

5.1.4. Public Areas Inside a Building

Once the number of storeys for each building is estimated, it is necessary to subtract from each storey the common or public areas, where its inhabitants can move inside the building for either departure or arrival purposes. This consideration is done for two reasons, the first one is that those areas require different Electrical Energy Appliances and the second one is that after the removal of those areas, the remanning one can be assumed as private or area assigned to dwellings. This kind of assumptions will not take place on the moment that a LOD4 of the building is available.

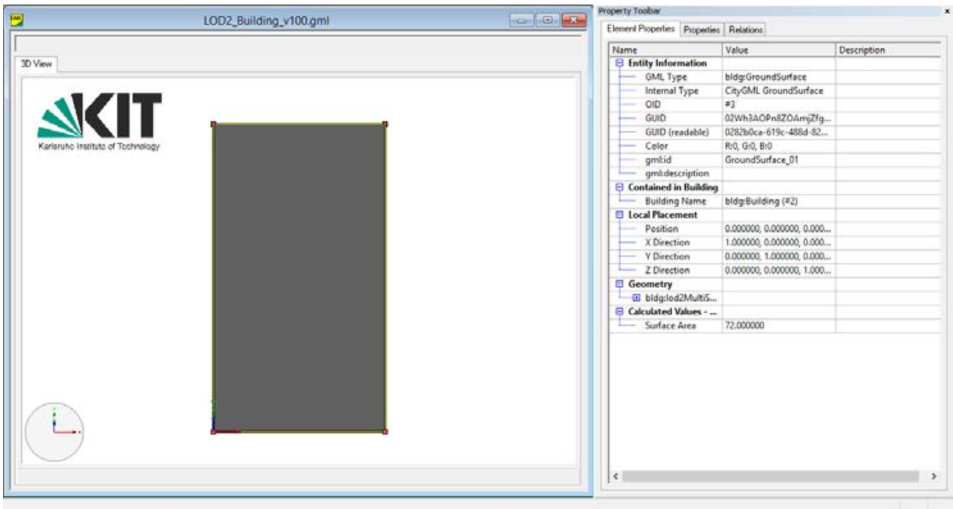


Figure 5.6.: Ground Surface feature of a building

source: Own graph using FZKViewer-2.3 (KIT 2012)

Figure 5.6 presents the GroundSurface of a building, as it was stated at section 5.1.3, this feature is considered as the footprint or constructed area of a building, examples of area that can be removed from this feature is presented in figure 5.7 and its based on (Neufert et al. 2005).

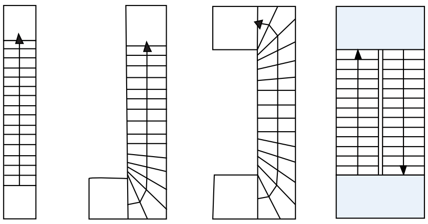


Figure 5.7.: Several designs of public stairs inside a building

source: Own graph based on (Neufert et al. 2005)

As it was stated before in this document, section 2.1.1 , a Building can be modelled as a complex relation of multiple Building Parts the Building's footprint area will be the sum of its *GroundSurfaces*. Based on (Loga, Diefenbach, Knissel & Born 2005), the 25% of the footprint of the building will be assigned as its common area.

5.1.5. Dwellings / Inhabitants

This is a critical part of the master thesis because the number of dwellings and inhabitants per storey are estimated. Several authors such as (Wohnungsanwalt 2009, Amt für Statistik Berlin-Brandenburg 2011) and (DESTATIS 2009) indicate that the average Flat area in Berlin is $71m^2$, furthermore (Wohnungsanwalt 2009) states that rooms have an average size of $19,57m^2$. An approach on the estimation of the number of inhabitants of a building could done based on (Senatsverwaltung für Stadtentwicklung 2010) which states the following statistical values for Berlin.

- $70,4m^2$ – Mean area per dwelling
- $38,8m^2$ – Mean area per person in a inhabited dwelling
- $1,82$ – Mean number of people per dwelling

Another approach to the estimation of the number of dwellings in a building is the use of several flat prototypes as they are presented in (Neufert et al. 2005). Some examples are shown in both table 5.7 and figure 5.8.

Dwelling	**Area in m^2**
1-Person Flat	40,46
2-People Flat	56,47
3-People Flat	80,50
4-People Flat	103,23

Table 5.7.: Relation between the number of inhabitants per dwelling place and its corresponding area in square meters
source: Bauentwurfslehre: Grundlagen, Normen, Vorschriften (Neufert et al. 2005)

The following examples shown a direct relation between the number of inhabitants and the number of rooms in a dwelling. Those apartments present an increase of their size in m^2 close to the value stated by (Wohnungsanwalt 2009) of $19,57m^2$.

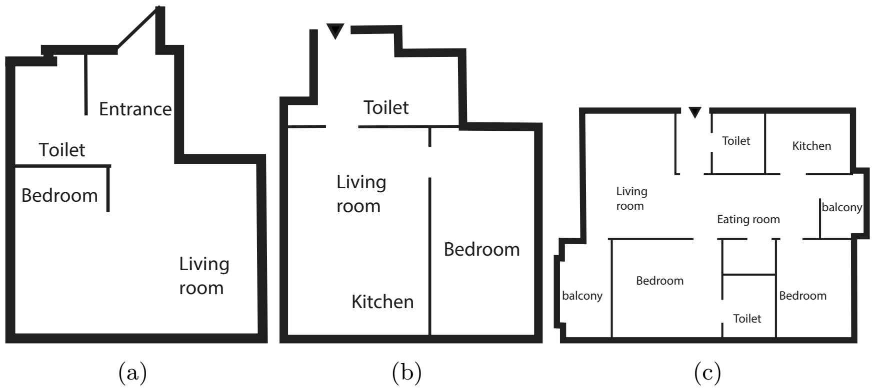


Figure 5.8.: Examples of dwellings, figure(a) one room flat ($40m^2$), figure (b) two rooms flat ($54m^2$), figure (c) three rooms flat ($95m^2$)
source: Translate graphs based on (Neufert et al. 2005)

Those examples presented in figure 5.8 are only for visualisation purposes, no special dwelling or building design is considered in this master thesis due to the complexity that it implies. The statistical values of(Senatsverwaltung für Stadtentwicklung 2010) will be the approach that is used for the estimation of the number of inhabitants of a building an consequently on the estimation of electrical energy demand.

5.1.6. Workflow of the Estimation of Building Parameters

Figure 5.9 presents the UML activity diagram[1] for the estimation of building properties in this master thesis.

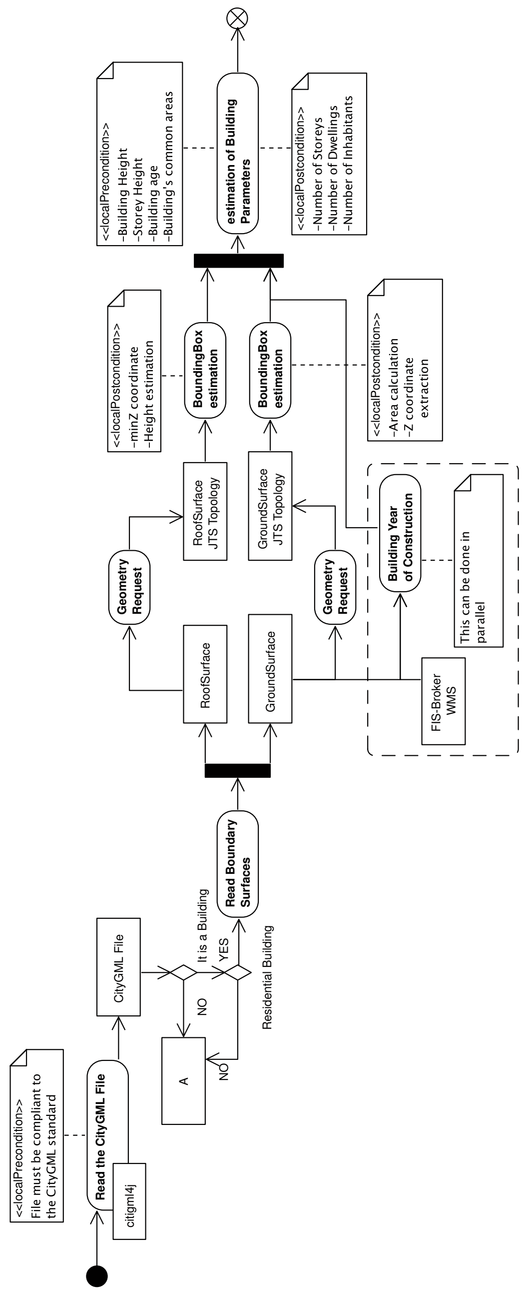


Figure 5.9.: Activity Diagram for the estimation of Building Parameters

source: Own diagram

[1] Unified Modelling Language. "shows the workflow from a start point to the finish point detailing the many decision paths that exist in the progression of events contained in the activity" (Sparx Systems Pty Ltd 2013)

5.2. Energy Appliances

As it is stated in section 3.1.5 the End-Use method is the selected one for the energy forecasting. Furthermore, section 3.3 presents the definition of the electrical energy appliances as well as indicates the devices taken into consideration. This section presents the energy consumption values of that equipment.

Values present here we obtained from several web sources, the main one is a Web site of the Ministerio de Energía y Minas (Ministry of Energy and Mining) of Peru that presents an explanation of the estimation of consumption of a residential client (a dwelling), including basic concepts and a list of house equipment with their consumption values (Min.EnergiaMinas n.d.). Those values are presented in table 5.8.

Appliance	Consumption in kWh
Fridge	0.35 / per year
Freezer	0.25 / per year
Freezer / Fridge	0.408(1) / per year
Hob (4 cooking places)	4.5
Ovens	1.56(1)
Chimney Hood	0.3
Microwave Oven	1.2
Dishwasher	1.44(1)
Washing Machine	0.63(1) / per load
Tumble Dryer	2.5 / per load
Electrical Lighting (Lamps)	
Lamp 100	0.1
Lamp 40	0.04
Lamp 32	0.032
Saverlamp	0.02
TV	0.176 (6) 0.001 Standby
Home Theater	0.105 (5)
Gaming System	0.002 Standby 0.102 on
Personal Computer	0.2
Printer/scanner	0.01
Modem ADSL	0.03
Mobile Phone	0.005(4)
Tablet	0.012(4)
Docking station	0.007(3)
Vacuum	1.3
Iron machine	1
Coffee machine	0.6
Digital TV Adapter	0.01

Table 5.8.: Energy Appliances and their energy consumption
sources: (Min.EnergiaMinas n.d.), (1) (Carbon Footprint Ltd. n.d.), (2) (Striatum Energy 2010), (3) (Sony 2013), (4) (Ho 2009), (5)(Philips 2013), (6)(Bluejay 2010) Value of a 42" LCD TV

This method requires the specification of the energy appliances that are considered for the forecasting as well as the number of units and users, this master thesis will consider only one device per appliance. The number of users per dwelling will be the result of the process done in section 5.1.

5.3. Human Behaviour

After the presentation of the energy appliances (section 5.2). It is necessary to define a life style model or schedule of users as it is mention in (Yamaguchi et al. 2011). For that reason I divide the week on two type of days, weekday (monday to friday) and weekends (saturdays, sundays, public holiday). Days are split in three main sectors, sleeping time, at home and outside, and here is where the difference between days is presented. This is possible to see in figure 5.10.

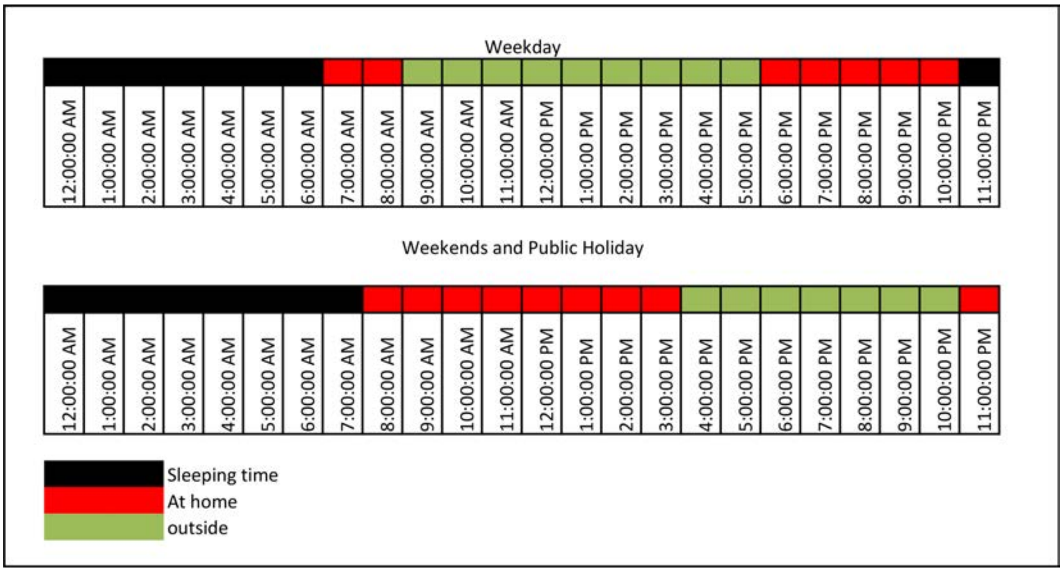


Figure 5.10.: Proposal of classification of Occupants behaviour

source: Own graph

The purpose of splitting the day on three main activities is to propose a time framework that indicates when the residents are at home, during that time there is a clear difference on energy consumption when people are either awake or sleeping.

After the definition of the general time framework, a time schedule is defined for each of the appliances as is presented in (Clevenger & Haymaker 2006). This is done in order to analyse human occupancy influence and is classified in three Ranges *low, medium, high* for each energy appliance (table 5.9).

Appliance	High	Medium	Low
Food Preparation	2^h	1^h	0.5^h
Fridge/Freezer	on all time		
Laundry	2 loads/week	1 load/week	0,5 load/week
Electrical Lithing	16^h	8^h	4^h
Entertainment and Technology, Personal Computer Miscellaneous			
Weekday	6^h	3^h	$1,5^h$
Weekend	8^h	4^h	2^h
Microwave Oven	20^{min}	10^{min}	5^{min}

Table 5.9.: Schedule ranges per energy appliance

source: Own table

The time of use of each energy appliance was defined only when people are awake with the respective specific exception of fridges and modems/routers because they are considered on all the time.

5.3.1. Workflow of the Estimation of Energy Consumption

Figure 5.11 presents the UML activity diagram for the estimation of energy consumption of a building. This figure is a continuation of figure 5.9 as building properties are required for this purpose.

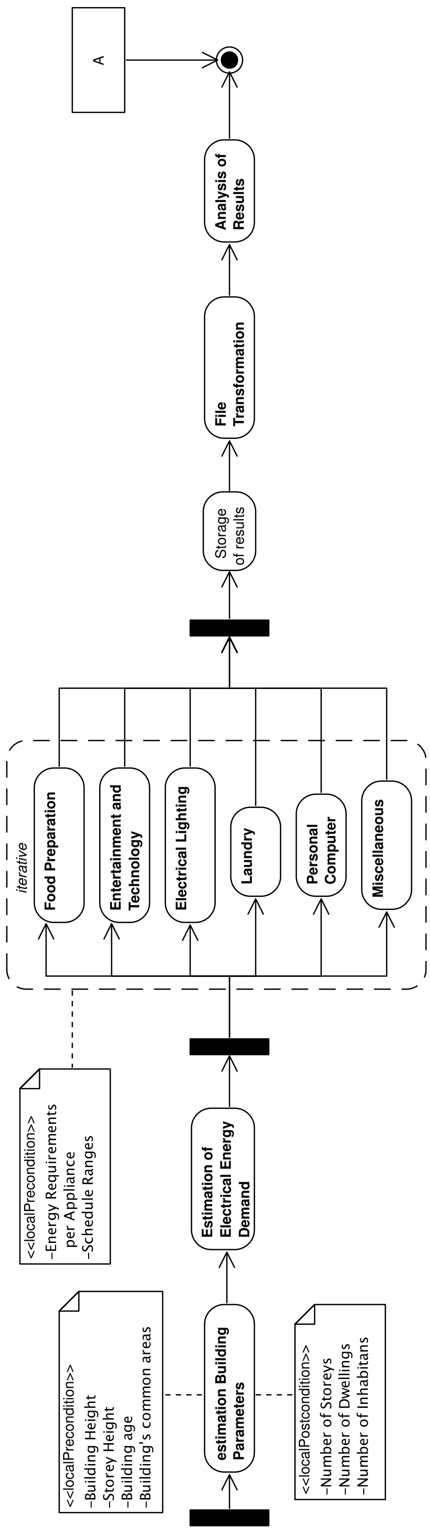


Figure 5.11.: Activity Diagram for the estimation of Energy Consumption

source: Own graph

6. Results

The work-flow presented in section 5 leads to the estimation of the energy demand of a building based on a LoD2 CityGML model which is the scope of this master thesis (Section 1.2). Furthermore it leads as well to the calculation of some other values that can be obtained such as the number of storeys, dwellings and residents of those buildings. The following section presents those results and analysed them, first the building parameters values that are required for the estimation of the energy demand of a building (section 5.1) to conclude with the energy demand values.

6.1. Building Parameters

In order to check the results a small survey was done inside the area of study, the information of 144 buildings was collected. The survey involved to count the number of storeys per building and the number of rings that were available at the entrances of the buildings assuming that each one of them belong to a different flat. There was no special criteria for the survey despite of just to walking through the borough. Figure 6.1 shows the residential buildings in the area of study, marked with blue colour all those that were observed.

Figure 6.1.: Survey of the area of study

source: Own graph using ArcGIS

Table 6.1 shows the classification of the surveyed buildings by their year of construction as they are presented in table 5.5.

Year of Construction	Number of buildings
<1900	63
1901 - 1918	24
1946 - 1961	37
1962 - 1974	12
>1975	8

Table 6.1.: Surveyed buildings classified by building's year of construction

source: Own graph

Figure 6.2 presents the frequency of the number of storeys per building grouping them by their year of construction.

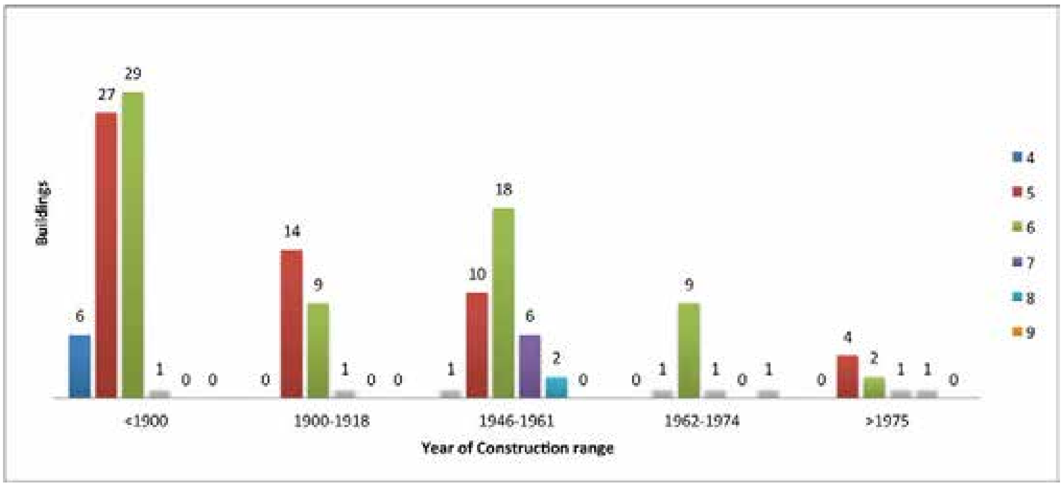


Figure 6.2.: Number of storeys per building classified by year of construction

source: Own graph using Excel

6.1.1. Storeys per Building

Two methods were used for the estimation of building's number of storeys, in the first one the standard Storey Height (S_H) and the second one the storey height classified by year of construction (YoC) as it is explained in section 5.1.3. Table 6.2 presents a small table of the results obtained.

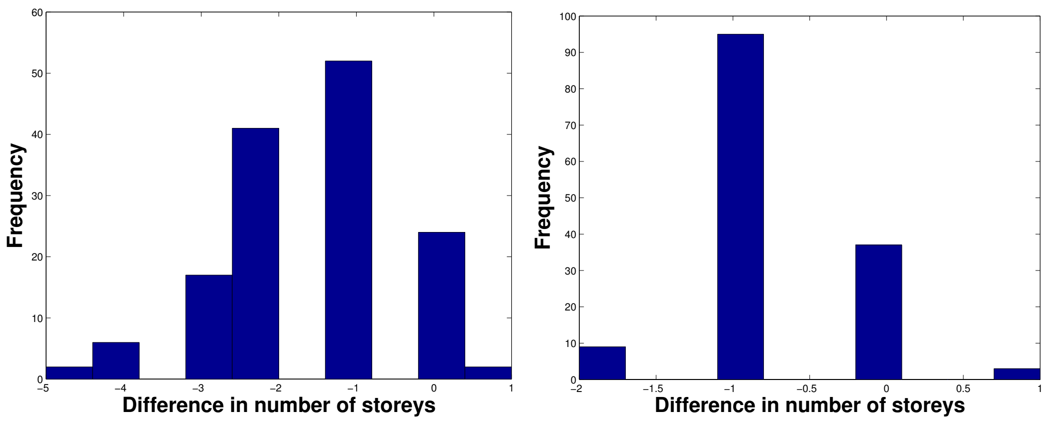
Building ID	Storey	$S_{Std.H}$	ϵ	BldgAge	$S_{H,YoC}$	ϵ
BLDG_0003000000067203	7	9	-2	1961	9	-2
BLDG_0003000000069010	6	9	-3	1899	7	-1
BLDG_000300000006f0e2	6	8	-2	1899	6	0
BLDG_000300000006e689	5	10	-5	1918	6	-1
BLDG_0003000f001d3542	6	7	-1	1961	7	-1
BLDG_0003000f001f67be	6	10	-4	1899	7	-1
BLDG_0003000e005b3d5a	7	7	0	1899	6	1
BLDG_0003000000071392	5	5	0	1975	5	0
BLDG_0003000f001d355a	5	6	-1	1961	6	-1
BLDG_0003000f001d35a9	6	7	-1	1961	7	-1

Table 6.2.: Comparison of number of storeys per building between the observed values and the estimated number of storeys in the implementation
source: Own table

Table 6.2 shows that a discrimination of the year of construction and its respective standard storey height does have an massive impact on the results of the estimation of the number of storeys of a building. Errors between the observations and the estimated values are considerably reduced by including this variable in the estimation process. The standard deviation σ of both methods is presented below. $\mathbf{S_{Std.H}}$ means standard storey height, $\mathbf{S_{H,YoC}}$ for the storey height based on the building year of construction.

- $\sigma_{S_{Std.H}} = 1.15265$
- $\sigma_{S_{H,YoC}}$ =0.59115

The histograms of both estimation methods are shown in figure 6.3.



(a) (b)

Figure 6.3.: Histograms of the estimation of number of storeys per building, figure(a) shows the histogram for the $\mathbf{S_{Std.H}}$ method, figure (b) shows the histogram for the $\mathbf{S_{H,YoC}}$
source: own graphs using Matlab

Based on (Greenwood & Nikulin 1996), the statistic testx^2 is done to evaluate the goodness of fit of data with equation 6.1.

$$x^2 = \sum_{i=1}^{n} \frac{(O_i - \mathrm{E}_i)^2}{\mathrm{E}_i} \tag{6.1}$$

Where:

- x^2 = Cumulative statistical test, which asymptotically approaches a normal distribution
- O_i = Observed value
- E_i = Expected value
- n = Number of observations

With a confidence level of 95% and a degree of freedom of 143, the critical value is $T_{x^2} = 171.907$ so the H_O is accepted if the statement shown in equation 6.2 is fulfilled.

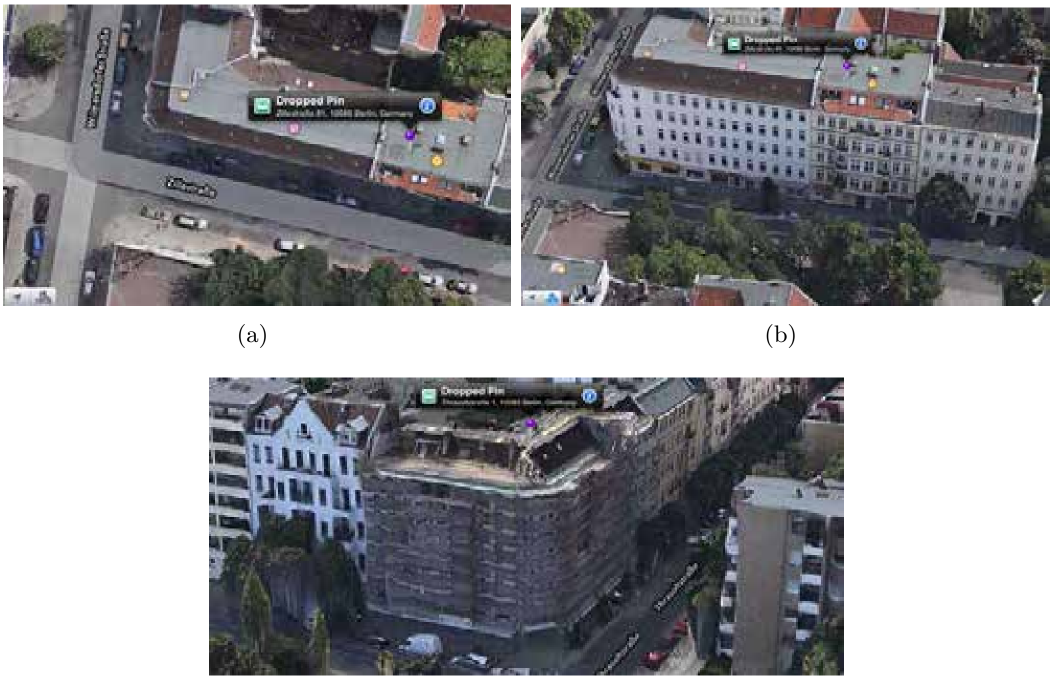
$$q_{\alpha,f} < T_{x^2} \tag{6.2}$$

The results obtained by both methods are presented below.

- $\mathbf{S_{Std.H}}$: 62.8764 < 171.907
- $\mathbf{S_{H,YoC}}$: 19.955 < 171.907

For both methods the null hypothesis is accepted meaning that the observations follow a normal distribution.

Despite of the fact that error between observations and measured values were minimised, most of the buildings shown in table 6.2 have an error of one or two storeys. In my opinion, it is important to state that there is no physical parameter that defines if a Roof is used as an attic. Many buildings that physically could use that space as residential do not used it without a known reason. Examples of such a case are presented in figure 6.4



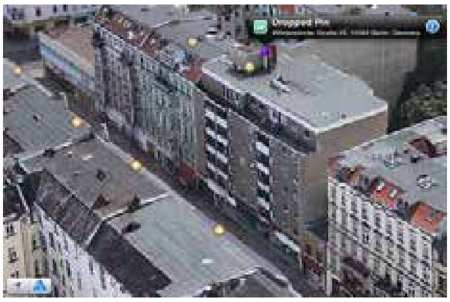
(a) (b)

(c)

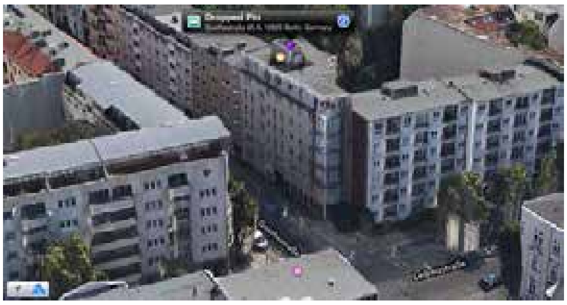
Figure 6.4.: Example of buildings with and without without residential attics. Figure(a) shows the location of the buildings, figure (b) shows a perspective image of the buildings. Figure (c) shows a building with its attic under construction
source: own graphs using Apple Maps for iPad

Despite of the fact that the three buildings that are shown in figure 6.4(b), have the same type of roof based on what is visible in the image, only the middle uses its roof area for residential purposes (see the big windows and balconies in the roof) so it is an additional storey for that building. Figure 6.4(c) shows a building that was refurbished and during this process its roof was renewed and turned into a residential space.

Another physical factor that could had influenced into a wrong estimation of the number of storeys is the additional constructions that are on the roofs, which could be seen on several buildings (figure 6.5). This ”additional” level or construction is done so users or residents can go to the roof. Figure 6.5(a) shows an example of a building with a flat roof. Figure 6.5(b) shows an example of several building with different kind of roofs and some additional constructions on them.



(a)



(b)

Figure 6.5.: Examples of additional roof constructions
source: own graphs using Apple Maps for iPad

6.1.2. Dwellings per Building

The statistical value stated in (Senatsverwaltung für Stadtentwicklung 2010) (section 5.1.5) about the average size of a flat in Berlin is used for the estimation of the number of dwellings per building, first the number per storey is calculated and then multiplies by the number of storeys to obtain the final value of the building. Table 6.3 shows the comparison of results for the same buildings that were presented in section 6.1.1.

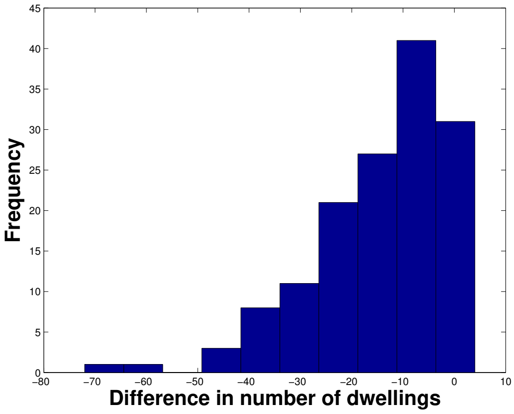
Building ID	Dwellings	$D_{Std.H}$	$\epsilon_{Std.H}$	BldgAge	$D_{H,YoC}$	$\epsilon_{H,YoC}$
BLDG_0003000000067203	36	63	-27	1961	63	-27
BLDG_0003000000069010	12	36	-24	1899	28	-16
BLDG_000300000006f0e2	12	48	-36	1899	36	-24
BLDG_000300000006e689	22	60	-38	1918	36	-14
BLDG_0003000f001d3542	18	21	-3	1961	21	-3
BLDG_0003000f001f67be	12	40	-28	1899	28	-16
BLDG_0003000e005b3d5a	13	21	-8	1899	18	-5
BLDG_0003000000071392	24	25	-1	1975	25	-1
BLDG_0003000f001d355a	10	12	-2	1961	12	-2
BLDG_0003000f001d35a9	18	21	-3	1961	21	-3

Table 6.3.: Comparison of number of dwellings per building between the observed values and the estimated number of dwellings in the implementation
source: Own table

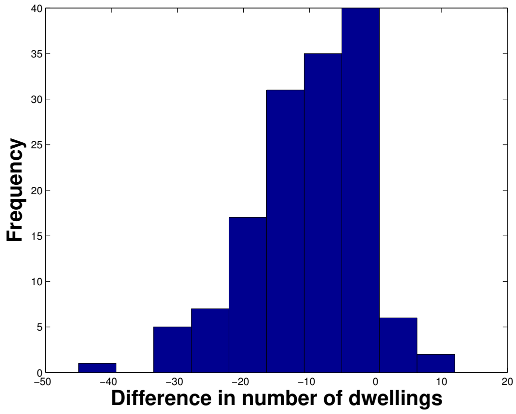
Where:

- $\mathbf{D_{Std.H}}$: number of dwellings considering a standard storey height S_H
- $\mathbf{D_{H,YoC}}$: number of dwellings using a different storey height based on the building's year of construction

The user can see that there are dramatic differences between observations and the results obtained using the average size of a flat in Berlin, the first conclusion can be the discrepancies on the values of the number of storeys per building. Another statement that should be considered is that the value used might be the average size area of the hole Berlin but either it does not represent properly the area of study or that value should be discriminated as well by the building year of construction. The standard deviation for both set of results are presented below as well of their histograms (figure 6.6).



(a)



(b)

Figure 6.6.: Histograms of the estimation of number of dwellings per building, figure(a) shows the histogram for the $\mathbf{S_{Std.H}}$ method, figure (b) shows the histogram for the $\mathbf{S_{H,YoC}}$ method

source: own graphs using Matlab

The statistical test T_{x^2} will be done, being H_0 that the dataset follows a normal distribution as it was done to the results in section 6.1.1. The standard deviation of the two methods are shown below.

- $\sigma_{\mathbf{D_{Std.H}}} = 13.45284$
- $\sigma_{\mathbf{D_{H,YoC}}} = 9.25783$

With a confidence level of 95% and a degree of freedom of 143, the critical value is $T_{x^2} = 171.907$. H_0 is accepted if equation 6.2 is fulfilled. The results of both estimations are shown below.

- $\mathbf{D_{Std.H}}$: $1095.230 > 171.907$
- $\mathbf{D_{H,YoC}}$: $2918.346 > 171.907$

For both methods H_0 is rejected, meaning that the datasets do not follow a normal distribution.

Dwelling estimation by building's year of construction

After the initial results, I decided to estimate the average dwelling size of the surveyed buildings for the year of construction ranges that were stated in table 5.5. The area per dwelling for the observed buildings was obtained by calculating the full constructed area of the building (summing the area of all ground surfaces times its number of storeys) and then dividing that value by the number of dwellings of that building (equation 6.3).

$$Area = \frac{ConstructedArea \cdot NoStoreys}{NoDwellings} \tag{6.3}$$

Once that value was obtained, the average area per dwelling for the test area was estimated as $\mathbf{82.34m^2}$, which totally differs from Berlin's average flat size of $\mathbf{70.4m^2}$(Senatsverwaltung für Stadtentwicklung 2010). Figure 6.7 presents the scatter plot of dwellings' areas for the surveyed buildings.

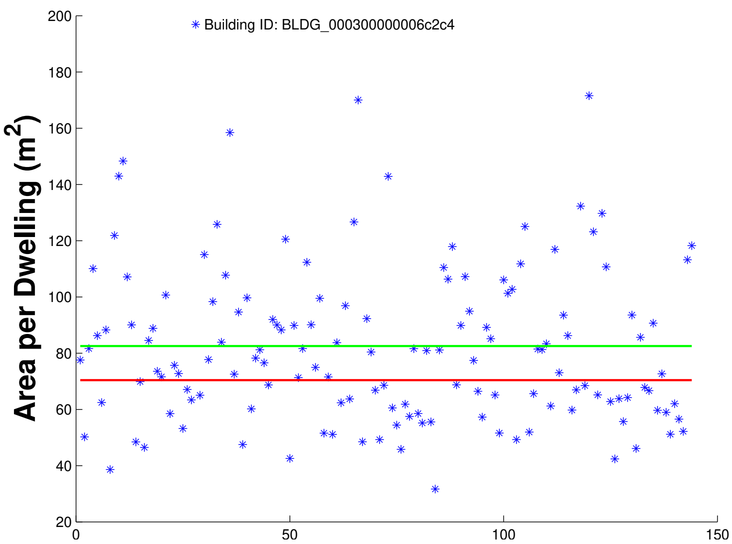
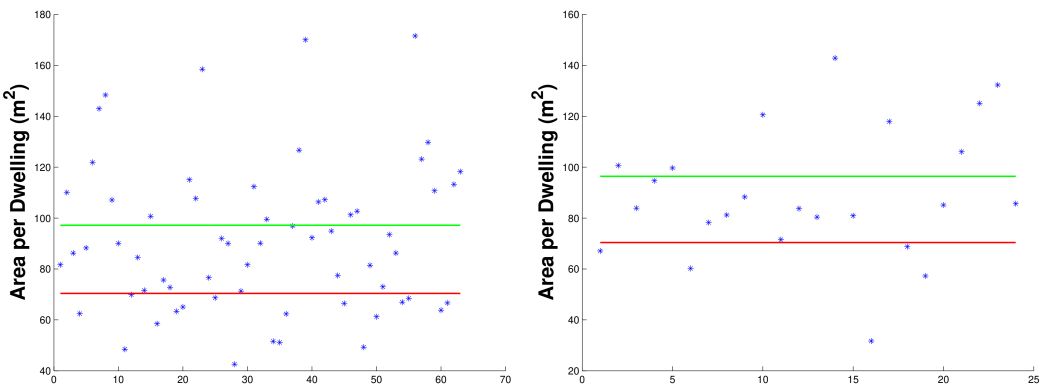


Figure 6.7.: Scatter plot of dwelling's areas at test area. The green line represents the average size for the test area, the red line represents the average size for Berlin

source: Own graph

Due to the discrepancies of areas and the rejection of the null hypothesis, I decided to estimate the average size per residential unit according to surveyed buildings grouping them by their year of construction with the expectation of improving the estimation results. To do so average dwelling areas per year range was estimated using the surveyed data. Figure 6.8 shows the scatter plots for the different groups.



(a) (b)

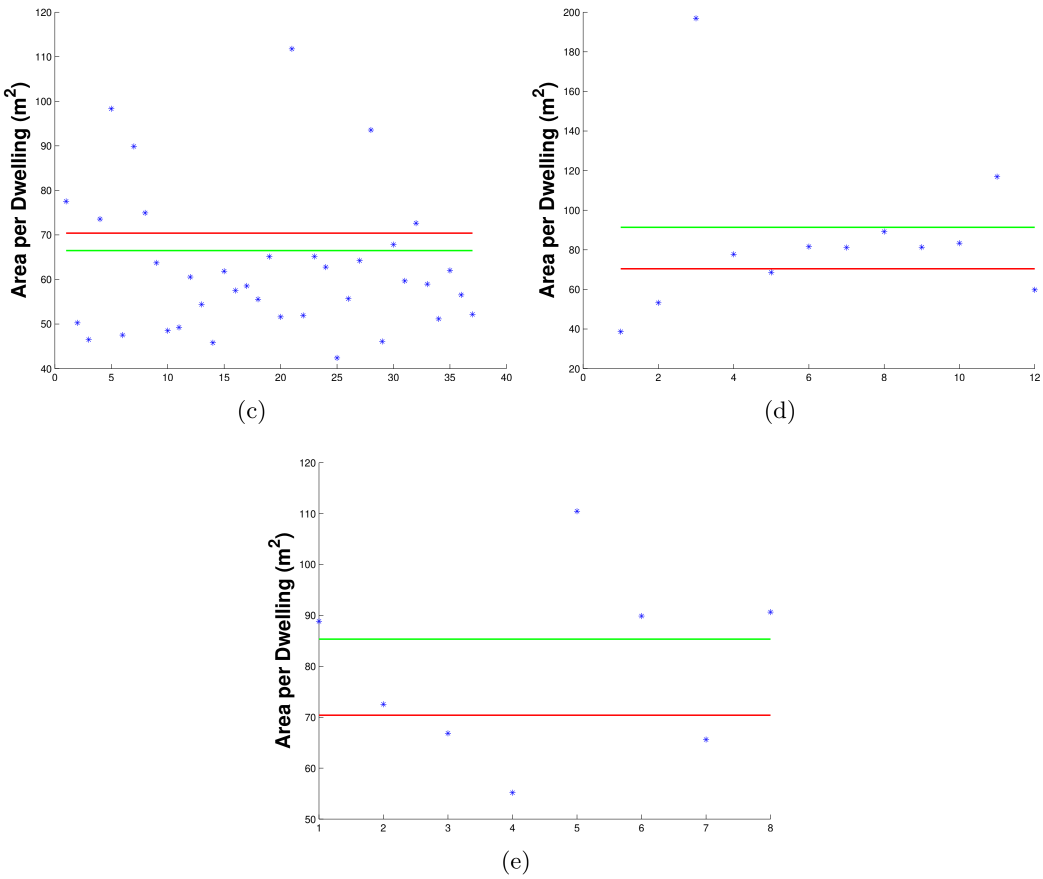


Figure 6.8.: Scatter plot of dwelling's areas at test area according to its year of Construction (a) (< 1900), (b) (1900 – 1918), (c) (1946 – 1961), (d) (1962 – 1974), (e) (> 1975). The green line represents the average size for the test area in that year range and the red line represents the average size for Berlin

source: Own graph

Table 6.4 presents the average area value for each year of construction category.

Year of Construction	Average Area
< 1900	91.11
1900 – 1918	89.32
(1946 – 1961)	62.31
(1962 – 1974)	85.68
(> 1975)	80.00

Table 6.4.: Average dwelling area of the test area classified by building's year of construction

source: Own table

A new estimation of the number of dwellings of a building was done based on the values presented in table 6.4. A small presentation of the results can be seen in table 6.5.

Building ID	Dwellings	$D_{H,YoC}$	$\epsilon_{H,YoC}$	BldgAge	$D_{HA,YoC}$	$\epsilon_{HA,YoC}$
BLDG_0003000000067203	36	63	-27	1961	54	-18
BLDG_0003000000069010	12	28	-16	1899	21	-9
BLDG_000300000006f0e2	12	36	-24	1899	24	-12
BLDG_000300000006e689	22	36	-14	1918	30	-8
BLDG_0003000f001d3542	18	21	-3	1961	21	-3
BLDG_0003000f001f67be	12	28	-16	1899	21	-9
BLDG_0003000e005b3d5a	13	18	-5	1899	12	1
BLDG_0003000000071392	24	25	-1	1975	20	4
BLDG_0003000f001d355a	10	12	-2	1961	12	-2
BLDG_0003000f001d35a9	18	21	-3	1961	21	-3

Table 6.5.: Comparison of the number of dwellings per building between the observed values and the two estimations done in the implementation
source: Own table

Where:

- $\mathbf{D_{H,YoC}}$: number of dwellings using a different storey height based on the building's year of construction
- $\mathbf{D_{HA,YoC}}$: number of dwellings using a different storey height and an average dwelling size based on the building's year of construction

Having different dwelling sizes based on the year of construction lead to a reduction on the discrepancies in the estimation, as can be seen on its histogram (figure 6.9).

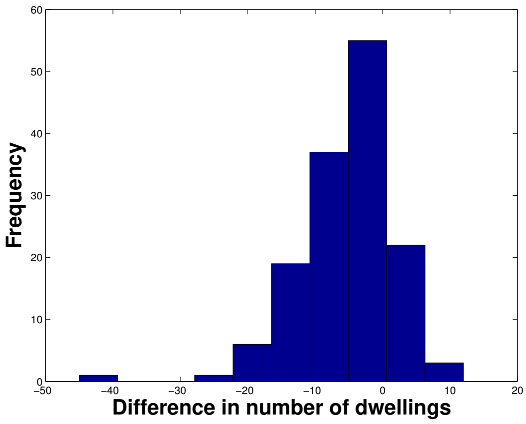


Figure 6.9.: Histogram of the number of dwellings considering an average size per year of construction
source: Own graph

Finally the statistical test x^2 is done to evaluate if data follow a normal distribution, when the H_0 (equation 6.1) is fulfilled. The test is done with a confidence level of 95% and a degree of freedom of 143, the critical value is $T_{x^2} = 171.907$. The results are shown below.

- $\sigma_{\mathbf{D_{HA,YoC}}} = 7.367$
- $\mathbf{D_{HA,YoC}}$: $356.6528 > 171.907$

The result indicates that the dataset does not follow a normal distribution, it could be that the dataset neither represent correctly the are of study of it is not significant and a new survey should be done.

In my opinion, there are three factors that could help to understand the results obtained. The first one is the methodology of the estimation of the number of dwellings using an average area size. That average number might be for the hole city of Berlin but it clearly does not represent the borough where this master thesis was done. For that reason I decided to estimate an average dwelling size for the area and specifically for the year of construction ranges.

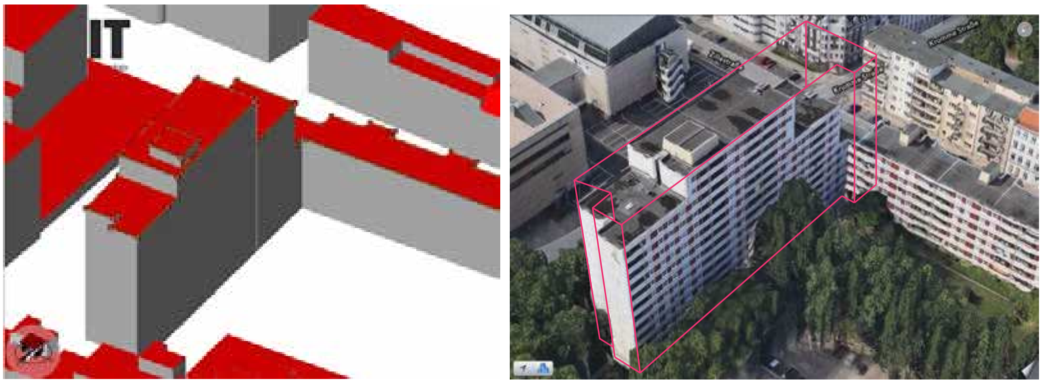
The second factor is regarding the methodology used for the estimation. As it was stated in section 5.6 the constructed area was estimated as the result of the sum all *GroundSurface* features, because a building can be modelled as a complex relation of multiple building parts. Even though the model does split buildings into multiple parts, it is not explicitly expressed as it is declared by the encoding standard (figure 6.10).

```
<xs:complexType name="BuildingPartType">
  <xs:complexContent>
    <xs:extension base="AbstractBuildingType">
      <xs:sequence>
        <xs:element ref="_GenericApplicationPropertyOfBuildingPart" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ============================================================================ -->
<xs:element name="BuildingPart" type="BuildingPartType" substitutionGroup="_AbstractBuilding"/>
<!-- ============================================================================ -->
<xs:element name="_GenericApplicationPropertyOfBuildingPart" type="xs:anyType" abstract="true"/>
```

Figure 6.10.: Extract of the CityGML encoding standard for the declaration of building parts

source: Own graph

This means that it is not possible to identify the different parts of a building in the implementation so the ground surface is always considered as a hole and building height is not discriminated for each part. For understanding purposes figure 6.11 shows some examples of buildings that were modelled with a complex relation of building parts but the CityGML file does not explicitly present them. Figure 6.11(a) shows the CityGML model of a building in the area of study. Figure 6.11(b) shows the same building in 3D as well as a sketch of the building as it was read in the implementation (read box).



(a) (b)

Figure 6.11.: Example of buildings with multiple uses
source: Own graph

The last factor that is the buildings that were included as residential during this master thesis. Some of those buildings have a function code that states multiple purposes, i.e. 2100 “Building and open space - mixed use with housing” (table 5.4). Meaning that part of the building or complete storeys are not residential so for that reason the total number of dwellings is lower than the author would expected in some of them, for instance a 5 storeys building, like the one shown in figure 6.12(a), have 8 residential units instead of 10. Figure 6.12 presents some photos that were captured during the survey.

(a) (b)

Figure 6.12.: Example of buildings with multiple uses
source: Own graph

6.1.3. Number of Inhabitants

The number of residents in a dwelling is critical for the estimation of energy consumption as it is stated in equation 3.8. The statistical value stated in (Senatsverwaltung für Stadtentwicklung 2010) ,section 5.1.5, regarding the residential area per person is used for the estimation of the number of residents in a dwelling and consequently in a building. Nevertheless after taking into consideration the results shown in the previous section (section 6.1.2) lead me to do the estimation considering the two methods, which are presented below.

First Method

The number of inhabitants per dwelling is estimated basically by dividing its area by the area per person (equation 6.5), finally the number of inhabitants per building is estimated by multiplying this result by the total number of dwellings of the building (equation 6.5).

$$N_I = int\left(\frac{A_D}{A_p}\right) \tag{6.4}$$

$$N_{I,B} = N_I \cdot N_D \tag{6.5}$$

Where:

- N_I = Number of inhabitants per dwelling
- A_D = Dwelling's area
- A_p = Area per person
- N_D = Building's number of dwellings
- $N_{I,B}$ = Building's number of inhabitants

Second Method

For the second method first the number of inhabitants per storey is estimated dividing the constructed area by the area per person(equation 6.8), then the total number of the building is estimated (equation 6.8), finally this value is divided by the number of dwellings in that building (equation 6.8).

$$N_{I,S} = int\left(\frac{CA_S}{A_p}\right) \tag{6.6}$$

$$N_{I,B} = N_{I,S} \cdot N_S \tag{6.7}$$

$$N_I = int\left(\frac{N_{I,B}}{N_D}\right) \tag{6.8}$$

Where:

- CA_S = Constructed Area of a storey (as it is defined in section 5.1.5
- $N_{I,S}$ = Storey's number of inhabitants

- N_S = Building's number of storeys

A comparison of the results obtained by the two methods are shown in table 6.6.

	Method I			Method II				
Building ID	N_I	$D_{HA,YoC}$	$N_{I,B}$	$N_{I,S}$	$N_{I,B}$	N_I	$\Delta_{I,D}$	$\Delta_{I,B}$
BLDG_0003000000067203	3	63	189	11	99	2	1	90
BLDG_0003000000069010	4	21	84	6	42	2	2	42
BLDG_000300000006f0e2	5	24	120	9	54	3	2	66
BLDG_000300000006e689	3	30	90	11	66	3	0	24
BLDG_0003000f001d3542	2	21	42	4	28	2	0	14
BLDG_0003000f001f67be	4	21	84	7	49	3	1	35
BLDG_0003000e005b3d5a	3	12	36	5	30	3	0	6
BLDG_0003000000071392	2	20	40	7	35	2	0	5
BLDG_0003000f001d355a	2	12	24	4	24	2	0	0
BLDG_0003000f001d35a9	2	21	42	5	35	2	0	7

Table 6.6.: Number of inhabitants per building

source: Own table

I decided to continue with the second approach and this is because of the difference between the two of them on the final estimation of the number of residents of a building, which is relevant and influences directly on the values of the estimation of electrical energy consumption. Another way to evaluate the quality of results is to compare these results with the official statistical values for the borough of the area of study (Charlottenburg-Wilmersdorf) that are presented in **Ergebnisse des Mikrozensus im Land Berlin 2011** (Amt für Statistik Berlin-Brandenburg 2012), which are shown in table 6.7.

Borough	**Total**	**1 Person**	**Number of people**				**average**
			Together	**2**	**3**	**4/more**	
	1000						**People**
Mitte	202,7	126,9	75,9	45,1	15,5	15,3	1,65
Friedrichshain-Kreuzberg	166,7	104,2	62,5	36,8	13,0	12,7	1,64
Pankow	228,2	134,3	93,9	59,4	20,1	14,4	1,64
Charlottenburg-Wilmersdorf	194,9	114,3	80,7	52,9	14,9	12,8	1,64
Spandau	127,7	65,0	62,7	39,8	13,0	9,8	1,79
Steglitz-Zehlendorf	159,1	77,3	81,8	51,5	14,3	16,0	1,84
Tempelhof-Schöneberg	192,2	102,5	89,7	56,8	17,6	15,3	1,76
Neukölln	173,0	95,5	77,4	44,6	16,1	16,8	1,80
Treptow-Köpenick	137,6	68,0	69,5	47,0	12,7	9,9	1,75
Marzahn-Hellersdorf	134,3	59,2	75,1	48,5	16,7	9,8	1,86
Lichtenberg	151,9	74,3	77,6	55,0	13,4	9,1	1,73
Reinickendorf	127,1	57,2	69,9	43,6	12,0	14,3	1,91
Total Berlin	**1995,4**	**1078,8**	**916,6**	**581,2**	**179,3**	**156,2**	**1,74**

Table 6.7.: Households in the City of Berlin in 2011 by borough and household size

source: Translated version of table "6.2 Privathaushalte im Land Berlin 2011 nach Bezirken und Haushaltsgröße" (Amt für Statistik Berlin-Brandenburg 2012)

So considering the average number of inhabitants of the borough 1,64 and multiplying this value for the number of dwellings give us an approximated value that building should have, values for the same buildings are shown in table 6.8.

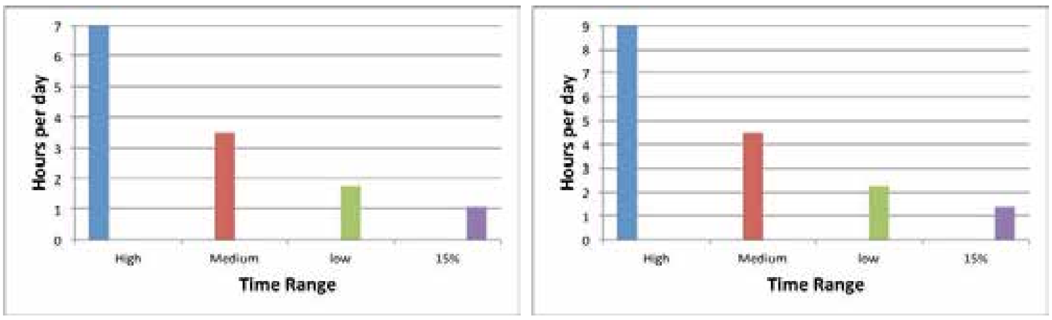
Building ID	$D_{HA,YoC}$	avg. Inh	Mtd. I	$\Delta_{Mtd.\ I}$	Mtd. II	$\Delta_{Mtd.\ II}$
BLDG_0003000000067203	63	103.32	189	-86	99	4
BLDG_0003000000069010	21	34.44	84	-50	42	-8
BLDG_000300000006f0e2	24	39.36	120	-81	54	-15
BLDG_000300000006e689	30	49.2	90	-41	66	-17
BLDG_0003000f001d3542	21	34.44	42	-8	28	6
BLDG_0003000f001f67be	21	34.44	84	-50	49	-15
BLDG_0003000e005b3d5a	12	19.68	36	-16	30	-10
BLDG_0003000000071392	20	32.8	40	-7	35	-2
BLDG_0003000f001d355a	12	19.68	24	-4	24	-4
BLDG_0003000f001d35a9	21	34.44	42	-8	35	-1

Table 6.8.: Comparison of the two methods for the estimation of the number of inhabitants against the average number of resident per dwelling
source: Own Table

Where **avg. Inh** is the theoretical number of inhabitants based on the average value for the borough, the comparison results where obtained from table 6.6. Based on the results presented on table 6.8 the decision of using **Method II** for the estimation of the number of inhabitants is strengthen.

6.2. Electrical Energy Consumption

The estimation of the electrical energy consumption was done based on the number of dwellings per building (Section 6.1.2), number of inhabitants per dwelling (Section 6.1.3) and the energy appliances (Section 5.2) that were assumed as presented on each building. Another factor variable that was include was the life style proposed (Section 5.3), figure 6.13 shows the life style scenarios of several electrical appliances, for instance electrical lighting.



(a) (b)

Figure 6.13.: Life style example for the electrical lighting. Figure (a) shows the life style for week days. Figure (b) shows the life style for weekends and bank holidays
source: Own graph

Where:

- 100% Lamps are on the full time that users are at home.
- 50% Lamps are on half of the time that users are at home.
- 25% Lamps are on quarter of the time that users are at home.
- 15% Lamps are on a sixth part of the time that users at home.

Initially only three time ranges were proposed to be evaluated, nevertheless an additional one (15%) was include in order to evaluate what is the result of a low use of the appliances.

6.2.1. Electrical Energy Consumption per Building

This section presents the results per building. First the consumption of electrical energy per day is estimated for a single dwelling, then the total value of the building is computed. The week value is calculated by assuming 5 labour days and two weekend days. Week is the time framework that is used to estimated the final Year result by multiplying the initial result by the number of weeks of a year (52). Figure 6.14 shows an activity graph of the electrical energy consumption estimator used during the master thesis.

Figure 6.14.: Extract of the activity diagram for estimation of energy consumption
source: Own graph

Table 6.9 presents the results of the energy consumption per building. It is possible to see that the constructed area of the building (which in this scenario is the constructed area of the ground floor times number of storeys) has a big influence on the estimation of the electrical energy consumption for the methodology that was used in this master thesis and this is because almost all parameters (except for the energy appliances) are estimated based on the constructed area of the building.

Building ID	Const. Area	High 100%	Medium 50%	Low 25%	15%
BLDG_0003000000067203	3589	454085.3996	231668.9144	120460.6718	75977.3748
BLDG_0003000000069010	1541	295191.7541	149802.1645	77107.36975	48029.45184
BLDG_000300000006e689	2331	421702.5059	214003.0922	110153.3854	68613.50262
BLDG_000300000006f0e2	2040	337362.0047	171202.4738	88122.70829	54890.8021
BLDG_0003000000071392	1324	168179.7776	85803.30164	44615.06364	28139.76844
BLDG_0003000e005b3d5a	961	168681.0024	85601.23688	44061.35414	27445.40105
BLDG_0003000f001d3542	968	176588.7665	90093.46673	46845.81683	29546.75687
BLDG_0003000f001d355a	716	168681.0024	85601.23688	44061.35414	27445.40105
BLDG_0003000f001d35a9	1096	176588.7665	90093.46673	46845.81683	29546.75687
BLDG_0003000f001f67be	1656	295191.7541	149802.1645	77107.36975	48029.45184

Table 6.9.: Building's energy consumption results (kW/H Year) for different life styles

source: Own Table

Figure 6.15 presents the results that are shown in table 6.9.

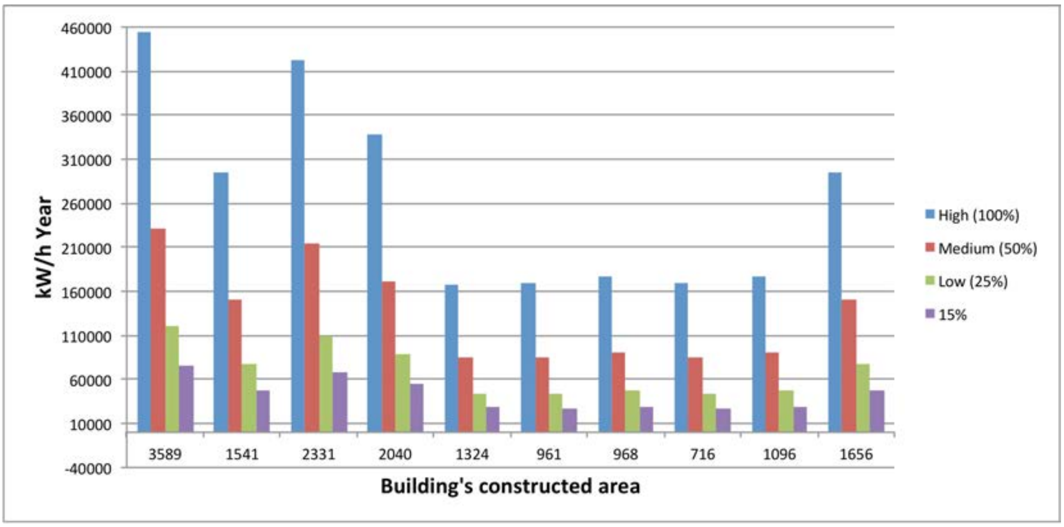


Figure 6.15.: Building's energy consumption results (kW/H Year) for different life styles

source: Own graph

The results are logical on the fact that the bigger the building the more electrical energy it consumes, nevertheless table 6.15 shows us a interesting value that must be taken into consideration. A wrong estimation of the building parameters leads to a wrong estimation of the energy consumption and this can be seen in the cases of buildings id *BLDG_0003000e005b3d5a, BLDG_0003000f001d355a*. Despite of the fact that they have different constructed areas, they do have the same value of consumption **168681.0024 kW/H year**.

The results of estimation of the number of storeys of a building said that for building *BLDG_0003000e005b3d5a* , it has 6 storeys whether than in real life it has seven and for the *BLDG_0003000f001d355a* the estimator says that it has 6 storeys whether in real life it has 5 (table 6.2).

6.2.2. Electrical Energy Consumption per Dwelling

As it is stated in figure 6.14 energy consumption values were also estimated per dwelling, this value can vary according to the total number of residents and dwellings of the building. Table 6.10 shows the results of the estimation of annual electrical energy consumption of dwelling in those buildings.

Building ID	$D_{HA,YoC}$	High 100%	Medium 50%	Low 25%	15%
BLDG_0003000000067203	54	8408.988882	4290.165082	2230.753182	1406.988422
BLDG_0003000000069010	21	14056.7502	7133.436407	3671.779512	2287.116754
BLDG_000300000006e689	30	14056.7502	7133.436407	3671.779512	2287.116754
BLDG_000300000006f0e2	24	14056.7502	7133.436407	3671.779512	2287.116754
BLDG_0003000000071392	20	8408.988882	4290.165082	2230.753182	1406.988422
BLDG_0003000e005b3d5a	12	14056.7502	7133.436407	3671.779512	2287.116754
BLDG_0003000f001d3542	21	8408.988882	4290.165082	2230.753182	1406.988422
BLDG_0003000f001d355a	12	14056.7502	7133.436407	3671.779512	2287.116754
BLDG_0003000f001d35a9	21	8408.988882	4290.165082	2230.753182	1406.988422
BLDG_0003000f001f67be	21	14056.7502	7133.436407	3671.779512	2287.116754

Table 6.10.: Average dwelling's energy consumption results (kW/H Year) for different life styles at the surveyed buildings
source: Own Table

The values of the electrical energy consumption of a dwelling are homogeneous and this is due to its number of inhabitants. For that reason only three different values were obtained for the surveyed buildings and they are shown below for the 100% Range.

- **8,408.988882 kW/H**: 1 Person Dwelling
- **14,056.7502 kW/H**: 2 People Dwelling
- **17,366.52172 kW/H**: 3 People Dwelling

Those results are logical based on the statement that an increase on the number of residents involves an non-linear increase in the estimation of the electrical energy consumption (equation 3.8). Values are presented for a better visualisation in figure 6.16.

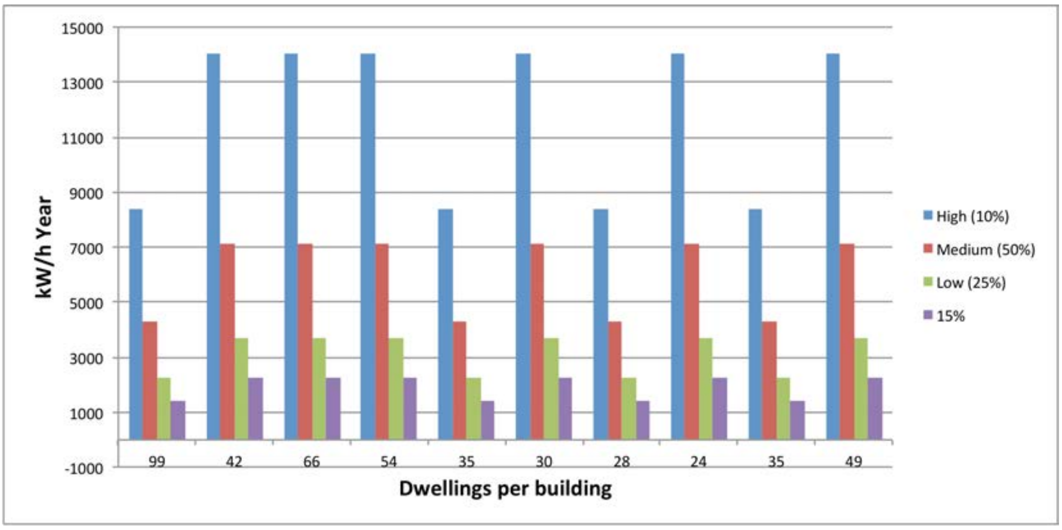


Figure 6.16.: Average dwelling's energy consumption results (kW/H Year) for different life styles at the surveyed buildings
source: Own graph

6.2.3. Electrical Energy Consumption per Inhabitant

The results that are presented here (table 6.11 and figure 6.17), were estimated from the annual building energy consumption divided by its number of residents so a final average value per person was estimated.

Building ID	$Bldg.Inh_{Mtd.II}$	High 100%	Medium 50%	Low 25%	15%
BLDG_0003000000067203	99	4586.721208	2340.090045	1216.774463	767.4482303
BLDG_0003000000069010	42	7028.375098	3566.718203	1835.889756	1143.558377
BLDG_000300000006e689	66	6389.431907	3242.471094	1668.990687	1039.598525
BLDG_000300000006f0e2	54	6247.444532	3170.416181	1631.902005	1016.496335
BLDG_0003000000071392	35	4805.136504	2451.522904	1274.716104	803.9933841
BLDG_0003000e005b3d5a	30	5622.700078	2853.374563	1468.711805	914.8467016
BLDG_0003000f001d3542	28	6306.741662	3217.623812	1673.064887	1055.241317
BLDG_0003000f001d355a	24	7028.375098	3566.718203	1835.889756	1143.558377
BLDG_0003000f001d35a9	35	5045.393329	2574.099049	1338.451909	844.1930533
BLDG_0003000f001f67be	49	6024.321513	3057.187031	1573.619791	980.1928946

Table 6.11.: Average energy consumption per person results (kW/H Year) for different life styles at the surveyed buildings
source: Own Table

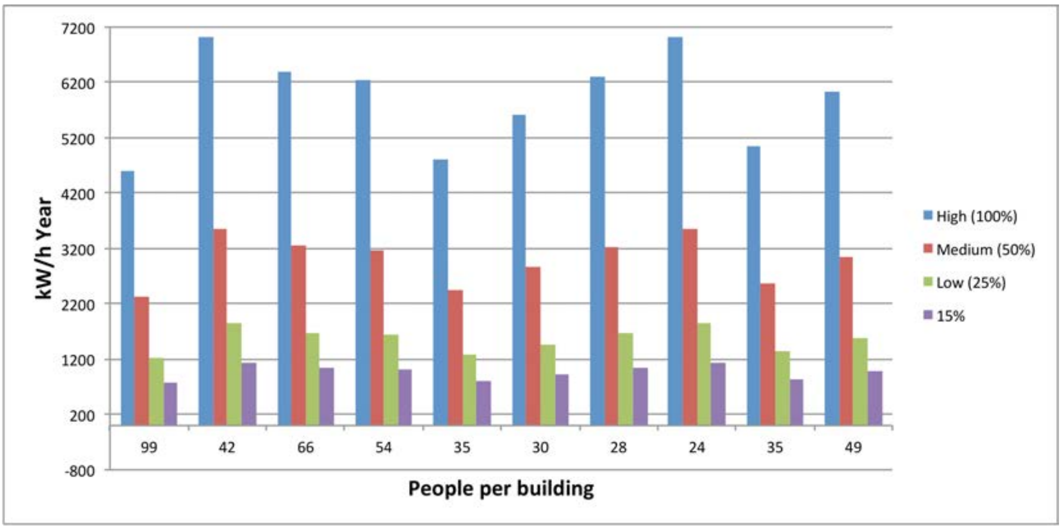


Figure 6.17.: Average energy consumption per person results (kW/H Year) for different life styles at the surveyed buildings
source: Own graph

Based on the fact that the number of residents of a building is not estimated according to the number of inhabitants per dwelling rather than by the number of inhabitants per storey, the average value energy consumption of each building differs from the ones that are shown in section 6.2.2.

As it has been seen on the results of the entire document I considered only integer values for the number of storeys, dwellings and residents. This is because at the end there are no 1.64 residents in a dwelling in real life. They are either 1 in a positive scenario or 2 in a negative scenario. I decided to consider the negative scenario and use the ceiling function on all estimations for the building parameters. For that reason buildings such as *BLDG_0003000000067203* has the following results, 28 dwellings and 63 Inhabitants.

6.3. Concrete Case of Study

A concrete building is shown in order to have a better visualisation of influence of the variables in the forecasting done in this master thesis. The building is shown in figure 6.18. For identification purposes, the building's Id is *BLDG_000300000006ca52*.

Figure 6.18.: Concrete example
source: Own graph using Apple Maps for iPad

It is important to state that it was possible to do a small poll to a resident of that building in order to compare the results obtained in the implementation, figure 6.19 presents the scanned image of the poll filled by the resident.

Address: Spielhagenstr. 11
Area: 110 m2
Number of residents: 2
Number of rooms: 3
Energy consumption last year: 2.780 Kwh

Appliance	Units	Time of Use (hrs /day)
Freezer / Fridge	1	24
Hob (4 cooking places)	1	1
Ovens	1	1/2h
Chimney Hood	—	—
Microwave Oven	1	2 min
Dishwasher	1	1/2h
Washing Machine	1	1h
Tumble Dryer	1	1h
Electrical Lighting (Lamps)		
Lamp 100		
Lamp 40	—	
Lamp 32	—	
Saverlamp	26	1h
TV	1	2h
Home Theater	—	—
Gaming System	—	—
Computer	2	4
Printer/scanner	1	1/2
Modem ADSL	1	24
Mobile Phone	2	1
Tablet	1	2
Docking station	—	—
Vacuum	—	—
Iron machine	1	1/2
Coffee machine	1	1/3
Digital TV Adapter	1	1

Table C.2.: Example of the survey made to the residents
Source: Own table based on (KEMA-XENERGY 2004) and section 5.2

Figure 6.19.: Scanned image of the poll done to a resident
source:Own Graph

The building has the following parameters.

- Number of storeys: 5
- Number of ring bells at the entrance[1]: 20

[1] This value is assumed as the number of dwellings in the building, based on the fact that every dwelling has its on ring bell.

- Year of construction range: 1900 - 1918
- Constructed Area: 536.76m^2, average dwelling size: 107.35m^2
- Average dwelling size according to the year of construction (table 6.4):95.27m^2

It is relevant to mention two characteristics of this building, the first one is that the ground floor of the building is used for commercial activities, based on this fact it can be stated that the number of dwellings per storey is 5 (number of rings/number of storeys) and the second one is that despite of the fact that the roof space is tall enough to be used for residential purposes that is no the case of this building. The results obtained of the building parameters are shown in table 6.12.

Storeys	Dwellings	Inhabitants per dwelling
$S_{Std.H} = 8; \epsilon = -3$	$D_{Std.H} = 64; \epsilon = -44$	$\mathbf{N_{I,Mtd.\ II} = 3; \epsilon = -1}$
$\mathbf{S_{H,YoC} = 6; \epsilon = -1}$	$D_{H,YoC} = 48; \epsilon = -28$	
	$\mathbf{D_{HA,YoC} = 36; \epsilon = -16}$	

Table 6.12.: Case of study. Building parameters results

source: Own Table

It is possible to see the dramatic difference in the number of dwellings of the building, this clearly indicates that the average flat area in Berlin does not fit the characteristic of this building. Furthermore, the average dwelling size according to the building year of construction estimated during this master thesis has a significant difference with the size of the flat that was polled, which values can be seen in figure 6.19.

Estimation of Energy Consumption

The estimation of the electrical energy consumption of the building is presented for each of the energy appliances that were presented in section 3.3, all values were estimated on a daily basis as it is stated in table 5.8. Table 6.13 presents the food preparation energy appliance (table), fridge's consumption value assumed for the year is divided by 365 so the daily value was obtained, due to the fact that it is always on there is no variation on the estimation value.

Laundry group was declared as a number of cycles weekly so those values are divided by 7 to have the daily value (table 6.14). The electrical lighting (tables 6.15 and 6.16), Entertainment and Technology (tables 6.17 and 6.18), Personal Computer and home offices (tables 6.19 and 6.20) and Miscellaneous groups (tables 6.21 and 6.22) are divided into Business (week) days and weekend days based on the life style model assumed in this master thesis (section 5.10).

The reason for not splitting the Food Preparation (table 6.13) and Laundry (section 6.14) energy appliances into business and weekend days stays on the fact that the first one is a basic need that people must supply daily and the latter one the time scale used, which is a weekly consumption. Table 6.13 shows the high influence that cooking has on the energy consumption of a dwelling, almost all the devices considered require a high amount of electricity for their operation, so an update on the kitchen equipment will have as a direct consequence the reduction on the consumption of electrical energy.

The difference between the life style model assumed in this master thesis and the concrete example that is presented in this section is that the residents do not have a Chimney Hood, a device that in the worst scenario could have a consumption of circa 1,5 kW/h.

In the case of the Laundry energy appliance (table 6.14), its values will be reduced dramatically it the dwelling either not has a electrical tumble dryer or it has a gas based one.

Time Range	Time (h)	Fridge	Hob	Oven	Chimney Hood	Microwave	Dishwasher	Total
100%	2	0.00112	18.88751	6.54767	1.25917	0.40000	5.03667	32.13214
50%	1	0.00112	9.44376	3.27384	0.62958	0.20000	2.51833	16.06663
25%	0.5	0.00112	4.72188	1.63692	0.31479	0.10000	1.25917	8.03387
15%	0.3	0.00112	2.83313	0.98215	0.18888	0.06000	0.75550	4.82077

Table 6.13.: Case of study. Food preparation energy appliance results

source: Own Table

Time Range	Time (cycles)	Washing Machine	Tumble Dryer	Total
100%	2	0.37775	1.49901	1.87676
50%	1	0.18888	0.74950	0.93838
25%	0.5	0.09444	0.37475	0.46919
15%	0.3	0.05666	0.22485	0.28151

Table 6.14.: Case of study. Laundry energy appliance results

source: Own Table

The Electrical lighting (tables 6.15 and 6.16) is a sensitive energy appliance more than any other. It is pretty much influenced by several factors like the room illumination, time of the day, user's behaviour, as well as the economy because saver lamps are much expensive than the incandescent light bulbs. It is important to mention that for the model used here, the highest consumer are the 100W bulbs, so a reduction on the use of those kind of bulbs reduces the energy consumption.

Time Range	Time (h)	100w (2 Lamps)	40w (2 Lamps)	32w (2 Lamps)	Saver Lamp (3 Lamps)	Total
100%	7	2.93806	1.17522	0.94018	0.08814	5.1416
50%	3.5	1.46903	0.58761	0.47009	0.04407	2.5708
25%	1.75	0.73451	0.29381	0.23504	0.02204	1.2854
15%	1.05	0.44071	0.17628	0.14103	0.01322	0.77124

Table 6.15.: Case of study. Electrical lighting energy appliance results. Business day

source: Own Table

Time Range	Time (h)	100w (2 Lamps)	40w (2 Lamps)	32w (2 Lamps)	Saver Lamp (3 Lamps)	Total
100%	9	3.7775	1.511	1.2088	0.11333	6.61063
50%	4.5	1.88875	0.7555	0.6044	0.05666	3.30531
25%	2.25	0.94438	0.37775	0.3022	0.02833	1.65266
15%	1.35	0.56663	0.22665	0.18132	0.017	0.99159

Table 6.16.: Case of study. Electrical lighting energy appliance results. Weekend day
source: Own Table

The Entertainment and Technology energy appliance group (tables 6.17 and 6.18) has a special characteristic, the energy consumption of the TV (in this case a brand new Phillips model) is lower than the energy consumption of the Home Theatre, which in this case is a home theatre system from the same brand.

The idea of using energy consumption values of the latest models was done because that equipment require less energy. Notwithstanding not all the times that a TV is used involves the use of the other equipment, also the energy consumption of the TV includes as well the consumption of a digital TV adapter, which might not be required by new models.

Time Range	Time (h)	TV on	TV standby	Home Theatre on	Home Theatre standby	Total
100%	7	2.73239	0.17170	1.54248	0.00745	4.45402
50%	3.5	1.36620	0.20705	0.77124	0.01332	2.35781
25%	1.75	0.68310	0.22473	0.38562	0.01626	1.30971
15%	1.05	0.40986	0.22014	0.23137	0.01744	0.87881

Table 6.17.: Case of study. Entertainment and Technology energy appliance results. Business day
source: Own Table

Time Range	Time (h)	TV on	TV standby	Home Theatre on	Home Theatre standby	Total
100%	9	3.51308	0.15150	1.98319	0.00409	5.65186
50%	4.5	1.75654	0.19695	0.99159	0.01164	2.95673
25%	2.25	0.87827	0.21968	0.49580	0.01542	1.60916
15%	1.35	0.52696	0.21379	0.29748	0.01693	1.05516

Table 6.18.: Case of study. Entertainment and Technology energy appliance results. Weekend day
source: Own Table

The results obtained in the Personal Computer and Home Office (tables 6.19 and 6.20) are for a single PC per dwelling. Nevertheless this is not the scenario in the polled dwelling, where each of the residents do have a computer. This means that the energy consumption of that device could be double or higher than the value that is presented here.

The reader can see that computers have a high demand at least on the polled house because it is used 4^h a day which in terms of the time range proposed for this master thesis means half of the time that a person is at home. It is not clear if the value wrote in this field express the hours used per person or the total time.

Time Range	Time (h)	PC	Multifunctional	Modem	Total
100%	7	0.88142	0.02099	0.072	0.9744
50%	3.5	0.44071	0.01049	0.072	0.5232
25%	1.75	0.22035	0.00525	0.072	0.2976
15%	1.05	0.13221	0.00315	0.072	0.20736

Table 6.19.: Case of study. Personal Computer and Home Office energy appliance results. Business day
source: Own Table

Time Range	Time (h)	PC	Multifunctional	Modem	Total
100%	9	1.13325	0.02099	0.072	1.22624
50%	4.5	0.56663	0.01049	0.072	0.64912
25%	2.25	0.28331	0.00525	0.072	0.36056
15%	1.35	0.16999	0.00315	0.072	0.24514

Table 6.20.: Case of study. Personal Computer and Home Office energy appliance results. Weekend day
source: Own Table

The final energy appliance group is called Miscellaneous (tables 6.21 and 6.22). It presents those devices that were not classified into the previous categories, mobile phones and tablets are part of this group and their consumption is estimated to the time they are charged. Based on this statement, the consumption was considered as constant as there is the tendency of users of leave their devices to charge during the night (while users are sleeping), circa 8^h a day.

The time of use of the other devices varies, for example the maximum range for vacuum and coffee machine was assume as 1^h daily, 1^h weekly. The iron machine time ranges are the same as the ones in the previous energy appliances groups.

Range Time	Mobile	Tablet	Vacuum	Iron Machine	Coffee Machine	Docking station	Total
100%	0.12	0.20147	0.38974	0.29980	1.25917	0.10283	2.37301
50%	0.12	0.20147	0.19487	0.14990	0.62958	0.05142	1.34724
25%	0.12	0.20147	0.09744	0.07495	0.31479	0.02571	0.83435
15%	0.12	0.20147	0.05846	0.04497	0.18888	0.01542	0.62920

Table 6.21.: Case of study. Miscellaneous energy appliance results. Business day
source: Own Table

Range Time	Mobile	Tablet	Vacuum	Iron Machine	Coffee Machine	Docking station	Total
100%	0.12	0.20147	0.38974	0.29980	1.25917	0.13221	2.40239
50%	0.12	0.20147	0.19487	0.14990	0.62958	0.06611	1.36193
25%	0.12	0.20147	0.09744	0.07495	0.31479	0.03305	0.84170
15%	0.12	0.20147	0.05846	0.04497	0.18888	0.01983	0.63361

Table 6.22.: Case of study. Miscellaneous energy appliance results. Weekend day
source: Own Table

The final result is computed by the sum of the partial energy consumptions as it is stated in equation 3.19. Table 6.23 shows the final results of electrical energy consumption in daily, weekly and monthly basis for a mentioned Dwelling. The annual values are presented in table 6.24

Range Time	Business day	Weekend day	Weekly	Monthly
100%	46.95192919	49.90000641	334.5596588	1338.238635
50%	23.80405689	25.2780955	169.5764754	678.3059018
25%	12.23012074	12.96714004	87.08488378	348.3395351
15%	7.588895495	8.027778283	54.00003404	216.0001362

Table 6.23.: Case of study. Electrical energy consumption of a dwelling specified by day, week and month

source: Own Table

Range Time	Year	Building consumption	Consumption per Person
100%	17397.10226	626295.6812	626295.6812
50%	8817.976723	317447.162	317447.162
25%	4528.413957	163022.9024	163022.9024
15%	2808.00177	101088.0637	101088.0637

Table 6.24.: Case of study. Annual values of electrical energy consumption per dwelling, building and person

source: Own Table

The initial idea of having different time ranges was to evaluate the results of the worst scenario possible, which is the case that users will demand all the energy appliances at the same time when they are at home (100% or High time range). Obviously that kind of scenario is not realistic but nevertheless it gives us a good overview of which are the energy appliances that demand most of the energy that is consumed in a dwelling.

At the end and based on the results obtained the 15% range time obtained the closest results of the estimator for the polled dwelling **2780 kW/h** per year against the **2808.00177** obtained.

7. Summary and future work

A proposal for the estimation of the electrical energy consumption of a building using a 3D model is done in this master thesis, nevertheless there are certain topics that do need to be discussed.

A LoD2 CityGML model could be a sufficient tool for the extraction of the building parameters that were mentioned in this master thesis and that are required (number of dwellings and their number of inhabitants). Nevertheless there was a lack of data in the dataset that was available that clearly influenced the hole process.

The CityGML standard indicates that some of the data that was required could be available by only reading the feature and its attributes, *yearOfConstruction, storeysAboveGround, storeysBelowGround* among other attributes were not available on the dataset. That data was estimated but those results were not perfect and had errors that should not be ignore. In certain buildings the difference between observed and estimated number of storeys was of more than 2. Another way to overcome those problems could be the use of higher detailed model (LoD3 or LoD4), the latter one is a very demanding and expensive model (time and effort) even more for a complete city or region.

An observation that can be done to the dataset used (CityMGL version 1.0) is regarding roofs. This is because some of them might have additional constructions but they should not connected to the building itself but rather to be part of the roof as a hole like the entrances that were shown in figure 6.5.

The CityGML model itself is not explicit neither the number of dwellings or the number of residents of that building, so if this kind of data is going to be stored, it should be done as a generic attribute for both cases. Those attributes could store the total number of inhabitants of the building as well as a number that express the total of dwellings of the building.

I consider that dwellings do not have an specific attribute inside the CityGML standard because only the LoD4 model goes indoor in the modelling. Also the attribute term is only a semantical concept that indicates that several rooms can be grouped by a common factor, which is that their usage is residential all of them belong to the same residential unit.

In my opinion, the use of an average flat size and living area per person of a city are not a good indicator of the possible number of inhabitants in a dwelling as well the the number of dwellings in a building. A first reason is because construction legislation changes between certain periods of time (decades for example). Another one is more related to economy factors, wealthy people can pay more for housing meaning that their residential places are normally bigger than the average ones. This is the case of the area of study of this master thesis, despite of the fact that I use the official values stated by the Senate of Berlin, they clearly do not represented the borough of Charlottenburg-Wilmersdorf.

Regarding the electrical energy consumption estimation, I consider that the End-Use method was suitable for the scope of the master thesis, nevertheless the method should be improved by involving a bigger and detailed database of energy appliances, despite of the fact this is could be a tedious task for instance there a hundreds of Personal Computers, every single of them demanding a different amount of electrical energy for their operation.

Future Research

In future researches more detailed models should be used for the estimation of electrical energy consumption. Having a LoD3 model more possibilities to estimate for example the number of storeys of a building , i.e. evaluating the number of rows of windows in the facade, to mention one. Also having that kind of opening (window) will allow further evaluations, for instance room illuminance based on sun lighting and how does affect the usage of electrical lighting.

As a suggestion the CityGML standard could be modify by adding specific attributes to store more information regarding residential buildings. I consider that it is relevant for a residential building to have the number of dwellings that contains. Also for those buildings that its function is mixed, it is relevant to know which parts or storeys are dedicated to one activity and which others are used for only residential purposes. Several buildings of the area of study have this characteristic but it was not possible from the dataset to distinguish between usages.

Another variable that can be improved in future researches is the life style models, discriminating people by gentle, age, occupation, or behaviour to mention some possibilities. Only one dwelling was polled but it showed the need of a better model. One indicator of this situation was the number of bulbs at that place, in my proposal the number was 9 but in that flat it was 26 and all of them are saver lamps. A big survey should take place, so real values can be obtained and model as a consequence is better evaluated.

Finally, it would be a interesting to develop an application domain extension (ADE) for energy aspects of a building or the topics that were dealt during this master thesis. Having a XML schema to which a CityGML instance could be verified will lead to a better quality of the stored data as well as facilitate the exchange of them.

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A. Appendix A

The information that is contained in the DVD and memory flash that are attached to this master thesis are

- **MasterThesisCamiloLeon.zip** - Contains the Eclipse **Java** project developed in this master thesis, including all necessary files and libraries needed.
- **EnergyDemandEstimator.java** - This class was declared to initialise and call all classes used in the master thesis.
- **EDEBuilding.java** - In this class the estimation of the building parameters is done.
- **WriteFile.java** - This class was declared to write the final output file which is a txt file.
- **citygml_shape2citygml.fmw** - This **FME** workbench (version 2013) was used to integrate the year of construction for the buildings of the are of study with the CityGML file used in this master thesis.
- **MasterThesisCamiloLeon.jar** - Jar file of the Eclipse Java Project
- **CityGML_Files** - This Folder contains the original CityGML file and the resulting one after the FME process. It includes the CityGML files.
- **ArcGIS** - This Folder contains the ArcMap (version 10.1) file used for visualisation purposes, contains a shapefile with the *GroundSurface* of the Residential Building of the area and the results obtained in the Java Project.

The Java project requires Java 6 to work, the few indications that the user must take into consideration is presented below.

```
/* ******************************************************
* If you are using a CityGML file that does not have data regarding the year of construction,
please comment between code lines 123-126 and uncomment code line 127 this is to avoid an error
for not having that CityGML attribute in the file.
*
* ******************************************************
*
* If you are using a file that declares its SRS following the standard OCG, i.e. ¡gml:Envelope
srsName="urn:ogc:def:crs,crs:EPSG:X.XX:XXXX,crs:EPSG:X.XX:XXXX" srsDimension="X"¿.
* * please uncomment lines 135, 139-143, 165-166. And comment code line 167
*
* If you are using a file that does not declare the SRS following the standard OGC please put the
EPSG code manually in line 167
*
* * ***************************************************
```

The previous box appears in the java class *EDEBuilding.java*, despite of having Java

6 the user must Run or compile the project with the parameters that are presented in figure A.1.

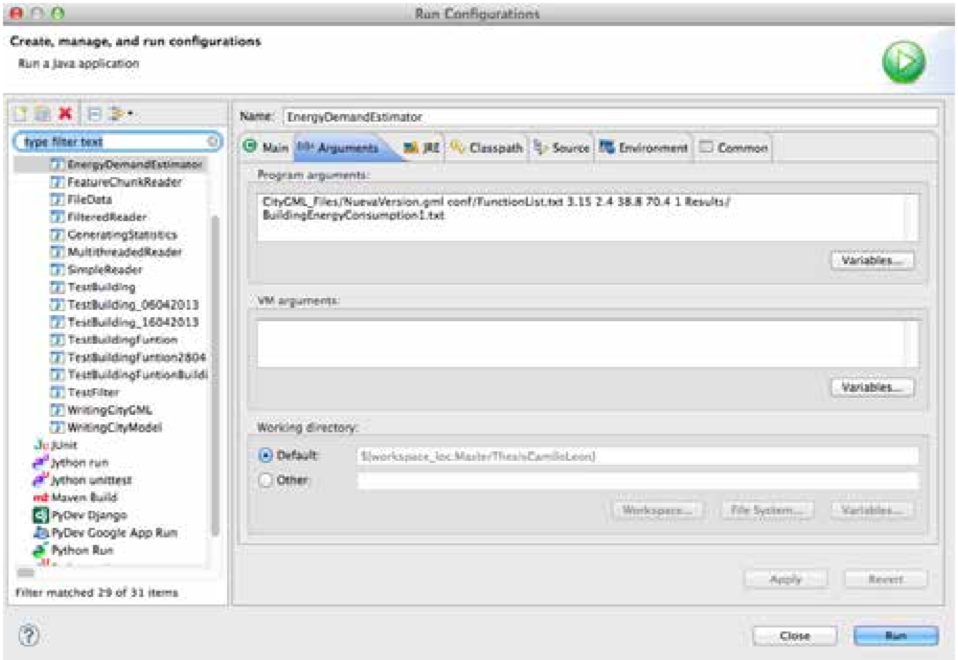

Figure A.1.: Run Configuration of Eclipse

source: own graph

Where:

- **1st arg**. CityGML_Files/NuevaVersion.gml - CityGML with building features
- **2nd arg**. conf/FunctionList.txt - List of function codes that indicates that the building is residential
- **3rd arg**. 3.15 - Standard storey height
- **4th arg**. 2.4 - Average roof height (to estimate if an attic could be residential or not)
- **5th arg**. 38.8 - Average residential area of a person
- **6th arg**. 70.4 - Average dwelling size
- **7th arg**. 1 - Range time considered for the estimator, i.e. 1 = 100% or 0.15 = 15%
- **8th arg**. Results/BuildingEnergyConsumption1.txt - File where results are stored.

B. Appendix B

B.1. Survey Form

Address:______________________________
Area:__________
Number of residents:__________
Number of rooms:__________
Energy consumption last year:__________

Appliance	Units	Time of Use
Freezer / Fridge		
Hob (4 cooking places)		
Ovens		
Chimney Hood		
Microwave Oven		
Dishwasher		
Washing Machine		
Tumble Dryer		
Electrical Lighting (Lamps)		
Lamp 100		
Lamp 40		
Lamp 32		
Saverlamp		
TV		
Home Theater		
Gaming System		
Computer		
Printer/scanner		
Modem ADSL		
Mobile Phone		
Tablet		
Docking station		
Vacuum		
Iron machine		
Coffee machine		
Digital TV Adapter		

Table B.1.: Example of the survey made to the residents

Source: Own table based on (KEMA-XENERGY 2004) and section 5.2