Universiteit Utrecht

TUHH
Technische Universität Hamburg-Harburg

Utrecht University

Graduate School of Geosciences:
Copernicus Institute of Sustainable Development

Hamburg University of Technology

Faculty of Process and Chemical Engineering:
Environmental Technology and Energy Economy (V-9)

Sustainable Healthcare Infrastructure: Modeling the Energy Performance of Individual Buildings Constituting a Complex Hospital, on the Basis of the University Medical Center Hamburg-Eppendorf

M.Sc. Thesis
submitted in partial fulfillment of the
Master of Science in Energy Science

Author:
Victor Jenicek, B.Sc. (3767809)

Supervisors, UU:
Dr. Evert Nieuwlaar
Prof. Dr. Wilfried Van Sark

Supervisors, TUHH:
Dipl.-Wi.-Ing. Nils Christiansen
Prof. Dr.-Ing. Martin Kaltschmitt

September 8, 2014

Contents

List of Figures

Declaration of Originality

I hereby declare that I am the sole author of the Master Thesis here enclosed.

The introduction, materials and methods, results, discussion, and conclusion sections all detail original research that I conducted on my own, and all words, tables, figures, and data compiled within this thesis are products of my own work, except where otherwise referenced.

Signed,

Victor Jenicek
September 2014

Statement of Confidentiality

During the writing of this thesis, I was granted access to certain files and data from the archives of the University Medical Center Hamburg-Eppendorf, and from the hospital's subsidiary, KFE Clinic Facility-Management GmbH.

These files and data are not available to the general public, nor will they be released to the public domain in the forseeable future; hence, all information about the UMC Hamburg-Eppendorf given in this thesis must be considered sensitive. Any and all information and data about the UMC Hamburg-Eppendorf that I have used in this thesis has, by contractual obligation, only been used for university research purposes. Disclosure of this information to any third-party is prohibited.

Abstract

The *Directive 2002/91/EC of the European Parliament on the Energy Performance of Buildings* obliges EU member states to develop a methodology for the calculation of the energy performance of buildings on the basis of a framework listed in Appendix A of the document. In Germany, the DIN V 18599 Series of Standards has been developed as the standardized methodology for the calculation of the energy performance of buildings. The complexity of this Series of Standards has led to calls within the German academic community to simplify the process of adhering to this methodology. It is for this reason that Dr.-Ing. Markus Lichtmeß has developed an Excel tool named EnerCalC to simplify the energy performance calculation process whilst ensuring compliance with DIN V 18599.

Hospitals are one of the categories of buildings identified in *Directive 2002/91/EC* for which an energy performance calculation methodology must be developed. This thesis focuses on using EnerCalC to calculate the energy performance of buildings O.10, S.50, and O.70 at the University Medical Center Hamburg Eppendorf, a complex hospital located in Hamburg, Germany. A significant part of this thesis is concerned a sensitivity and interdependency analysis of the building parameters given in EnerCalC so as to establish the most relevant real world data inputs required to carry out the energy performance analysis of a hospital building.

The sensitivity and interdependency analyses identified the most relevant parameters by inputting a defined sensitivity range into a reference building on a one-factor-at-a-time basis, and by investigating the interdependency of the net energy values output using a Pearson Chi Square Test. Finding the most relevant parameters in EnerCalC in this manner significantly reduces the real world data requirements when modeling the energy performance of a building using EnerCalC. Given EnerCalC's compliance DIN V 18599, this allows for reduced real world data requirements when modeling the energy performance of any building, not just hospital buildings.

A zoning procedure and the collection of building parameter data of buildings O.10, S.50, and O.70 followed the sensitivity and interdependency analyses. The total heating values of the three buildings were modeled with an accuracy between 63% and 103%. The difficulty of gathering data on the other utilities led to only S.50's energy performance being fully modeled, with cooling, lighting, and ventilation being modeled with an accuracy of 50%, 98%, and 47%, respectively.

Acknowledgments

I would hereby like to acknowledge the following individuals for their guidance, advice, support and/or camaraderie throughout the writing of this M.Sc. Thesis:

Dipl.-Wi.-Ing. Nils Christiansen, for being my thesis supervisor at the Hamburg University of Technology. Nils was my leading source of guidance and inspiration throughout the research and writing phases of this thesis. I was always impressed by his iron composure in the face of scientific adversity, his tenacious can-do attitude, and his uncanny ability to rapidly pinpoint and solve any of the problems I ran into regardless of whether they involved coding, working with EnerCalC, or processing data from the University Medical Center Hamburg Eppendorf. I am grateful to have contributed to his Ph.D. project and have no doubts that his perseverance will see him through to the successful completion of his project.

My supervisors Dr. Evert Nieuwlaar and Prof. Dr. Wilfried van Sark at Utrecht University, for monitoring my research progress and always being available whenever additional supervision was required. I was able to receive feedback either by email or by phone any time I required it, reducing any feeling of disconnection despite the distance between Hamburg and Utrecht.

University Medical Center Hamburg-Eppendorf archivist Harald Bohl, for granting access to the hospital's archives and for finding all the building records and architectural plans of buildings O.10, S.50, and O.70 that were of relevance to my research.

Prof. Dr.-Ing. Martin Kaltschmitt, for granting me the opportunity of writing this thesis at the Faculty of Process and Chemical Engineering: Environmental Technology and Energy Economy of the Hamburg University of Technology.

My parents Nelly and Karel, and my siblings David and Sarah, for their ongoing love and support.

1 Introduction

1.1 Societal Background

The University Medical Center Hamburg-Eppendorf (*Universitätsklinikum Hamburg Eppendorf*, UKE), founded in May 1889 in Hamburg, Germany, is the largest among Hamburg's hospitals, housing approximately 1460 hospital beds.[7] The UKE has more than 160 clinics and treats around 80 000 in-patients, 260 000 out-patients, as well as 113 000 emergency patients per year.[7] The UKE consists of many large buildings that are used for varying purposes and as such, the UKE constitutes a very complex power system.

According to the *Directive 2002/91/EC of the European Parliament on the Energy Performance of Buildings*, Member States are obligated to develop and apply a methodology for the calculation of the energy performance of buildings on the basis of a general framework presented in the Annex of the Directive.[6] This framework outlines the methodology, aspects, and building classes that are to be considered for the calculation of the energy performance of buildings.[6] Overall, this Directive and the framework given inside are aimed at improving the energy efficiency of buildings so as to help fulfill the EU's commitment to reduce CO_2 emissions as agreed in the Kyoto Protocol.

In accordance with the abovementioned *Directive 2002/91/EC*, the German Federal Ministry of Economics and Energy (*Bundesministerium fur Wirtschaft und Energie*, BMWi) has contracted a research project with the Hamburg University of Technology (*Technische Universität Hamburg Harburg*, TUHH) aimed at assessing the building performance of complex hospitals like the UKE.[8] The scope of this research project is not intended solely as an energy audit of the UKE, as this would be no different from the approach taken by a building analyst or consulting engineer. Rather, the motivation for this research project is to develop a more general engineering-economic model that can be applied to the UKE, and other similarly complex hospitals.[8] Thus, although the UKE serves as a basis for the development of the model, it is not to be the only complex hospital to which the model can be applied. The benefits of developing such a model is that it can, to some extent, circumvent the need for expensive, meticulous, and time-consuming energy audits that are usually carried out by consulting engineers.

This thesis aims to contribute to the realization of this building performance assessment model by developing a methodology for modeling the energy performance of the individual buildings at complex hospitals such as the UKE. The narrow focus of this thesis thus serves to contribute to a specific part of the scope of the research project contracted between the German Federal Ministry of Economics and Energy, and, by extension, to the obligations described in *Directive 2002/91/EC*.

1.2 Scientific Background

1.2.1 Energy Performance Calculation Framework

The Annex of the *Directive 2002/91/EC of the European Parliament on the Energy Performance of Buildings* establishes the following general framework for the calculation of energy performance of buildings:[6]

“1. The methodology of calculation of energy performances of buildings shall include at least the following aspects:

(a) thermal characteristics of the building (shell and internal partitions, etc.). These characteristics may also include air-tightness;

(b) heating installation and hot water supply, including their insulation characteristics;

(c) air-conditioning installation;

(d) ventilation;

(e) built-in lighting installation (mainly the non-residential sector);

(f) position and orientation of buildings, including outdoor climate;

(g) passive solar systems and solar protection;

(h) natural ventilation;

(i) indoor climatic conditions, including the designed indoor climate.

2. The positive influence of the following aspects shall, where relevant in this calculation, be taken into account:

(a) active solar systems and other heating and electricity systems based on renewable energy sources;

(b) electricity produced by CHP;

(c) district or block heating and cooling systems;

(d) natural lighting.

3. For the purpose of this calculation buildings should be adequately cla0ssified into categories such as:

(a) single-family houses of different types;

(b) apartment blocks;

(c) offices;

(d) education buildings;

(e) hospitals;

(f) hotels and restaurants;

(g) sports facilities;

(h) wholesale and retail trade services buildings;

(i) other types of energy-consuming buildings."

The development of an energy performance calculation methodology according to the points defined in 1. and 2. of the above cited framework, and applying it to the "hospitals" category listed in point 3.(e) of this framework, is the defining focus of the research being carried out in this thesis.

1.3 Current Literature & State of the Art

Since *Directive 2002/91/EC of the European Parliament on the Energy Performance of Buildings* is approximately twelve years old and thus fairly recent as far as research timelines are concerned, little research on modeling the energy performance of complex hospitals has been published. Research that has been carried out has mostly focused on modeling the operation of specific aspects of a hospital, such as ventilation and building operation strategies.

In Germany, Article 3 of *Directive 2002/91/EC of the European Parliament on the Energy Performance of Buildings* gave rise to the DIN (*Deutsches Institut für Normung e. V.*, German Institute for Standardization) Series of Standards known as DIN V 18599. DIN V 18599 "Energy efficiency of buildings - calculation of the net, final, and primary energy demand for heating, cooling, ventilation, domestic hot water and lighting" consists of eleven parts totaling over 1000 pages.[4] This Series of Standards serves as the guideline for assessing the energy performance of buildings in Germany; hence, current literature or research most relevant to this thesis is centered around DIN V 18599.

The present state of the art is characterized by German academia's attempts to come to terms with DIN V 18599, which has been in development for years and is nonetheless still in a prestandard state. A recent full prestandard draft consisting of an eleven part Series of Standards was published in December 2011;[4] however, revisions are ongoing, as evidenced by the publication of a revised draft of Part 1 in May 2013.[3]

Ongoing revisions aside, energy balancing according to DIN V 18599 has been frequently criticized because of its complexity and time-consuming application.[2] Calls were made within the community to simplify the process soon after the first prestandards from this Series of Standards were published. This has led to the creation of tools such as EnerCalC,[2] an Excel tool developed by Dr.-Ing. Markus Lichtmeß as part of his Ph.D. dissertation[5] for the Department of Building Physics and Technical Building Services at the University of Wuppertal, Germany. EnerCalC enables the energy performance requirements for a building to be balanced in accordance with DIN V 18599,[2] and will be used as the basis for this thesis' focus on modeling the energy performance of buildings constituting complex hospitals.

2 Objectives

2.1 Goal

The goal of this thesis is to model the energy performance of UKE buildings O.10, S.50, and O.70 using EnerCalC so as to ensure compliance with DIN V 18599. An important focus of this thesis is the development of an energy performance modeling method that is transparent and flexible enough to to be applied to other hospital buildings comprising the UKE, as well as to the buildings comprising other complex hospitals as well. The overall motivation for developing a transparent and flexible energy performance calculation methodology that is compliant with *Directive 2002/91/EC* and DIN V 18599 means that this modeling method can, in theory, be applied to any complex hospital in Germany.

2.2 Problem Description

1) What are EnerCalC's most relevant building parameters required to model the energy performance of the individual buildings comprising a complex hospital such as the UKE?

A statistical sensitivity and interdependency analysis of the the building parameter data inputs in EnerCalC will be carried out to find the most relevant parameters. Finding the most relevant parameters should help minimize the amount of real world data required to model the energy performance of a hospital building; these reduced real world data requirements should in theory allow for the application of the energy performance modeling method to a greater number of individual buildings in a complex hospital. The applicability of the modeling method is also strongly dependent upon the compatibility of obtained real world data with the data inputs of EnerCalC.

2) What is the energy performance of UKE buildings O.10, S.50, and O.70, and how can it be modeled using EnerCalC?

The UKE was established in May 1889 and consists of buildings of various ages, constructed using different materials and methods, and used for a variety of purposes; as a result, the building constituting the UKE most probably deliver a wide range of energy performances. Dr.-Ing. Markus Lichtmeß's Excel tool EnerCalC will be used to model the energy performance of three UKE buildings of varying sizes, uses, and ages - O.10, S.50, and O.70. Energy performance will be modeled by gathering and processing real world data on O.10, S.50, and O.70, inputting it into EnerCalC, and comparing the modeled values with real world values. Real world data will be gathered from the facility management and archives of the UKE and will include basic architectural and energy consumption data on the buildings being investigated.

3) How can each building in a complex hospital be split up into purpose-oriented "zones," so as to assess how each zone contributes to the energy demand of each building?

A complex hospital consists of many buildings used for medical, residential, research and infrastructural purposes. It is not unlikely for each building within a complex hospital to contain facilities, wings and departments that can be used for multiple, varying, and potentially unrelated purposes. Thus, to assess energy performance, each building in a complex hospital must be split up into purpose-oriented "zones", in which each zone is defined as the combination of all of the rooms serving that zone's purpose. For example, hallways, which may constitute about 20% of the interior areas of the UKE's buildings, may be defined as a "hallway zone", and all hallways in a building can thus be considered constituents of the building's "hallway zone." A problem here is that some zones will be more clearly definable than others. Hence, establishing building zones ("zoning") will proceed according to the definitions outlined in DIN V 18599, and will be followed by an assessment of how each zone contributes to energy performance. This assessment will be carried out for UKE buildings O.10, S.50, and O.70.

2.3 Research Framework

This research aims to model the energy performance of individual buildings in a complex hospital (i.e. a building system), and as such, the assessment will not extend beyond system relevant boundaries. The outer boundaries of the system can be defined as the perimeter of the complex hospital, beyond which nothing can be considered system relevant. The boundaries within the system can be defined by the limits of each individual building constituting the complex hospital.

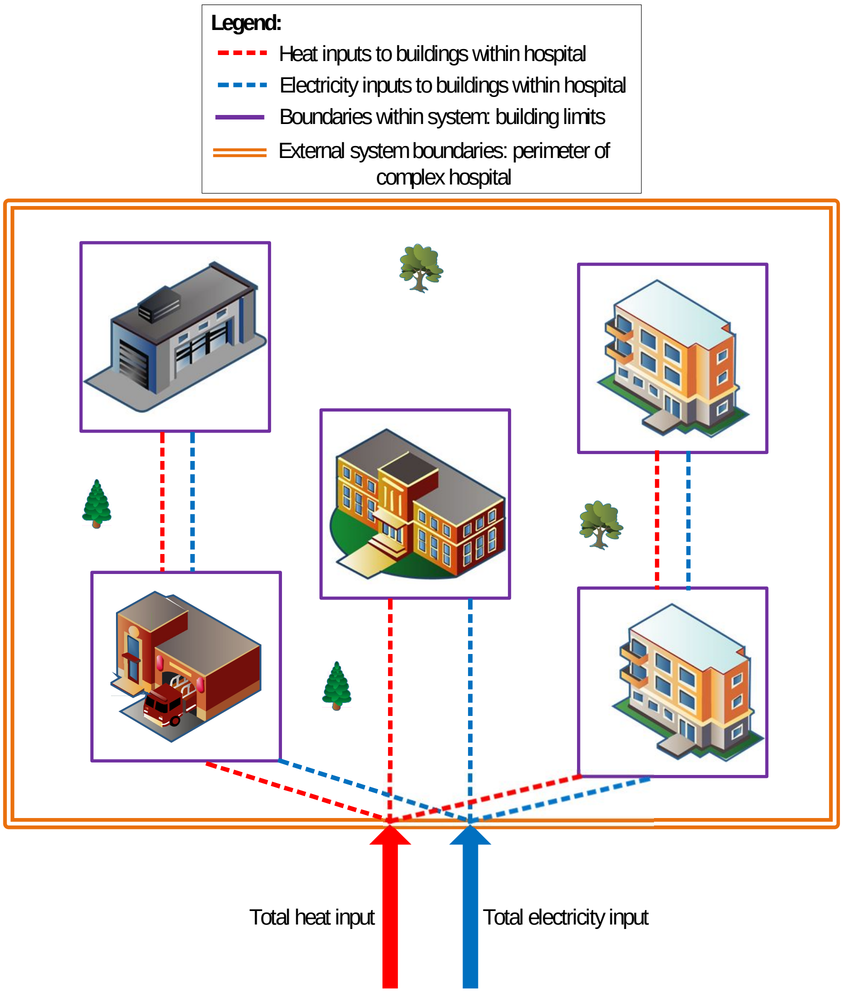


Figure 2.1: A simplified depiction of the power system represented by a complex hospital

2.3.1 Understanding Energy Performance - Use and Definition

The chief purpose of modeling energy performance is to understand the balance of energy input and output by a building that is required in order to maintain certain interior climate (through heating, hot water, or cooling) and environment (through lighting and ventilation) conditions. Hence, it is important to understand that, within the context of this thesis, the term “energy performance” refers strictly to the internal heating, hot water heating, cooling, lighting, and air conditioning net energy requirements of the building, and all of the factors that contribute to increasing or decreasing these net energy requirements. These factors include the building envelope, outdoor climate, airtightness, modes of operation, and other aspects defined in *Directive 2002/91/EC* and DIN V 18599 that can affect the interior climate and environment of a building.

The term “energy performance” should therefore not be confused with “energy demand,” which can refer to a building’s partial or total energy demand. Neither EnerCalC nor the methodology proposed in this thesis can control for the energy demand caused by any and all appliances featured within a building that are not involved with regulating interior climate and environment conditions; this includes everything from IT to medical equipment. The distinction between "energy performance" and "energy demand" is particularly important to make in the healthcare sector, where an increasing degree of mechanization and the presence of highly electricity-intensive devices such as x-ray / MRI scanners are leading to increasing electricity requirements. These requirements will contribute to the total (electrical) "energy demand" of each building, but are irrelevant within the context of "energy performance", as they do not partake in regulation of interior climate.

In investigating energy performance, the main focus is on EnerCalC's "Nutzenergie" or net energy value data output; this is where the net internal heating, hot water heating, cooling, lighting, and air conditioning energy requirements for a given building are calculated. This net energy balancing output is given the in "Gesamtbilanz" sheet of EnerCalC, see Figure 3.3.

2.3.2 Topics Considered Irrelevant to Modeling Energy Performance

The following topics will not be considered due to overall irrelevancy or minimal added informational value towards modeling energy performance:

- Life Cycle Analyses of the energy flows needed to power a complex hospital. This kind of cradle-to-grave analysis would require extensive knowledge on the primary energy sources (e.g. coal, natural gas, uranium), energy systems (e.g. power plants), energy carriers (e.g. electricity) used, and associated extraction (cradle-to-gate), conversion (gate-to-gate), and delivery (gate-to-grave) efficiencies involved in, delivering utilities such as district heat and electricity to a complex hospital. Although the hospital can improve the energy performance of its buildings, it cannot influence the efficiencies with which power utility companies produce, transmit, and distribute heat and electricity. Such an analysis would therefore confer minimum added value to a model whose focus is on modeling the energy performance of buildings in a complex hospital itself, rather than the efficiency with which its energy inputs are being produced. Hence, due to focus on phenomena occurring beyond the relevant system boundaries, Life Cycle Analyses are not within the scope of this research.

- Greenhouse gas (GHG) emissions. GHG emissions are caused by the release of CO_2, H_2O, CH_4, N_2O, O_3, and chlorofluorocarbons (CFCs) into the atmosphere. Although a building's improved energy performance will certainly reduce GHG emissions and lessen the environmental impact, calculating baseline and curtailed GHG emissions of the buildings in a complex hospital is beyond the scope of this research for two reasons. First, such calculations would require investigation of hospital buildings on a case-by-case basis to develop baseline and curtailed GHG emission projections, which in itself distracts from the focus of developing an energy performance modeling method that is applicable to multiple complex hospitals. Furthermore, a good portion of GHG emissions are not caused by the hospital operation in and of itself, but by the power utility companies that are supplying energy to the complex hospital. Second, the relationship between energy consumption and GHG emissions can be assumed to be relatively linear, separated only by the conversion factor (kWh to g Co2) of the power utility supplying the energy input. Thus, GHG emission calculations provide limited informational added value when developing a method that assesses hospital buidings' energy performance, and will not be included into scope of this research.

- Energy Market Dynamics. Given their massive energy requirements and conservative, risk-averse attitude towards capital expenditure, complex hospitals tend to negotiate fixed contracts with power utility companies, rather than playing the energy market to secure cheaper energy prices. Hence, energy market dynamics will not be considered within this research.

- Transmission and distribution losses. Transmission of electricity and district heat from the power plant to the hospital, as well as conversion and distribution of these utilities within the hospital, will result in some losses. These will not be factored into building performance / energy efficiency calculations for the complex hospital, as they are outside of the system boundaries responsible for building performance.

- On-site, decentralized energy generation. Some complex hospitals can be equipped with photovoltaic panels or boilers that will deliver electricity or heat to buildings on a decentralized basis. While it could be argued that it increases the energy efficiency of the building system, it is only energy consumption, not the source of energy input, that is relevant when assessing building performance.

3 Materials & Methods

3.1 Materials

- PC with Intel Core i5-2450M CPU and 8 GB RAM
- 64-bit Windows 7 Professional Operating System
- Microsoft Office Professional Plus 2013
- Excel 2013 and Microsoft Visual Basic for Applications 7.1
- EnerCalC v4.43.104 (released April 2014)
- Trimble Navigation SketchUp Make 14.1.1282

3.2 EnerCalC 2013

Figure 3.1: EnerCalC Title Page

EnerCalC 2013[2] is an Excel-based tool that was developed by Dr.-Ing. Markus Lichtmeß as part of his Ph.D. dissertation[5] for the Department of Building Physics and Technical Building Services at the University of Wuppertal, Germany. EnerCalC allows the energy inputs and outputs of a building to be balanced in accordance with DIN V 18599,[2] and is used as the basis for this research assessing the energy performance of the individual buildings comprising complex hospitals.

EnerCalC simplifies the energy balancing procedure defined in DIN V 18599 by condensing data input requirements to a selection of building parameters. Over fifty parameters, ranging from building envelope (surface area, heat transmission coefficients, meteorology) to building technology properties (cooling, lighting, heat generation) are included in EnerCalC. Certain parameters, such as surface area and heat transmission coefficients, are input as numerical values, whereas others, such as meteorology and type of lighting, are input as pre-configured options. Thus, each building parameter in EnerCalC can be varied either by inputting a different numerical value or by selecting a different option from the drop-down list given for that parameter.

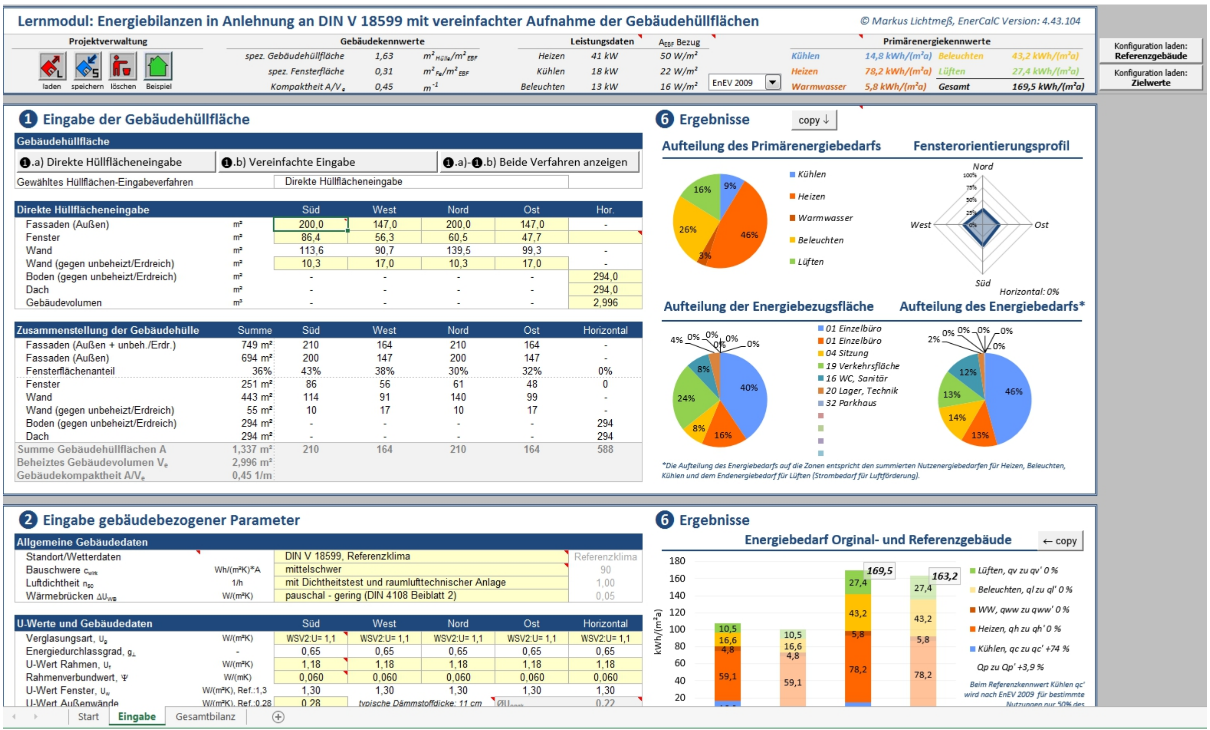
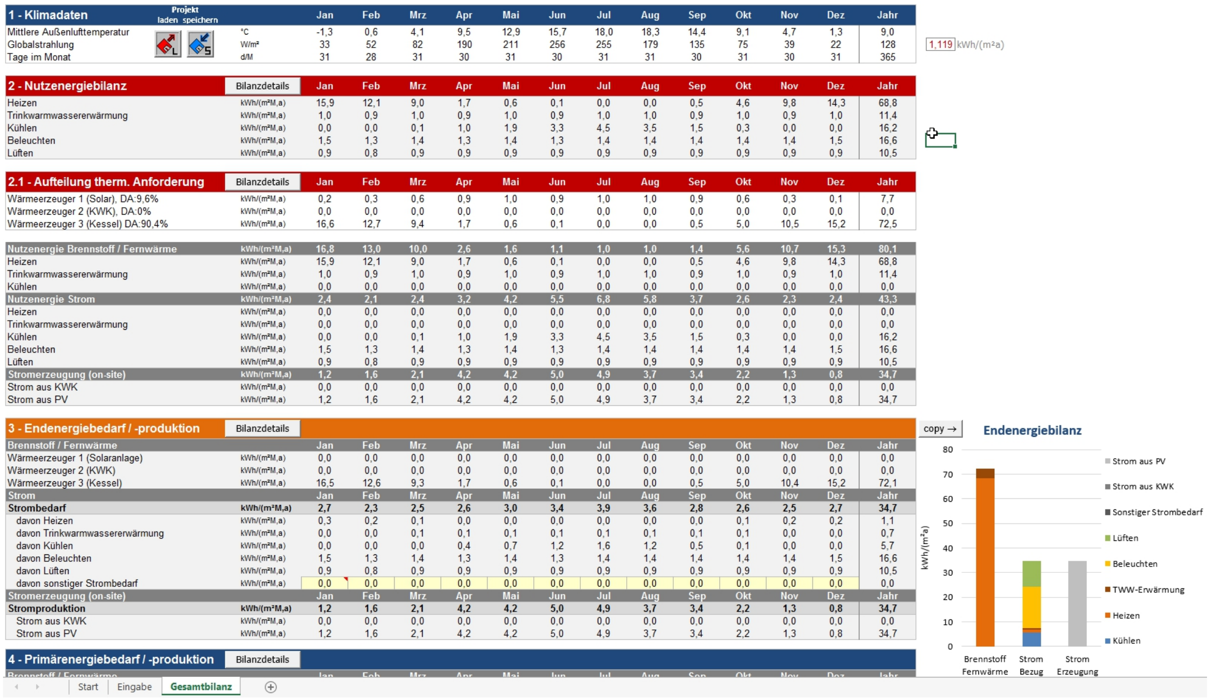


Figure 3.2: EnerCalC Building Parameter Input Page

Varying the building parameter data input into EnerCalC leads to the calculation and output of the corresponding energy balancing values. These include primary energy, net energy, and total energy balances, as well as other related data such as CO2 emissions. Of greatest relevance to assessing energy performance are the net energy values calculated by EnerCalC, as it is the net or effective energy values that allow the most precise determination of the balance of energy input and output by the building.



1 - Klimadaten	Projekt laden speichern	Jan	Feb	Mrz	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez	Jahr
Mittlere Außenlufttemperatur	°C	-1,3	0,6	4,1	9,5	12,9	15,7	18,0	18,3	14,4	9,1	4,7	1,3	9,0
Globalstrahlung	W/m²	33	52	82	190	211	256	255	179	135	75	39	22	128
Tage im Monat	d/M	31	28	31	30	31	30	31	31	30	31	30	31	365
2 - Nutzenergiebilanz	Bilanzdetails	Jan	Feb	Mrz	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez	Jahr
Heizen	kWh/(m²M,a)	15,9	12,1	9,0	1,7	0,6	0,1	0,0	0,0	0,5	4,6	9,8	14,3	68,8
Trinkwarmwassererwärmung	kWh/(m²M,a)	1,0	0,9	1,0	0,9	1,0	0,9	1,0	1,0	0,9	1,0	0,9	1,0	11,4
Kühlen	kWh/(m²M,a)	0,0	0,0	0,1	1,0	1,9	3,3	4,5	3,5	1,5	0,3	0,0	0,0	16,2
Beleuchten	kWh/(m²M,a)	1,5	1,3	1,4	1,3	1,4	1,3	1,4	1,4	1,4	1,4	1,4	1,5	16,6
Lüften	kWh/(m²M,a)	0,9	0,8	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	10,5
2.1 - Aufteilung therm. Anforderung	Bilanzdetails	Jan	Feb	Mrz	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez	Jahr
Wärmeerzeuger 1 (Solar), DA:9,6%	kWh/(m²M,a)	0,2	0,3	0,6	0,9	1,0	0,9	1,0	1,0	0,9	0,6	0,3	0,1	7,7
Wärmeerzeuger 2 (KWK), DA:0%	kWh/(m²M,a)	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Wärmeerzeuger 3 (Kessel) DA:90,4%	kWh/(m²M,a)	16,6	12,7	9,4	1,7	0,6	0,1	0,0	0,0	0,5	5,0	10,5	15,2	72,5
Nutzenergie Brennstoff / Fernwärme	kWh/(m²M,a)	16,8	13,0	10,0	2,6	1,6	1,1	1,0	1,0	1,4	5,6	10,7	15,3	80,1
Heizen	kWh/(m²M,a)	15,9	12,1	9,0	1,7	0,6	0,1	0,0	0,0	0,5	4,6	9,8	14,3	68,8
Trinkwarmwassererwärmung	kWh/(m²M,a)	1,0	0,9	1,0	0,9	1,0	0,9	1,0	1,0	0,9	1,0	0,9	1,0	11,4
Kühlen	kWh/(m²M,a)	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Nutzenergie Strom	kWh/(m²M,a)	2,4	2,1	2,4	3,2	4,2	5,5	6,8	5,8	3,7	2,6	2,3	2,4	43,3
Heizen	kWh/(m²M,a)	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Trinkwarmwassererwärmung	kWh/(m²M,a)	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Kühlen	kWh/(m²M,a)	0,0	0,0	0,1	1,0	1,9	3,3	4,5	3,5	1,5	0,3	0,0	0,0	16,2
Beleuchten	kWh/(m²M,a)	1,5	1,3	1,4	1,3	1,4	1,3	1,4	1,4	1,4	1,4	1,4	1,5	16,6
Lüften	kWh/(m²M,a)	0,9	0,8	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	10,5
Stromerzeugung (on-site)	kWh/(m²M,a)	1,2	1,6	2,1	4,2	4,2	5,0	4,9	3,7	3,4	2,2	1,3	0,8	34,7
Strom aus KWK	kWh/(m²M,a)	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Strom aus PV	kWh/(m²M,a)	1,2	1,6	2,1	4,2	4,2	5,0	4,9	3,7	3,4	2,2	1,3	0,8	34,7
3 - Endenergiebedarf / -produktion	Bilanzdetails													
Brennstoff / Fernwärme		Jan	Feb	Mrz	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez	Jahr
Wärmeerzeuger 1 (Solaranlage)	kWh/(m²M,a)	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Wärmeerzeuger 2 (KWK)	kWh/(m²M,a)	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Wärmeerzeuger 3 (Kessel)	kWh/(m²M,a)	16,5	12,6	9,3	1,7	0,6	0,1	0,0	0,0	0,5	5,0	10,4	15,2	72,1
Strom		Jan	Feb	Mrz	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez	Jahr
Strombedarf	kWh/(m²M,a)	2,7	2,3	2,5	2,6	3,0	3,4	3,9	3,6	2,8	2,6	2,5	2,7	34,7
davon Heizen	kWh/(m²M,a)	0,3	0,2	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,2	0,2	1,1
davon Trinkwarmwassererwärmung	kWh/(m²M,a)	0,0	0,0	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,0	0,0	0,7
davon Kühlen	kWh/(m²M,a)	0,0	0,0	0,0	0,4	0,7	1,2	1,6	1,2	0,5	0,1	0,0	0,0	5,7
davon Beleuchten	kWh/(m²M,a)	1,5	1,3	1,4	1,3	1,4	1,3	1,4	1,4	1,4	1,4	1,4	1,5	16,6
davon Lüften	kWh/(m²M,a)	0,9	0,8	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	10,5
davon sonstiger Strombedarf	kWh/(m²M,a)	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Stromerzeugung (on-site)		Jan	Feb	Mrz	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez	Jahr
Stromproduktion	kWh/(m²M,a)	1,2	1,6	2,1	4,2	4,2	5,0	4,9	3,7	3,4	2,2	1,3	0,8	34,7
Strom aus KWK	kWh/(m²M,a)	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Strom aus PV	kWh/(m²M,a)	1,2	1,6	2,1	4,2	4,2	5,0	4,9	3,7	3,4	2,2	1,3	0,8	34,7
4 - Primärenergiebedarf / -produktion	Bilanzdetails													

Figure 3.3: EnerCalC Energy Balancing Output Page

The first step involved in modeling the energy demand of individual buildings comprising a complex hospital will be to analyze EnerCalC itself. To this end, a statistical sensitivity and interdependency analysis of the the building parameter data inputs in EnerCalC will be carried out to find the building parameters that make the greatest contribution to the calculation of net energy values. Isolating these parameters will help establish the minimal amount of data required for a reliable building performance assessment, which will allow the model to be applied to the widest possible range of individual buildings constituting complex hospitals such as the UKE.

EnerCalC's frontend is written in German, hence, German to English translations the EnerCalC features relevant to this thesis are provided in Tables 7.1 and 7.2. The fact that EnerCalC is written in German is also evident in the decimal system being used, in which a comma is used as a decimal separator. It is very important to set Excel up to use a comma as a decimal separator, or EnerCalC will not execute the energy balancing calculations correctly. For the sake of consistency, a comma will be used as a decimal separator, and a decimal as a thousands separator, within this thesis as well.

3.3 Sensitivity Analysis

The goal of the sensitivity analysis was to examine the influence of individual building parameters (data inputs) on the calculated net energy values (data outputs) of EnerCalC. Variations in certain building parameters, such as those defining the building envelope, are likely to cause larger fluctuations in the calculated net energy values than others, such as shadowing and insolation properties of the building. The sensitivity analysis allows for the statistical evaluation of the degree with which each building parameter causes fluctuations in net energy values. Ultimately, the sensitivity analysis should identify the building parameters in EnerCalC that have the greatest impact on net energy values; the discovery of these parameters is key in establishing the minimal amount of data required for modeling the energy performance of a building.

3.3.1 Building Envelope Area Input Modes, Parameter Input Types

EnerCalC features two modes for the input of the "Gebäudehüllfläche", or building envelope area. The first, and default mode, is called "Direkte Hüllflächeneingabe" (direct building envelope area input), whereby the building envelope is defined by inputting the areas of the building facades, windows, floor, roof, and total building volume.

The second mode is called "Vereinfachte Eingabe" (simplified input), whereby the building envelope is defined by inputting the lengths of the subterranean and above-ground floors, the percent window surface area of above-ground floors, the ratio of the gross floor area (GFA) to the gross internal area (GIA), the type of roof, and number and height of floors.

Since both of these building envelope area input modes present two different ways of inputting information about a building into EnerCalC, both of these input modes will be investigated in the sensitivity analysis to maximize the flexibility with which energy performance can be modeled.

Each parameter in EnerCalC has one of two building parameter input types: numerical, and drop-down lists. Numerical building parameter inputs, such as surface area and heat transmission coefficients, are parameters where data is input as a number. Drop-down list building parameter inputs, such as meteorology and type of lighting, are parameters where data is input as a pre-configured option from a drop-down list. No parameter exists in EnerCalC for which data can be input both numerically and from a drop-down list. This is important because it means that two approaches, suited to each input type, must be used to analyze the sensitivity of each parameter. This is described in greater detail in 3.3.5.

3.3.2 Setup of Reference Building

In order for the sensitivity analysis to have a baseline, a reference building was set up in EnerCalC with the building parameter values described in Tables 3.1 to 3.7. The building was heavily based upon the default parameter values loaded by EnerCalC, with the exception of the parameters described in Table 3.8.

1) Building Envelope Area Input

Direct Building Envelope Area Input Mode	Reference Value	Unit	Input Type
Facade (outside), North	67	m^2	numerical
Facade (outside), South	67	m^2	numerical
Facade (outside), East	49	m^2	numerical
Facade (outside), West	49	m^2	numerical
Window, North	27	m^2	numerical
Window, South	27	m^2	numerical
Window, East	20	m^2	numerical
Window, West	20	m^2	numerical
Wall (adjacent to unheated / Earth), North	0	m^2	numerical
Wall (adjacent to unheated / Earth), South	0	m^2	numerical
Wall (adjacent to unheated / Earth), East	0	m^2	numerical
Wall (adjacent to unheated / Earth), West	0	m^2	numerical
Floor	324	m^2	numerical
Roof	324	m^2	numerical
Building Volume	1071	m^3	numerical

Table 3.1: EnerCalC reference model building envelope area input values in direct input mode

Simplified Building Envelope Input Mode	Reference Value	Unit	Input Type
Subterranean Façade Length, North / South	0	m	numerical
Subterranean Façade Length, East / West	0	m	numerical
Above-Ground Façade Length, North / South	20	m	numerical
Above-Ground Façade Length, East / West	14,7	m	numerical
Percent Window Area on Above-Ground Façade, N/S/E/W	40	%	drop-down list
Gross Floor Area to Gross Internal Area Ratio	0,92	ratio	numerical
Heated Subterranean Floors	0	number	numerical
Proportion of Area	0	%	numerical
Floor Height	0	m	numerical
Heated Above-Ground Floors	1	number	numerical
Proportion of Area	100	%	numerical
Floor Height	3,33	m	numerical

Table 3.2: EnerCalC reference model building envelope area input values in simplified input mode

2) Building Parameter Input

General Building Data	Reference Value	Unit	Input Type
Location / Meteorology	DIN V 18599, reference climate	-	drop-down list
Construction Weight Type	medium	$Wh/(m^2K)*A$	drop-down list
Airtightness	incl. airtightness test and air conditioning	1/h	drop-down list
Thermal bridges	all inclusive, low standard (DIN 4108 Supplement 2)	$W/(m^2K)$	drop-down list

Table 3.3: EnerCalC reference model general building data input values

U-Values and Building Data	Reference Value	Unit	Input Type
Window Glazing Type, Ug	WSV2:U= 1,1	$W/(m^2K)$	drop-down list
Window Frame U-Value, Uf	1,18	$W/(m^2K)$	numerical
Window Spacer Bar U-Value, Y	0,06	W/(mK)	numerical
External Wall U-Value	0,28	$W/(m^2K)$	numerical
Roof U-Value (Fx=1)	0,2	$W/(m^2K)$	numerical
Floor U-Value (Fx=0,6)	0,35	$W/(m^2K)$	numerical

Table 3.4: EnerCalC reference model u-values and building data

Shadowing and Insolation Protection	Reference Value	Unit	Input Type
Double-skin Façade	no	-	drop-down list
Shadowing (Horizon)	none (up to 5°)	-	drop-down list
Shadowing (Vertical / Overhang)	none (up to 10°)	-	drop-down list
Sulight Control System	I_T_white	-	drop-down list
Sunlight Control System Operation Mode	manual, time-controlled	-	drop-down list
Glare Protection Measures	manual	-	drop-down list
Implementation of Sunlight Control and Glare Protection Measures	Sunlight Control System acts as Glare Protection Measure	-	drop-down list

Table 3.5: EnerCalC reference model shadowing and insolation protection input values

Air Conditioning Technology Specifications	Reference Value	Unit	Input Type
Efficiency Standard (pressure loss, total system efficiency)	EnEV 2009	-	drop-down list
Heat Recuperation of A/C Units	60	%	numerical

Table 3.6: EnerCalC reference model air conditioning technology specifications input values

3) Input of Zone-Related Parameters

Zone & Lighting Data	Reference Value	Unit	Input Type
Zone Profile	01 Single Office	-	drop-down list
GIA of Zone	294	m^2	numerical
Area Cooling	yes	-	drop-down list
Window Architrave (height from ceiling)	0,35	m	numerical
Window Height	2,4	m	numerical
Lighting Control System	manual	-	drop-down list
Type of Lighting	direct / indirect	-	drop-down list
Type of Light Bulb	LSL stab EVG	-	drop-down list

Table 3.7: EnerCalC reference model zone and lighting data input values

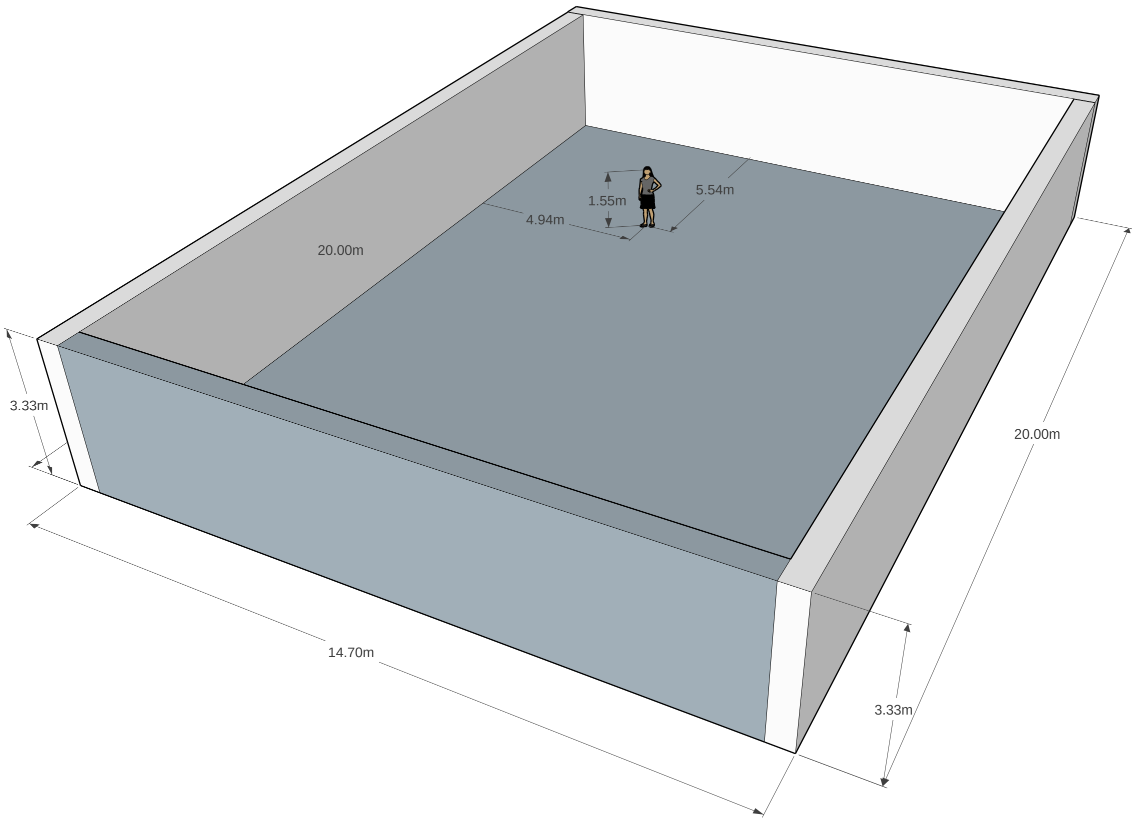


Figure 3.4: 3D CAD impression of dimensions of reference building

3.3.3 Deviations from Default EnerCalC Values

Deviations From Default EnerCalC Values in Building Envelope Inputs	EnerCalC Default Value	Model Reference Value	unit
Direct Building Envelope Area Input Mode			
Facade (outside), North	200	67	m^2
Facade (outside), South	200	67	m^2
Facade (outside), East	147	49	m^2
Facade (outside), West	147	49	m^2
Window, North	60,5	27	m^2
Window, South	86,4	27	m^2
Window, East	47,7	20	m^2
Window, West	56,3	20	m^2
Wall (adjacent to unheated / Earth), North	10,3	0	m^2
Wall (adjacent to unheated / Earth), South	10,3	0	m^2
Wall (adjacent to unheated / Earth), East	17	0	m^2
Wall (adjacent to unheated / Earth), West	17	0	m^2
Floor	294	321	m^2
Roof	294	321	m^2
Building Volume	2996	1071	m^3
Simplified Building Envelope Input Mode			
Subterranean Façade Length, North / South	3,1	0	m
Subterranean Façade Length, East / West	5,1	0	m
Heated Subterranean Floors	1	0	m
Proportion of Area	5	0	%
Floor Height	3,33	0	m
Heated Above-Ground Floors	3	1	m

Table 3.8: EnerCalC reference model values deviating from default EnerCalC values

The reasons for modifying the default values found in EnerCalC as described in Table 3.8 are multifold.

First, EnerCalC's default values in the “direct” building envelope input mode describe a building with outer façades facing north, south, east, and west, each with an area of 200 m^2. These façades are much larger than the ones defined in the default values of the “simplified” building envelope mode, which, with a façade length of 14,7 or 20 meters and a height of 3,33 meters, do not exceed 67 m^2. Consequently, the values in the “direct” building envelope input mode were modified (scaled down) to match the default values of the building defined in the “simplified” building envelope mode. The window areas, floor and roof areas, and building volume, were also scaled accordingly.

It is worth noting here that the “direct” building envelope input mode offers a lot more flexibility in defining the area and orientation of a building's façades than the “simplified” building envelope input mode. In the “direct” input mode, the area of each façade can be individually adjusted, for each orientation (i.e. facing north, south, east, and west). This stands in stark contrast to the “simplified” mode, in which EnerCalC forces the length of the facades facing north and south, or east and west, to be equal to each other. A similar phenomenon exists for the definition of the window area; in the “direct” input mode, each window orientation (north, south, east, west) can be individually adjusted, whereas in the “simplified” mode, the parameter “Percent Window Area on Above-Ground Façade” (see Table 3.2) applies the identical percentage value to all orientations. This is the reason why the parameters in the “direct” input mode in Table 3.8 are separately listed for each orientation, whereas in the “indirect” input mode, some parameters are listed with the orientations grouped together. Overall, this indicates that the sensitivity analysis of the building parameters in the “direct” input mode will yield more sets of data than the building parameters in the “indirect” input mode.

Second, the reference building for the sensitivity analysis was defined as a single-zone, single floor building so as to gain the clearest idea of what impact each building parameter would have the building’s overall energy performance. EnerCalC’s default values, which define a building with seven zones, three floors and one subterranean floor, were thus modified to define a reference building with one above-ground floor and zero subterranean floors. Six of the seven zones were erased and the one zone remaining was configured to have the profile of a single office and a Gross Internal Area of 294 m^2 so as to correspond to the the area given by facade lengths of 20 by 14,7 meters.

3.3.4 Finding Relevant Sensitivity Ranges

All sensitivity ranges were input on a one-factor-at-a-time basis, meaning that each parameter was varied individually whilst all others were held at their reference values (as defined by the reference building model in Tables 3.1 to 3.7).

A total of twenty four parameters with numerical inputs and twenty one parameters with drop-down list inputs are investigated in the sensitivity analysis. The former category requires input of a number and as such has a greater data input range than the latter, in which only the options given in the drop-down lists can be used as inputs. This discrete, static input range also means that the range of net energy values output by the drop-down list parameters is limited to the options available for each parameter.

Since the input range of drop-down list parameters is essentially fixed, it was the drop-down list parameters and their impact on the reference building that were investigated first. Each option of drop-down list of each parameter was input into the reference building and the net energy values output were recorded accordingly. A scatter plot of this multitude of discrete net energy value outputs is presented in Figure 4.4.

Since the majority of data points for the drop-down list parameter inputs was found to be output in the 90 - 110% net energy value range, a corresponding input range for the numerical parameters was sought out so as to have comparable sensitivity ranges output by both the numerical and drop-down list parameters. The sensitivity range for the numerical parameters was determined by sampling to be in the 50% to 150% of the reference values of the reference building.

3.3.5 Data Production

To produce data for the sensitivity analysis, Excel macros were programmed in Visual Basic to facilitate the input of a range of values into each building parameter, and to copy the ensuing data output into a separate Excel sheet. The source code for the data production macros for each parameter is listed in 7.2.

There are two types of data inputs for the building parameters listed in EnerCalC, which are listed under the "Input Type" column in Tables 3.1 to 3.7. Certain parameters, such as surface area and heat transmission coefficients, are input as numerical values, whereas others, such as meteorology and type of lighting, are input as pre-configured options. For the numerical value data inputs, the reference value was varied from 50% to 150% of its original (i.e. 100%) value, in 10% increments. Thus, a 1x10 matrix of values would be output for each building parameter with a numerical value data input. This matrix would display how variation of the input value from 50% to 150% affected the data output, or calculated net energy values, of the reference building.

For the building parameters where data is input as a pre-configured option, the option selected by default in EnerCalC was treated as the reference value. The other available options in the drop down list were each summarily selected; each option selected produced a new set of net energy values for the reference building. Data was produced for a total of over thirty building parameters found in EnerCalC. The results of the data production procedure for the sensitivity analysis are given in Section 4.1.

3.4 Interdependency Analysis

The sensitivity analysis investigates the impact of changes in building parameter input values on the calculated net energy values for the reference building; however, it does not examine the degree of interdependence that building parameters may have with each other. Identifying the degree of interdependency that building parameters have with each other confers valuable insights into the function of EnerCalC, and, by extension, the relationships between building parameters as described in DIN V 18599 and how they were interpreted by Dr.-Ing. Markus Lichtmeß into EnerCalC.

3.4.1 Mathematical Background

The interdependency analysis takes the reference (E_{ref}) and maximum (E_{max}) energy performance values output by each parameter in EnerCalC and analyzes interdependency using Pearson's chi squared test.

The general formula for calculating the test statistic is

$$X^2 = \sum_{i,j} \frac{(O_{ij} - E_{ij})^2}{E_{ij}}$$

whereby

X^2 = Pearson cumulative test statistic
O_{ij} = observed frequency
E_{ij} = expected (theoretical frequency)

Adapting this formula for use with the reference (E_{ref}) and maximum (E_{max}) energy performance values as i and j in the abovementioned formula yields:

$$X^2 = \frac{(E_1 Max)(E_2 Ref) + (E_1 Ref)(E_2 Max) - 2((E_1 Ref)(E_2 Ref))}{(E_1 Max)(E_2 Max) - (E_1 Ref)(E_2 Ref)}$$

3.4.2 Data Production

The reference total net energy values E_{ref} (170,80 kWh/(m²M,a)), and maximum total net energy values E_{max} (variable for each parameter) were input into the above equation in the following manner. The EnerCalC parameters were all listed in an overhead row and column as shown in Figure 4.5. Four such tables were made, for the calculation of E_1RefE_2Ref, E_1RefE_2Max, E_1MaxE_2Ref, and E_1MaxE_2Max. Then, for the calculation of E_1RefE_2Max, for example, the parameter named in the overhead column would be set to its maximum value in EnerCalC, and the parameter named in the corresponding row would be set to its reference value. The ensuing total net energy value output by EnerCalC when setting the parameters in the overhead column and row to their maximum and reference values, respectively, would then be copied into the cell (where the row and column intersect). When varying the overhead column and row parameters with the reference or maximum values, all other parameters were kept at their reference values (as defined by the reference building model in 3.3.2. In so doing, four lower triangular matrices, for E_1RefE_2Ref, E_1RefE_2Max, E_1MaxE_2Ref, and E_1MaxE_2Max, were generated.

Since this procedure involved hundreds if not thousands of permutations of inputting reference and maximum values into pairs of parameters in EnerCalC, a macro was written to accelerate the procedure. This macro can be inspected in Section 7.3.

Once the four lower triangular matrices E_1RefE_2Ref, E_1RefE_2Max, E_1MaxE_2Ref, and E_1MaxE_2Max were generated, the calculation of the chi square test value could take place. A fifth table was generated with same layout as the previous four tables, and a lower triangular matrix with chi-square test values was calculated by inputting the values of the E_1RefE_2Ref, E_1RefE_2Max, E_1MaxE_2Ref, and E_1MaxE_2Max matrices into the Pearson chi square statistic formula given in 3.4.1.

3.5 Zoning

3.5.1 Approach

In order to model the energy performance of O.10, S.50, and O.70, a zoning procedure was carried out for all of the rooms in each of the buildings. The "Raumbuch" (room listing) of each building was obtained from the UKE Facility Management and each room in each building was assigned a zone definition as given in Tables A.1 through A.49 in Appendix A of Part 10 ("Boundary Conditions of Use") of DIN V 18559. This was quite a time consuming procedure, as thousands of rooms totaling a few hundred thousand square meters of internal building area had to be processed. The results of this zoning procedure are given in Figures 4.7 through 4.9.

3.5.2 Zoning Features in EnerCalC

EnerCalC features a *Nutzungen* or "utilization" page in which the utilization patterns, lighting, climate, heating, air temperature, room geometry, and air conditioning requirements of each zone are listed (see Figure 3.5). The "utilization" page (an Excel tab) can be activated at the EnerCalC title page tab. By default, EnerCalC features thirty five zone definitions that are based upon the 2007 version of Part 10 of the DIN V 18599 Series of Standards. The definitions of the zones in the 2007 version of Part 10 of DIN V 18599 were found to be consistent with the definitions given in the 2010 version, hence, they were not modified.

The EnerCalC "utilization" page allows for the definition of five additional zones, yielding a maximum total of forty zone definitions; an advantageous feature given that a total of forty three zone definitions are given in DIN V 18599. Due to the absence of healthcare infrastructure relevant zones in EnerCalC's default thirty five zone definitions, five zone definitions were added during the zoning procedure. These are:

38. Laboratory
39. Examination and Surgery Rooms
40. Special / Intensive Care Units
41. Corridors of Common Care Units
42. Doctors' and Therapists' Offices.

The DIN V 18599 literature was researched to find the values for these custom zones. These custom zones were input into EnerCalC's "utilization" page and the values input can be found in Section 7.9. The numbers given beside the zone definitions indicate the number code of each zone definition as issued in DIN V 18599. For the sake of consistency, these number codes have been included in zoning-relevant figures within this thesis, in Figure 3.5 in this section, and Figures 4.7 to 4.9 in the results section.

It is worth noting that the input of zoning data into EnerCalC is somewhat limited as it allows for the input of a maximum of eleven separate zones. The zoning procedure of O.10, S.50, and O.70 yielded a total of up to as much as twenty zones. To fix this limitation, the first eleven zones with the greatest area were input into EnerCalC. This approach covered at least 90% of the total area of the buildings being assessed.

	Nutzungsprofile DIN V 18599 Teil 10, Ausgabe 2007			01 Einzelbüro	02 Gruppenbüro	03 Großraumbüro	04 Sitzung	05 Schalterhalle
				1	2	3	4	5
2	**Nutzungs- und Betriebszeiten**	**Einheit**	**Symbol**					
3	Nutzung Begin	[Uhr]	-	7:00	7:00	7:00	7:00	7:00
4	Nutzung Ende	[Uhr]	-	18:00	18:00	18:00	18:00	18:00
5	tägliche Nutzungsstunden	[h/d]	$t_{nutz,d}$	11	11	11	11	11
6	jährliche Nutzungstage	[d/a]	$d_{nutz,a}$	250	250	250	250	250
7	jährliche Nutzungsstunden zur Tagzeit	[h/a]	t_{Tag}	2543	2543	2543	2543	2543
8	jährliche Nutzungsstunden zur Nachtzeit	[h/a]	t_{Nacht}	207	207	207	207	207
9	tägliche Betriebsstunden RLT und Kühlung	[h/d]	$t_{v,op,d}$	13	13	13	13	13
10	jährliche Betriebstage RLT, Kühlung und Heizung	[d/a]	$t_{RLT-Betrieb}=d_{o}$	250	250	250	250	250
11	tägliche Betriebsstunden Heizung	[h/d]	$t_{h,op,d}$	13	13	13	13	13
12	**Beleuchtung**							
13	Wartungswert der Beleuchtungsstärke	[lx]	E_m	500	500	500	500	200
14	Höhe der Nutzebene	[m]	h_{Ne}	0,80	0,80	0,80	0,80	0,80
15	Minderungsfaktor Bereich Sehaufgabe	[-]	k_A	0,84	0,84	0,93	0,93	0,87
16	relative Abwesenheit	[-]	C_A	0,30	0,30	0,00	0,50	0,00
17	Raumindex	[-]	k	0,90	1,25	2,50	1,25	1,50
18	Teilbetriebsfaktor der Gebäudebetriebszeit für Beleuchtung	[-]	F_t	0,70	0,70	1,00	1,00	1,00
19	Wartungsfaktor Beleuchtung nach 18599 (pauschal)	[-]	WF	0,67	0,67	0,67	0,67	0,67
20	Wartungsfaktor für Beleuchtung nach EnEV 2009	[-]	WF	0,80	0,80	0,80	0,80	0,80
21	Anpassung Strombedarf Tabellenverfahren nach EnEV 2009	[-]	WF-Fak	0,84	0,84	0,84	0,84	0,84
22	Konstantlichtregelung nach EnEV 2009	[-]	Kon-Fak	0,90	0,90	0,90	0,90	0,90
23	**Raumklima**							
24	Feuchteanforderung	[Typ]	-	m. T.	m. T.	m. T.	m. T.	m. T.
25	Mindestaußenluftvolumenstrom	[m³/(h m²)]	V'_A	4,0	4,0	6,0	15	2,0
26	Mindestaußenluftvolumenstrom - reduz. Betrieb	[m³/(h m²)]	V'_A	0,0	0,0	0,0	0,0	0,0
27	**Wärmequellen** (negative Werte => Senken)							
28	Personen - mittel	[Wh/(m²d)]	$q_{I,p}$	30	30	42	96	36
29	Arbeitshilfen - mittel	[Wh/(m²d)]	$q_{I,fac}$	42	42	60	8	24
30	Personen - hoch	[Wh/(m²d)]	$q_{I,p}$	42	42	54	140	54
31	Arbeitshilfen - hoch	[Wh/(m²d)]	$q_{I,fac}$	90	90	114	12	57
32	Personen - Absenkbetrieb	[Wh/(m²d)]	$q_{I,p}$	0	0	0	0	0
33	Arbeitshilfen - Absenkbetrieb	[Wh/(m²d)]	$q_{I,fac}$	0	0	0	0	0
34	**Raumlufttemperatur**							
35	Raum-Solltemperatur Heizung	[°C]	$\vartheta_{i,h,soll}$	21	21	21	21	21
36	Temperaturabsenkung reduzierter Betrieb	[K]	$\Delta\theta_{i,NA}$	4	4	4	4	4
37	Raum-Solltemperatur Kühlung	[°C]	$\vartheta_{i,c,soll}$	24	24	24	24	24
38	Minimaltemperatur Auslegung Heizung	[°C]	$\vartheta_{i,h,min}$	20	20	20	20	20
39	Maximaltemperatur Auslegung Kühlung	[°C]	$\vartheta_{i,c,max}$	26	26	26	26	26
40	**weitere Randbedingungen**							
41	Tagesmittel Außentemperatur Auslegungstag Heizung	[°C]	$\vartheta_{e,min}$	-12	-12	-12	-12	-12
42	Tagesmittel Außentemperatur Auslegungstag Juli Kühlung	[°C]	$\vartheta_{e,max,Jul}$	24,6	24,6	24,6	24,6	24,6
43	Tagesmittel Außentemperatur Auslegungstag September Kühlu	[°C]	$\vartheta_{e,max,Sep}$	18,9	18,9	18,9	18,9	18,9
44	Abminderungsfaktor infolge von Verschmutzung	[-]	F_V	0,9	0,9	0,9	0,9	0,9
45	Verschmutzungsfaktor	[-]	k_2	0,9	0,9	0,9	0,9	0,9
46	**Zuordnung Kennwert-Tabelle Kälteerzeugung**							
47	Nummer der Kennwerte-Tabelle gem. DIN 18599 - Teil 7	[Typ]	-	A2	A2	A2	A2	A2
48	**Trinkwarmwasser Nichtwohngebäude** (siehe Tabelle 6)							
49	Anzahl der Spitzenzapfungen am Tag	[-]	n_{Sp}	1	1	1	1	
50	**spezifische Raumgeometrien (aus Teilkennwertemethode)**							
51	typische Raumhöhe	[m]	h_R	3,0	3,0	3,0	3,0	4,0
52	typische Raumbreite	[m]	b_R	3,0	6,0	12,0	6,0	10,0

Start | Eingabe | Gesamtbilanz | Nutzungen

Figure 3.5: EnerCalC Zone Definition Page

3.6 Modeling Energy Performance

3.6.1 UKE Building Selection Rationale

The selection of UKE buildings O.10, S.50, and O.70 for modeling and calculation of energy performance is due to fact that, according to the UKE Facility Management, they belong to the top five most energy consuming buildings at the UKE. All three buildings have large air conditioning requirements and are fitted with complex air conditioning systems, which significantly contributes to the electricity demand of the three buildings.

O.10 is a clinic and is the largest building in all of the UKE (see Figure 3.6). Despite its recent construction and modern thermal insulation measures it is still the building with the greatest heating and electricity demand amongst all of the buildings at the UKE. The diversity of zones constituting O.10, as can be seen in Figure 4.7, as well as the sheer size of the gross internal area, 76.215 m^2, are the main factors for this large heating and electricity demand.

S.50 is a molecular neurobiology research center and is the most homogenous of the three buildings, consisting primarily of laboratories and having the lowest variety of zone types. Featuring a gross internal area of 10.023 m^2, it is also the smallest of the three selected buildings. The large energy demand stems mainly from the utilities required to keep the laboratories operational.

O.70 is a heart institute and is fairly heterogenous, consisting of special / intensive care units, examination and surgery rooms, and technical rooms.

3.6.2 UKE Building Information

The following points describe some basic information about UKE buildings O.10, S.50, and O.70:

- O.10, *UKE Neues Klinikum*, Martinistraße 52, 20246 Hamburg
  - Year of construction: 2009
  - Gross Internal Area: 76.215 m^2
  - Total Building Envelope Area: 71.840 m^2
  - Total Heated Building Volume: 277.400 m^3
- S.50, *Forschungszentrum für Molekulare Neurobiologie*, Martinistraße 84, 20246 Hamburg
  - Year of construction: 1996

- Gross Internal Area: 10.023 m^2
- Total Building Envelope Area: estimated 8495 m^2
- Total Heated Building Volume: estimated 39.331 m^3

- O.70, *UKE Herzzentrum*, Martinistraße 52, 20246 Hamburg
  - Year of construction: 1990
  - Gross Internal Area: 14.052 m^2
  - Total Building Envelope Area: estimated 6678 m^2
  - Total Heated Building Volume: estimated 34.338 m^3

3.6.3 Building Plans

The 3D CAD diagrams of O.10, S.50 and O.70 presented in Figures 3.7 to 3.9 were constructed with the aid of architectural plans of the buildings which were supplied by the UKE archives. These building plans were important for determining the dimensions and surface area of the buildings being evaluated - this is important for input of the building envelope into EnerCalC. The goal of referring to these building plans was not to make a 100% faithful reconstruction of the buildings in CAD and EnerCalC, but rather to create a basic model with accurate dimensions and surface area values to use for modeling energy performance. Some discrepancies between the CAD designs and the satellite imagery of the buildings (provided in Figure 3.6) can be observed, particularly for O.10, whose modern construction includes patios and roofless inner courtyards to facilitate the insolation of multiple areas of the building. Not all of the buildings' envelope features could be accounted for. But overall, the CAD diagrams and the dimensions and surface area values remain quite faithful to the building plans provided, as can be seen in the accuracy with which the shapes and proportions of the CAD diagrams match with buildings in the satellite imagery.

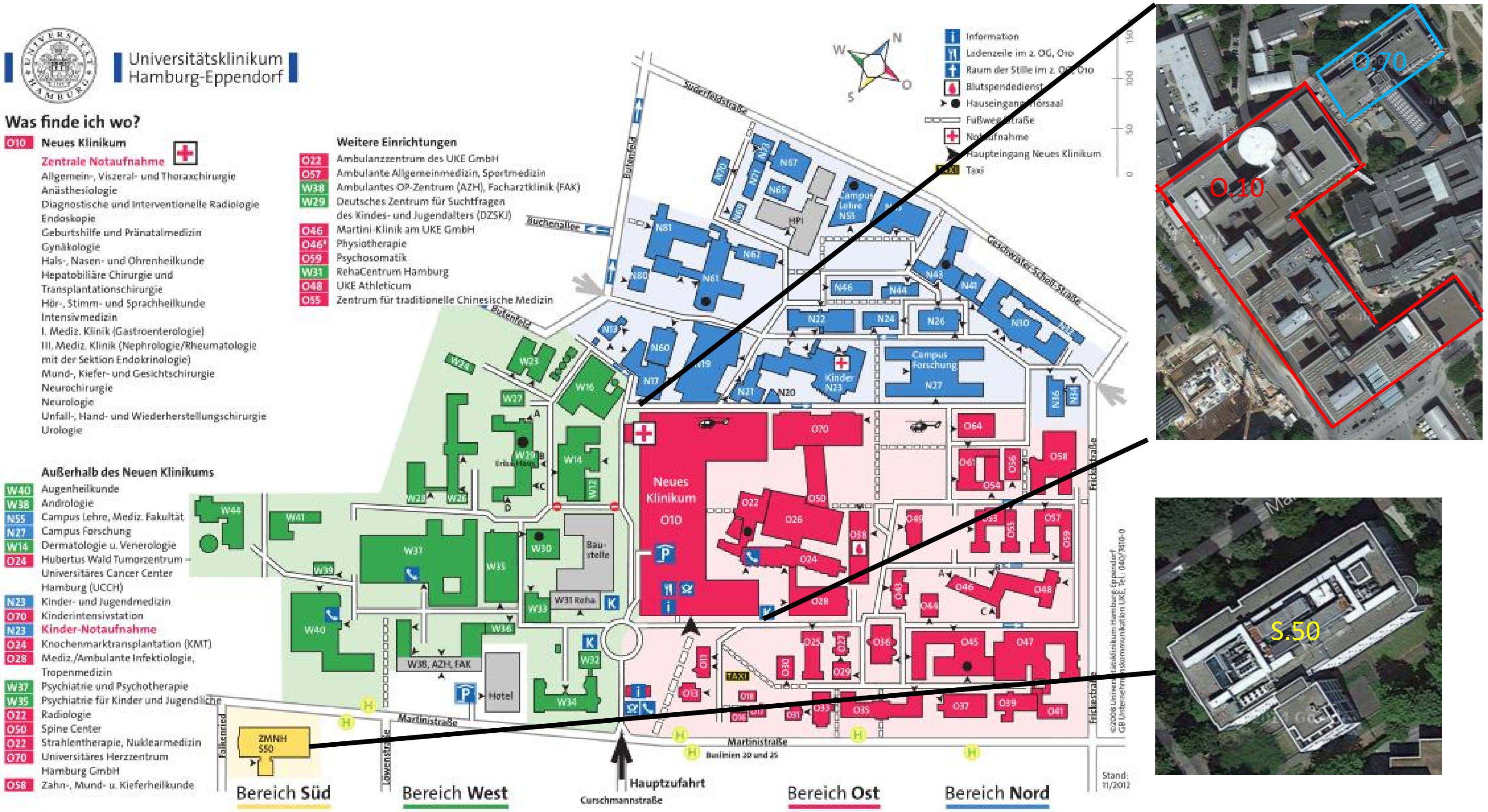


Figure 3.6: Map of the UKE, highlighting O.10, S.50, O.70

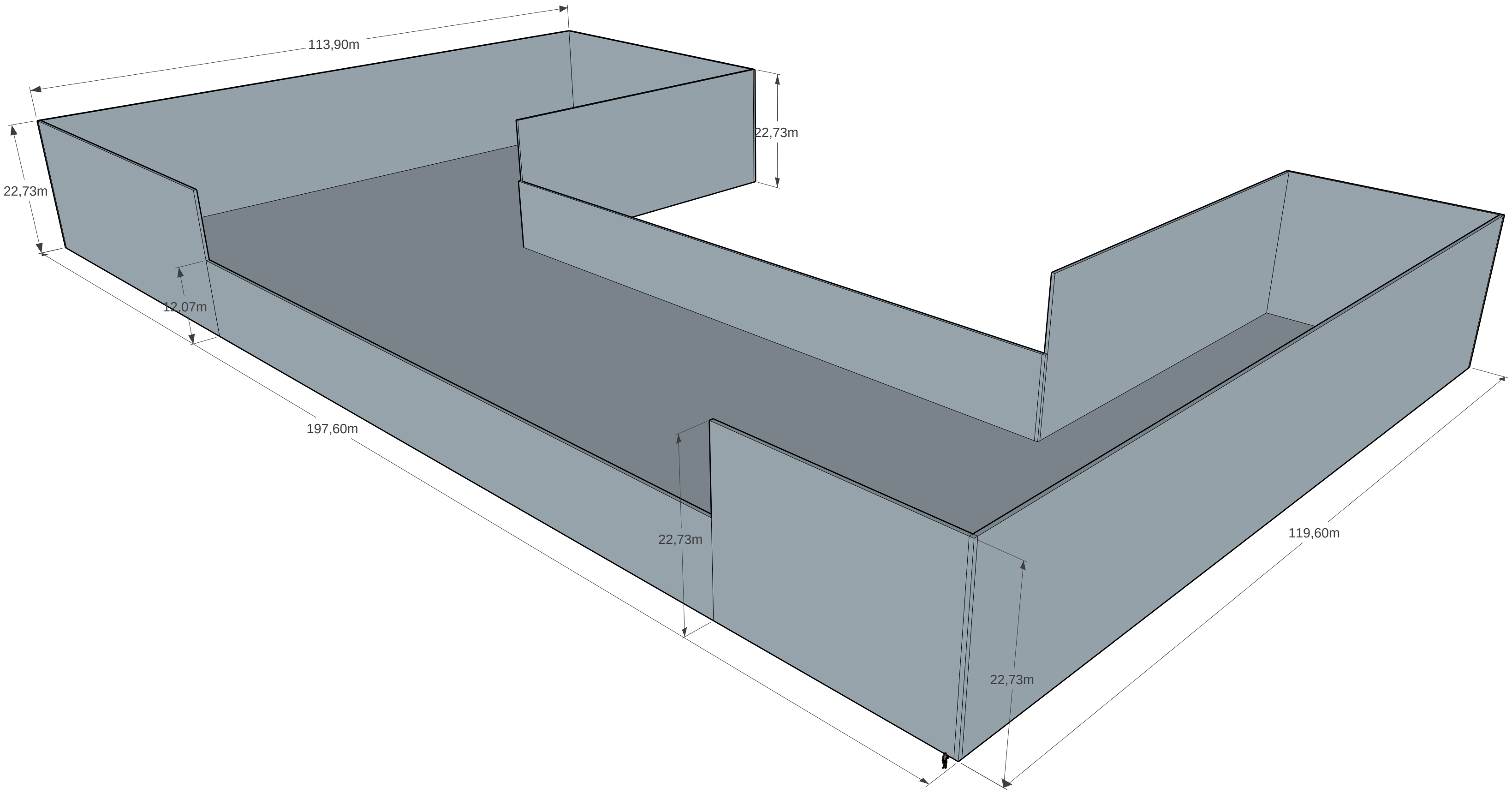


Figure 3.7: 3D CAD impression of O.10

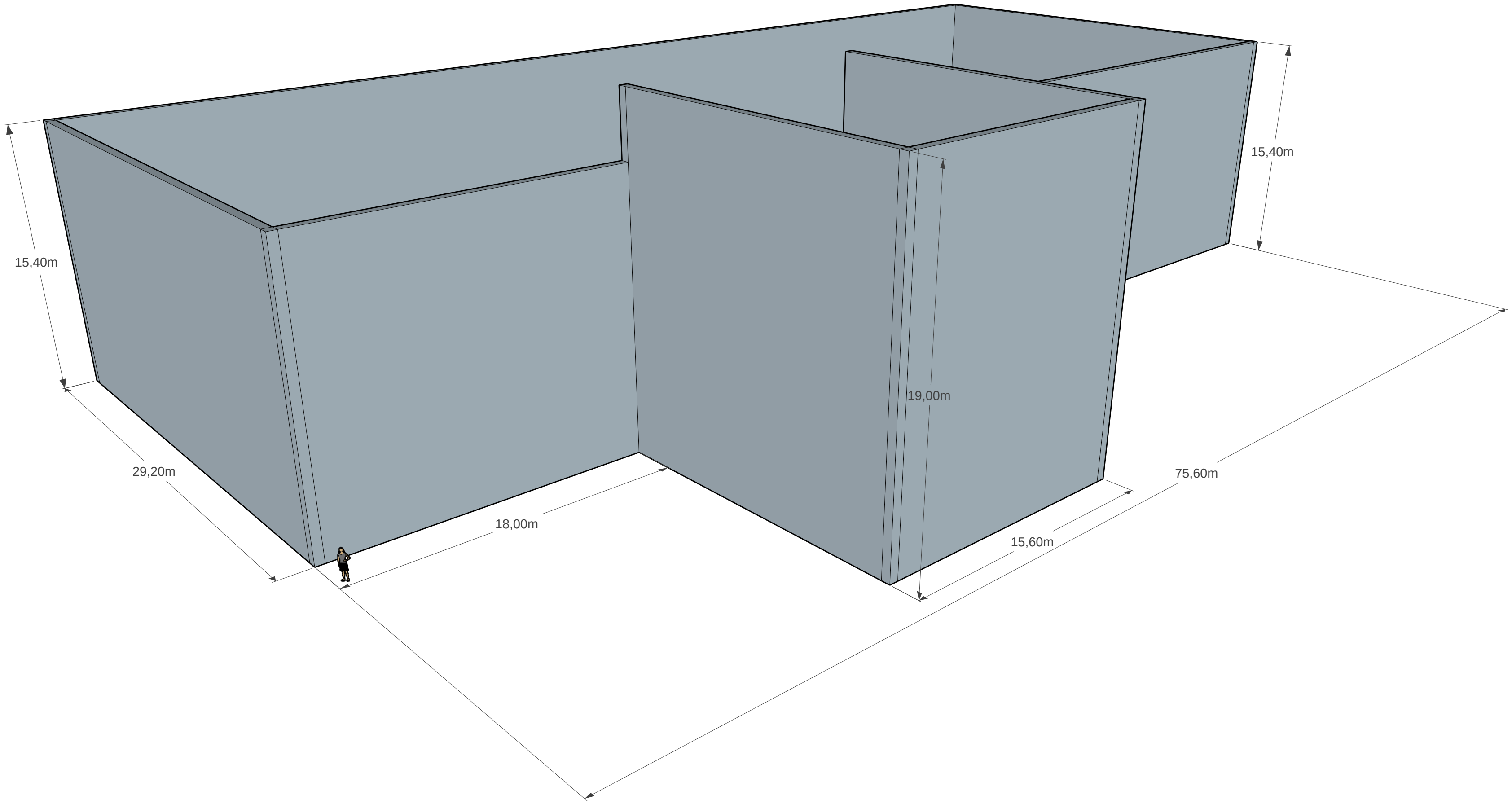


Figure 3.8: 3D CAD impression of S.50

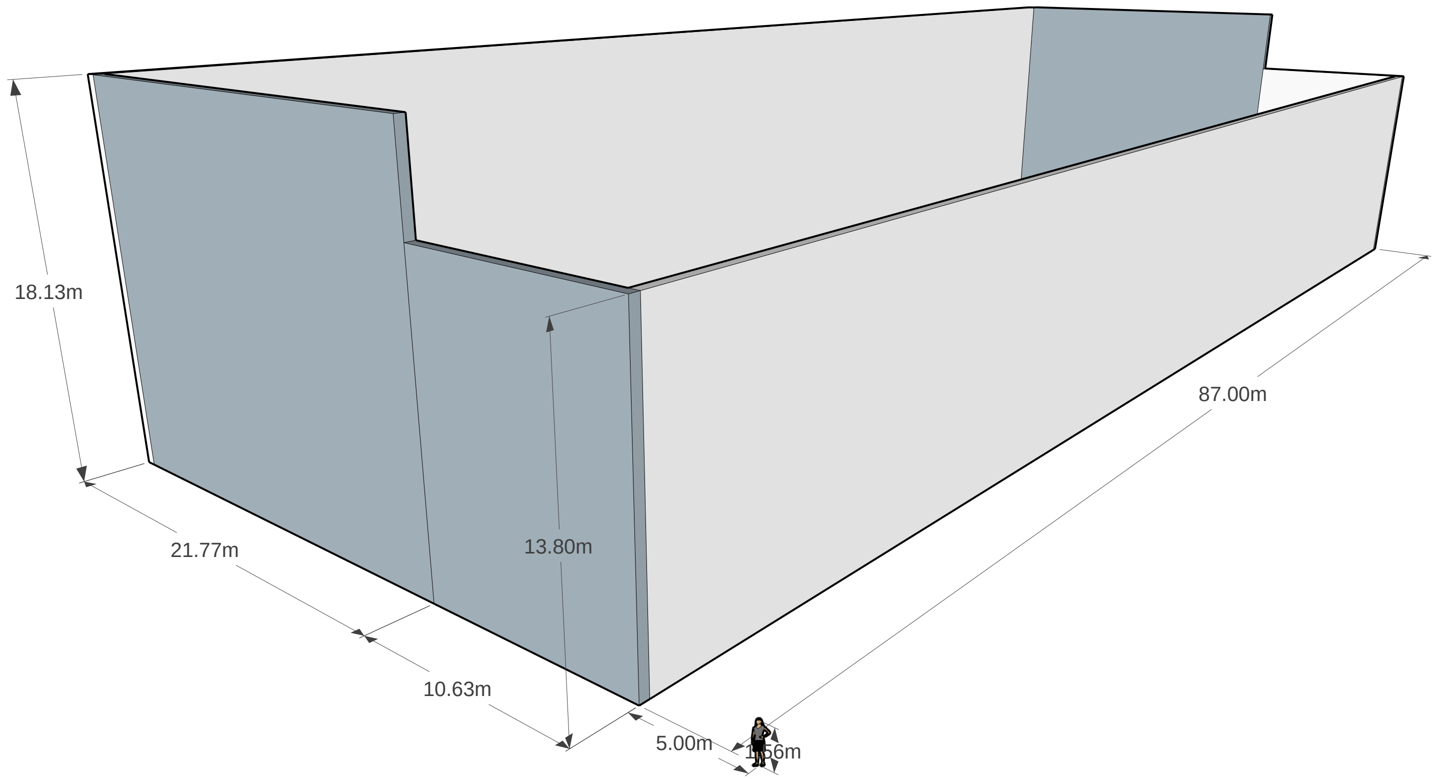


Figure 3.9: 3D CAD impression of O.70

3.6.4 Building Energy Demand

For O.10, S.50, and O.70, the yearly figures for electricity, water, sewage, and heating net energy values were obtained from the UKE Facility Management. Water and sewage are not modeled by EnerCalC and were thus deemed irrelevant. The yearly electricity and heating net energy values for O.10, S.50, and O.70, on the other hand, were used to validate the energy performance calculations of EnerCalC.

It is important to note that the total electricity net energy values for O.10, S.50, and O.70 far exceed the electricity required only for ventilation, cooling, and lighting within a building. Only for S.50 could ventilation, cooling, and lighting-specific electricity requirements be obtained. For O.10 and O.70, the heating net energy values were used to validate EnerCalC's heating and hot water utility calculations.

The real-world energy demand figures of O.10, S.50, and O.70 were primarily used to verify whether EnerCalC's energy performance calculations were valid; in other words, to investigate if the calculated heating, hot water, ventilation, cooling, and lighting energy requirements were close to reality. The results of the sensitivity and interdependency analyses were very important here, as they highlighted the building parameters in EnerCalC that were most relevant towards modeling a building's energy performance. Thus, instead of attempting to input as much real world data about each building into EnerCalC as possible, the focus could be narrowed on the few select parameters that were found to have the most impact on the calculation of energy performance. A rationale for the selection of these parameters is given in 4.5.

4 Results

4.1 Sensitivity Analysis

The results of the sensitivity analysis of the EnerCalC parameters are presented in Figures 4.1 to 4.4.

Since EnerCalC has two types of data inputs (numerical and drop-down list), varying methods were used to produce data. For the numerical inputs, the reference value was varied from 50% to 150% and the minimum and maximum net energy values calculated by EnerCalC from this input parameter variation are shown in Figures 4.1 and 4.2. For the drop-down list inputs, each of the entries in the drop down list were input into EnerCalC and the minimum and maximum values calculated from the range of input entries are shown in Figures 4.3 and 4.4.

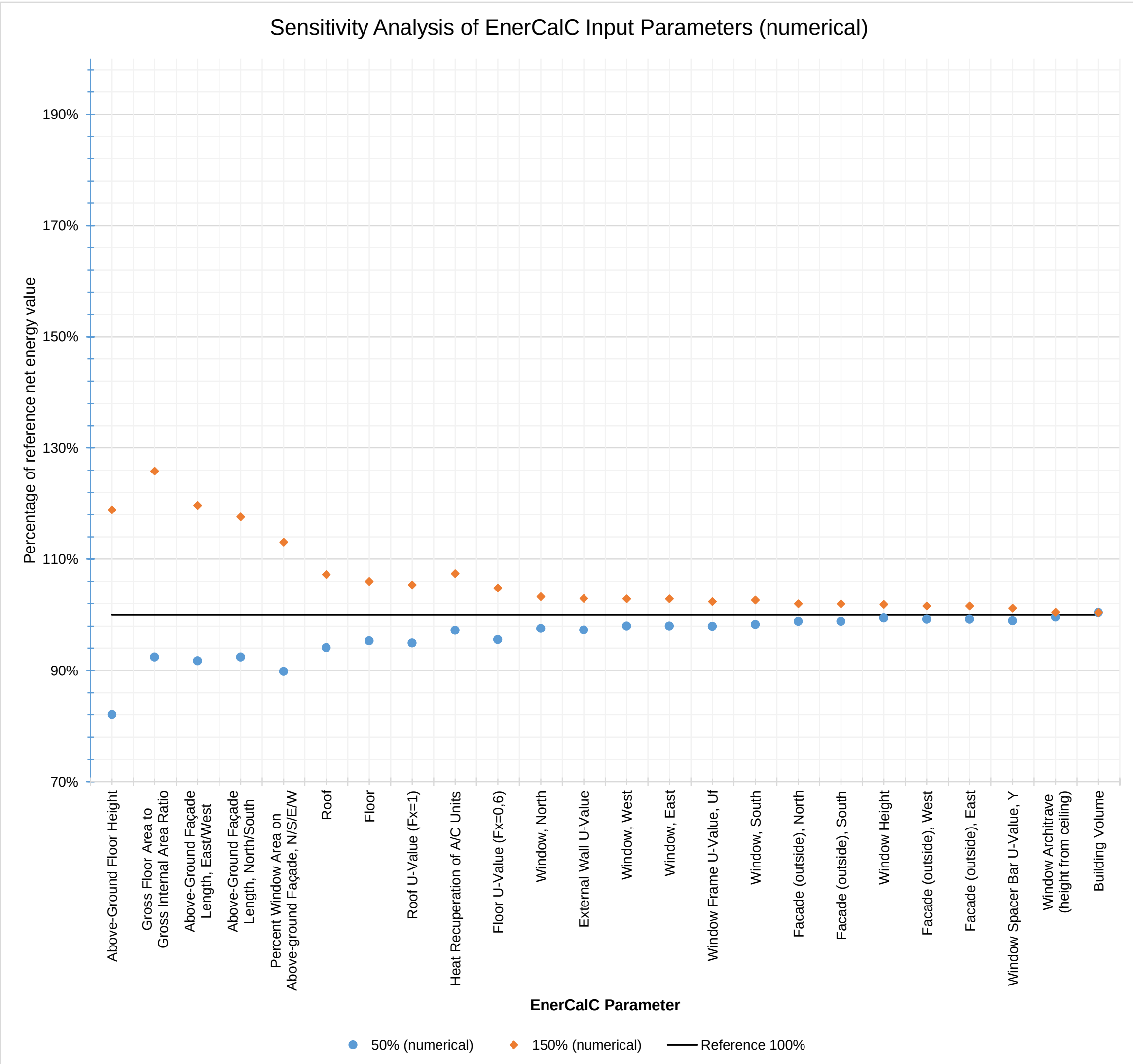


Figure 4.1: Sensitivity Analysis of Numerical EnerCalC Inputs

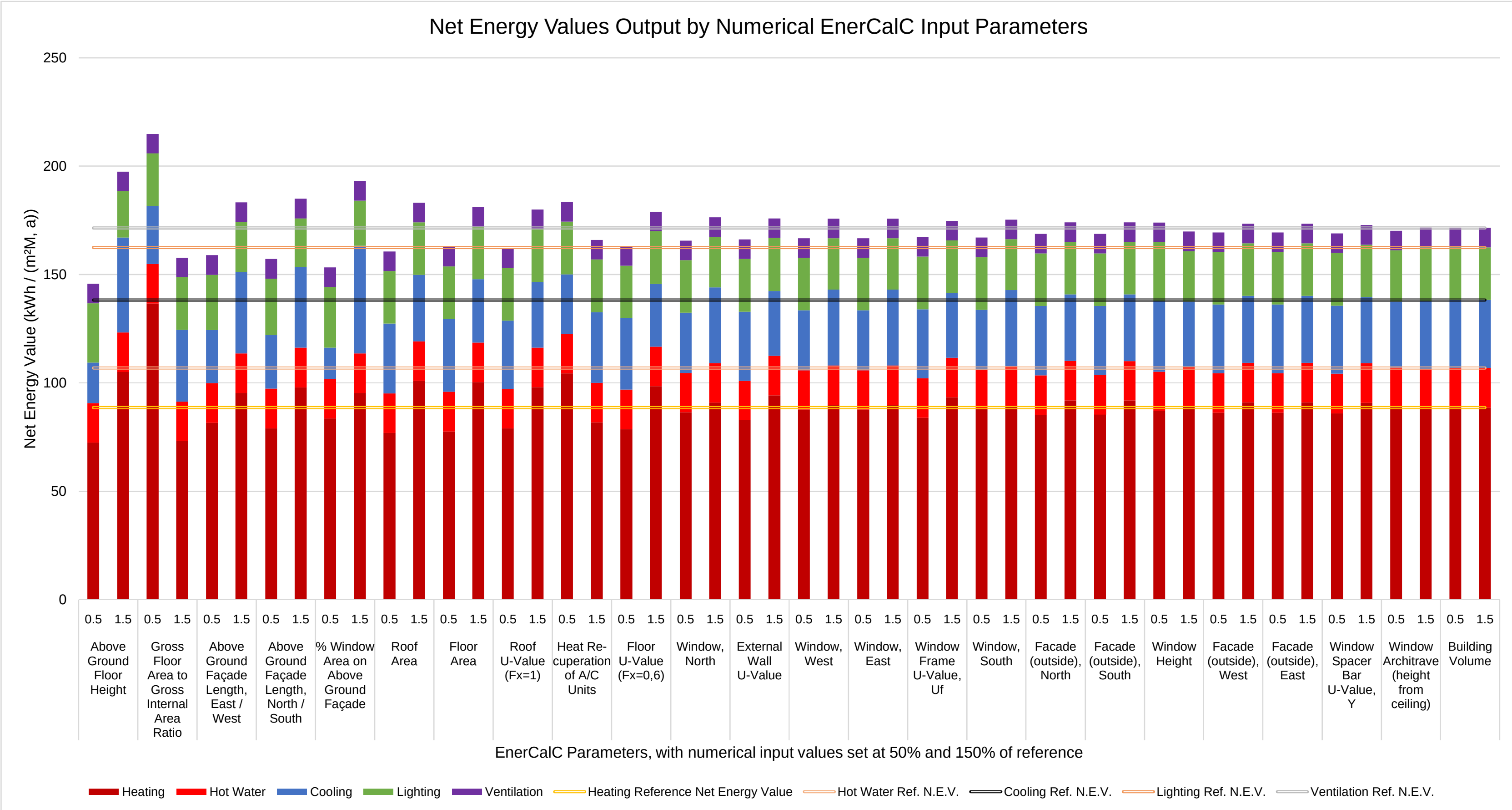


Figure 4.2: Bar Chart of Numerical EnerCalC Inputs

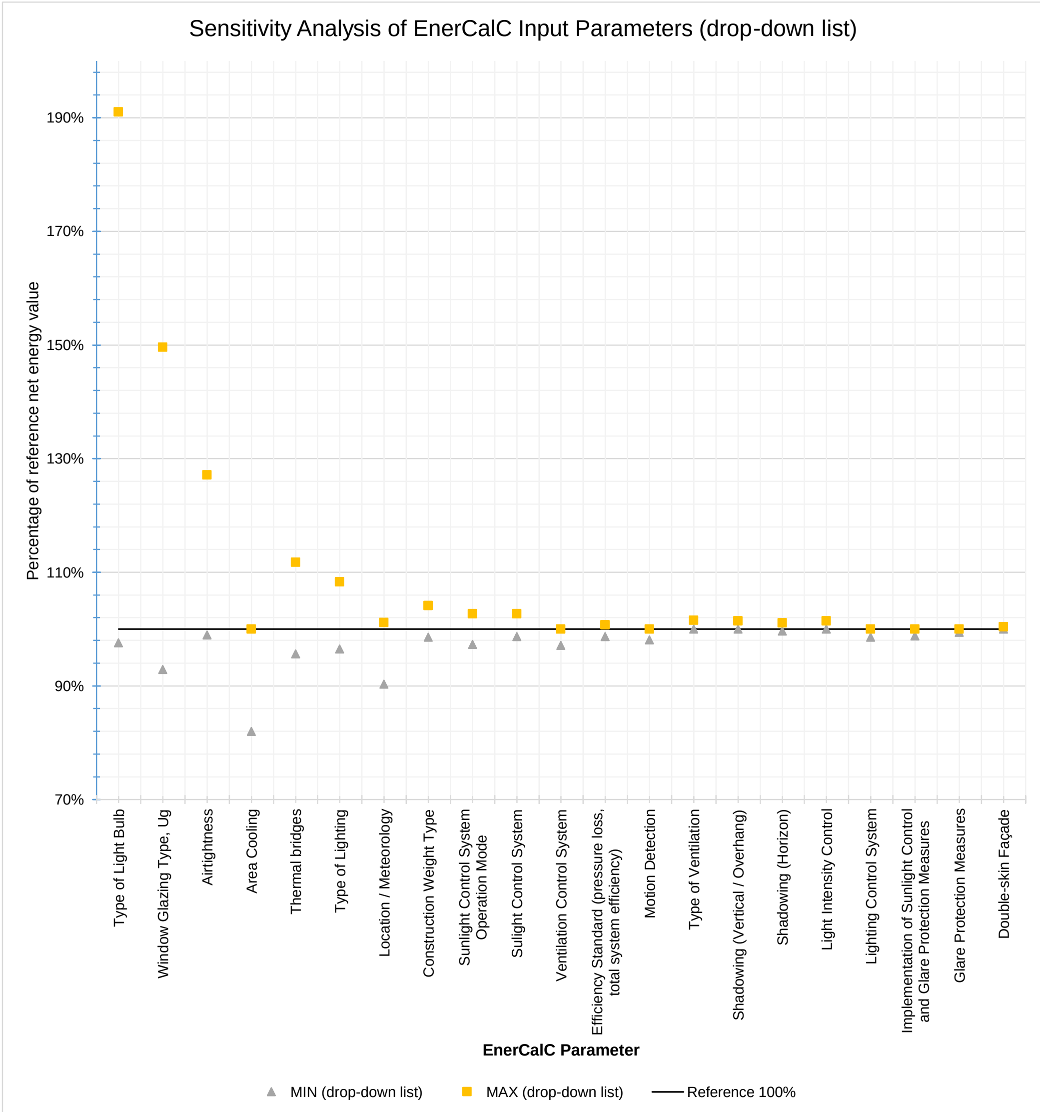


Figure 4.3: Sensitivity Analysis of Drop-Down List EnerCalC Inputs

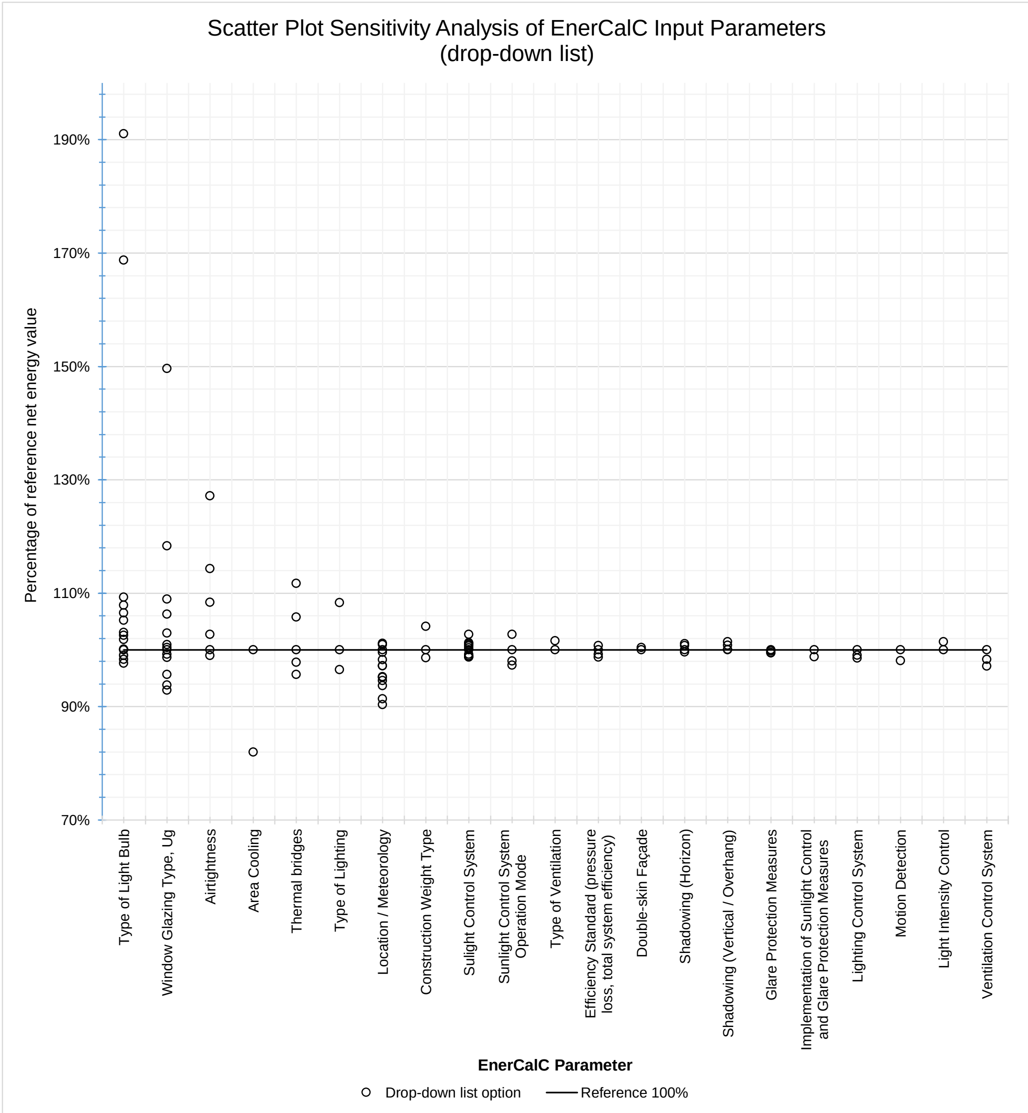


Figure 4.4: Scatter Plot of Drop-Down List EnerCalC Inputs

4.2 Sensitivity Analysis Observations

4.2.1 Description of Figures

Figure 4.1 shows the results of the sensitivity analysis for the numerical EnerCalC parameter inputs. Two sets of points indicate the percent change in the total net energy value of each parameter when the input value of that parameter is set to 50% and 150% of the reference input value. Figure 4.2 expands on the sensitivity analysis shown in Figure 4.1 by displaying how heating, hot water, cooling, lighting, and ventilation utilities comprise the total net energy values of each parameter. Again, for each parameter, the parameter's input value is set to 50% and 150% of the reference input value, and the net energy values output by each parameter are plotted in the bar chart. Additional lines are provided on top of the bars to show the reference net energy value for each utility.

Figure 4.3 shows the results of the sensitivity analysis for the drop-down list EnerCalC parameter inputs. Two sets of points indicate the percent change in the total net energy value of each parameter when selecting the two drop-down list options that output the lowest and highest net energy values for that parameter. In this sense, Figure 4.3 focuses on displaying the highest possible sensitivity that each parameter can exhibit, however, given that some parameters feature drop-down lists with more than two options, Figure 4.4 has been included as well. Figure 4.4 expands on the results of Figure 4.3 by showing a scatter plot of all of the possible results output the options of the drop-down list parameters input. Here it can be seen that although the parameter Type of Light Bulb, for example, can output a total net energy value over 190% of the reference when selecting a certain option (incandescent light bulbs), most of the options in the drop-down list yield values in the 95% to 110% range.

Figures 4.1 to 4.3 all feature the same y-axis range and on the x-axis, the parameters are all sorted according to the magnitude of the difference between the maximum and minimum total net energy value output, from greatest to least.

4.2.2 Numerical Input EnerCalC Parameters (Figures 4.1 & 4.2)

For seven out of the twenty four parameters with numerical inputs (as shown in Figure 4.1), EnerCalC calculates a net energy value between 82% and 95% of the reference net energy value when the input parameter is reduced to 50% of its reference value. For the same seven parameters, EnerCalC calculates a net energy value between 106% and 126% of the reference net energy value when the input parameter is increased to 150% of its reference value. These seven parameters are: Above-Ground Floor Height, Gross Floor Area to Gross Internal Area Ratio, Above-Ground Facade Length (East / West), Above-Ground Facade Length (North / South), Percent Window Area on Above-Ground Facade (North / South / East / West), Roof Area, and Floor Area.

Above-Ground Floor Height is the most negatively sensitive parameter; when the input parameter was set to 50% of the reference input value, EnerCalC calculated a net energy value of 82% of the reference net energy value. Gross Floor Area to Gross Internal Area Ratio is the most positively sensitive parameter; when the input parameter was set to 150% of the reference input value, EnerCalC calculated a net energy value of 126% of the reference net energy value.

The difference between the net energy values output when the input is set to 50% and 150% of each parameter's reference value provides insight into the overall sensitivity of each parameter. For example, with a net energy value of 82% at 50% input and 119% at 150% input, Above-Ground Floor Height is overall the most sensitive parameter with a 37% difference between the lowest and highest net energy value output. This is followed by Gross Floor Area to Gross Internal Ratio (33%), Above-Ground Facade Length (East / West) (28%), Above-Ground Facade Length (North / South) (25%), Percent Window Area on Above-Ground Facade (North / South / East / West) (23%), Roof Area (13%), and Floor Area (11%). Altogether, a total of seven numerical input parameters display a difference greater than 10% between the lowest and highest net energy values output by the same input range (50% to 150% of the reference input value).

Figure 4.2 shows how heating, hot water, cooling, lighting, and ventilation utilities contribute to the total net energy values of each parameter. Since most of the EnerCalC parameters with numerical inputs define the dimensions and thermal properties (i.e. U-values) of the building envelope, it is mostly the heating net energy values that change. The cooling net energy value also changes for the following parameters; Above-Ground Floor Height, Gross Floor Area to Gross Internal Area Ratio, Above-Ground Facade Length (East / West), Above-Ground Facade Length (North / South), and % Window Area on Above-Ground Facade.

4.2.3 Drop-down List Input EnerCalC Parameters (Figure 4.3)

Figure 4.3 features two sets of points that indicate the percent change in the total net energy value of each parameter when the input value of the parameter is set to the drop-down list option that outputs the lowest and highest possible net energy value for that parameter. Figure 4.3 is similar to Figure 4.1 in the sense that the two sets of points featured on the graph display the minimum and maximum percent change for each parameter, however, due to the varying modes of data input (numerical vs. drop-down list), the sensitivity ranges displayed are quite different.

If the drop-down list input parameters are inspected only on the basis of the input options that output the lowest and highest possible net energy value for each parameter (as shown in Figure 4.3, then the following observations can be made.

Area Cooling is the most negatively sensitive parameter; when inputting the appropriate option from the drop-down list ("No", i.e. the zone is not cooled), the resulting net energy value is 82% of the reference value. It is worth noting that this is only the case if the building consists of a single zone, such as in the reference building. If the building features several zones with some zones featuring cooling, then the net energy requirements will increase. Type of Light Bulb is the most positively sensitive parameter; the drop-down list option responsible for outputting a net energy value that is 191% of reference is the *Glühlampen* or incandescent light bulb option. This is understandable as incandescent light bulbs are the most inefficient compared to the other light bulb types in the drop-down list options available in the Type of Light Bulb parameter.

The difference between the net energy values output when inputting the drop-down list options yielding the minimum and maximum net energy value indicates which parameters are more sensitive to certain selections in drop-down list input options. For example, with a minimum of 98% and maximum of 191% of the reference net energy value, the Type of Light Bulb parameter displays the highest sensitivity with a maximum difference of 93%. This is followed by Window Glazing Type (57%), Airtightness (28%), Area Cooling (18%), Thermal Bridges (16%), Type of Lighting (12%), and Location / Meteorology (11%).

As with the numerical input parameters, a total of seven parameters with drop-down list inputs feature a difference greater than 10% between the lowest and highest net energy values output (when inputting each option from the drop-down list of each parameter). The main difference between the numerical and drop-down list inputs is that the input range cannot be as clearly defined for the latter (due to predefined options in the drop-down list) as they can for the former (for which numbers can be input).

Scatter Plot Drop-down List Inputs (Figure 4.3)

Figure 4.3 shows the scatter in the net energy values resulting from the plotting the net energy values output by the selection of each of the drop-down list options of each parameter.

Approximately half of the parameters output net energy values that are mostly concentrated in the range of 90 - 110 % of the reference net energy value, whereas the other half of parameters has net energy values that are closely clustered around the 100% reference value. Most of the outliers are highly positively sensitive, as can be seen in the parameters Type of Light Bulb, Window Glazing Type, and Airtightness. A scatter of net energy values between 90% and 100% of the reference value can be observed particularly for the parameters Location / Meteorology and Window Glazing Type. Location / Meteorology is a particularly curious parameter in this regard given that almost all of the net energy values output are actually below reference. This indicates that the reference climate option, "DIN V 18599, Referenzklima," to be colder than the other, region-adjusted climates.

Figure 4.4 provides noteworthy insights into the Type of Light Bulb, Window Glazing Type, and Airtightness parameters, because although they output the highest net energy values on the plot, it is made clear that this is only the output of a certain selection from the drop down list. With Type of Light Bulb, for example, beyond the two net energy values at 191% and 169% of the reference value, all other light bulb types output values between 98% and 110% of the reference value. This shows that sensitivity displayed by each parameter strongly depends on the range and selection of options given in the drop-down list. It is entirely possible to select drop-down list options that yield net energy values that are close to reference even for parameters that display a high sensitivity. Hence, just because a parameter outputs a high net energy value when a certain option is selected does not mean that all the other options of the same drop-down list will do the same. The sensitivity of each parameter is confined which selection is being made from the drop-down list, with some parameters having the potential to exhibit a greater sensitivity to its respective inputs than the others.

4.3 Interdependency Analysis

The results of the interdependency analysis of the EnerCalC parameters are presented in Figures 4.5 and 4.6.

Interdependency Analysis of EnerCalC Parameters (Chi Square Test value)	Above-Ground Façade Length, North/South	Above-Ground Façade Length, East/West	Percent Window Area on Above-ground Façade, N/S/E/W	Gross Floor Area to Gross Internal Area Ratio	Above-Ground Floor Height	Heat Recuperation of A/C Units	Window Architrave (height from ceiling)	Window Height	Location / Meteorology	Construction Weight Type	Airtightness	Thermal bridges	Window Glazing Type, Ug	Window Frame U-Value, Uf	Window Spacer Bar U-Value, Y	External Wall U-Value	Roof U-Value (Fx=1)	Floor U-Value (Fx=0,6)	Double-skin Façade	Shadowing (Horizon)	Shadowing (Vertical / Overhang)	Sulight Control System	Sunlight Control System Operation Mode	Glare Protection Measures	Implementation of Sunlight Control and Glare Protection	Efficiency Standard (pressure loss, total system efficiency)	Area Cooling	Lighting Control System	Motion Detection	Type of Lighting	Type of Light Bulb	Light Intensity Control	Type of Ventilation	Ventilation Control System	**Average**
Above-Ground Façade Length, North/South		1,12	1,92	0,99	1,30	1,16	0,92	0,97	1,09	1,20	0,95	0,98	0,93	1,02	1,03	0,98	1,06	0,97	0,85	0,85	1,01	1,01	1,00	0,99	1,11	0,99	0,97	1,02	1,00	0,71	0,94	1,00	1,01	1,00	**1,00**
Above-Ground Façade Length, East/West	1,12		2,25	0,99	1,68	1,13	0,91	0,98	1,10	1,31	0,93	0,97	0,91	1,01	1,02	0,99	0,95	0,95	0,91	0,91	1,01	1,02	1,00	1,00	1,10	0,99	0,97	1,03	0,99	-0,30	0,92	1,01	1,01	1,00	**0,99**
Percent Window Area on Above-ground Façade, N/S/E/W	1,92	2,25		0,92	0,75	1,59	0,95	1,07	0,79	0,68	0,93	0,96	1,09	1,02	1,03	0,95	1,06	0,95	0,83	0,83	1,03	1,07	1,00	0,97	0,30	0,99	0,95	1,10	0,99	1,05	1,19	1,01	1,04	1,00	**1,01**
Gross Floor Area to Gross Internal Area Ratio	0,99	0,99	0,92		1,02	0,72	0,90	1,08	1,11	1,04	0,95	0,98	0,95	0,53	0,59	1,00	0,91	0,99	1,13	1,13	1,00	1,00	1,00	1,03	0,95	1,00	1,01	0,98	0,98	0,51	0,93	1,02	0,96	1,01	**0,92**
Above-Ground Floor Height	1,30	1,68	0,75	1,02		1,03	0,95	0,75	0,72	0,72	0,94	0,97	0,93	1,00	1,00	0,99	0,97	0,93	0,93	0,93	1,03	1,04	1,00	1,01	0,10	1,02	1,03	1,10	0,97	1,11	1,44	1,02	1,04	1,00	**0,95**
Heat Recuperation of A/C Units	1,16	1,13	1,59	0,72	1,03		0,78	0,73	0,98	0,77	0,79	0,84	0,81	0,83	0,76	1,05	0,37	0,94	-9,61	-9,61	0,86	-0,23	1,00	0,64	2,44	1,05	1,07	-0,26	7,97	1,23	1,12	1,09	0,28	0,03	**0,42**
Window Architrave (height from ceiling)	0,92	0,91	0,95	0,90	0,95	0,78		0,97	0,94	0,97	0,98	0,99	0,98	0,97	0,97	0,97	1,09	0,96	0,96	0,96	1,01	0,92	1,00	0,96	0,86	0,97	0,96	1,05	1,10	0,92	0,94	0,96	1,07	1,03	**0,94**
Window Height	0,97	0,98	1,07	1,08	0,75	0,73	0,97		0,61	0,95	0,99	0,99	0,98	0,98	0,97	1,00	0,95	1,00	1,08	1,08	1,00	1,01	1,00	1,05	0,70	1,00	1,01	0,99	0,99	1,05	1,14	1,01	1,49	1,01	**0,96**
Location / Meteorology	1,09	1,10	0,79	1,11	0,72	0,98	0,94	0,61		0,29	0,97	0,98	0,96	0,92	0,93	1,00	1,00	1,01	0,96	0,96	1,00	1,02	1,00	1,06	1,25	1,00	1,00	1,00	0,99	1,01	24,75	1,00	0,95	1,01	**1,63**
Construction Weight Type	1,20	1,31	0,68	1,04	0,72	0,77	0,97	0,95	0,29		0,99	0,99	0,99	0,99	0,98	1,00	0,97	1,00	1,04	1,04	1,00	1,03	1,00	1,03	0,92	1,00	1,00	1,00	0,99	1,03	1,17	1,01	0,98	1,00	**0,94**
Airtightness	0,95	0,93	0,93	0,95	0,94	0,79	0,98	0,99	0,97	0,99		0,99	0,99	0,99	0,99	1,00	0,95	1,02	1,05	1,05	1,00	1,09	1,00	0,94	1,03	1,00	1,01	0,97	0,93	1,02	1,02	1,01	0,95	1,02	**0,95**
Thermal bridges	0,98	0,97	0,96	0,98	0,97	0,84	0,99	0,99	0,98	0,99	0,99		0,99	0,99	0,99	1,00	0,96	1,04	1,03	1,03	0,99	0,90	1,00	0,98	1,02	1,00	1,00	1,06	1,03	1,01	1,01	1,01	0,91	0,94	**0,96**
Window Glazing Type, Ug	0,93	0,91	1,09	0,95	0,93	0,81	0,98	0,98	0,96	0,99	0,99	0,99		0,99	0,99	1,00	0,95	1,02	1,05	1,05	1,00	1,06	1,00	0,91	1,03	1,00	1,01	0,98	0,96	1,02	1,02	1,01	0,96	1,01	**0,96**
Window Frame U-Value, Uf	1,02	1,01	1,02	0,53	1,00	0,83	0,97	0,98	0,92	0,99	0,99	0,99	0,99		0,99	1,00	0,96	1,01	1,04	1,04	1,00	1,03	1,00	1,20	1,02	1,00	1,00	0,99	0,98	1,02	1,03	1,01	0,97	1,01	**0,96**
Window Spacer Bar U-Value, Y	1,03	1,02	1,03	0,59	1,00	0,76	0,97	0,97	0,93	0,98	0,99	0,99	0,99	0,99		1,00	0,94	1,02	1,07	1,07	1,00	1,03	1,00	1,62	1,08	1,00	1,01	0,99	0,98	1,02	1,04	1,01	0,96	1,01	**0,97**
External Wall U-Value	0,98	0,99	0,95	1,00	0,99	1,05	0,97	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00		1,02	1,02	0,99	0,99	1,05	1,01	1,00	1,01	0,99	1,05	1,08	1,14	0,96	0,97	0,97	0,98	0,96	1,00	**0,97**
Roof U-Value (Fx=1)	1,06	0,95	1,06	0,91	0,97	0,37	1,09	0,95	1,00	0,97	0,95	0,96	0,95	0,96	0,94	1,02		1,02	1,95	1,95	0,86	-0,03	1,00	0,87	1,37	1,09	1,21	-1,45	1,02	1,01	0,95	1,00	0,60	0,73	**0,89**
Floor U-Value (Fx=0,6)	0,97	0,95	0,95	0,99	0,93	0,94	0,96	1,00	1,01	1,00	1,02	1,04	1,02	1,01	1,02	1,02	1,02		9,44	9,44	0,64	0,44	1,00	1,00	0,99	1,16	1,41	0,04	0,48	0,85	0,81	0,90	1,31	0,95	**1,40**
Double-skin Façade	0,85	0,91	0,83	1,13	0,93	-9,61	0,96	1,08	0,96	1,04	1,05	1,03	1,05	1,04	1,07	0,99	1,95	9,44		2,00	1,02	0,53	1,00	1,27	0,71	0,99	0,98	1,11	1,30	0,95	0,96	0,98	1,37	0,97	**0,97**
Shadowing (Horizon)	0,85	0,91	0,83	1,13	0,93	-9,61	0,96	1,08	0,96	1,04	1,05	1,03	1,05	1,04	1,07	0,99	1,95	9,44	2,00		1,02	0,53	1,00	1,27	0,71	0,99	0,98	1,11	1,30	0,95	0,96	0,98	1,37	0,97	**0,97**
Shadowing (Vertical / Overhang)	1,01	1,01	1,03	1,00	1,03	0,86	1,01	1,00	1,00	1,00	1,00	0,99	1,00	1,00	1,00	1,05	0,86	0,64	1,02	1,02		1,00	1,00	0,99	1,01	1,49	0,77	0,90	1,04	1,06	1,04	1,09	1,02	1,00	**0,97**
Sulight Control System	1,01	1,02	1,07	1,00	1,04	-0,23	0,92	1,01	1,02	1,03	1,09	0,90	1,06	1,03	1,03	1,01	-0,03	0,44	0,53	0,53	1,00		1,00	1,00	0,99	1,01	1,24	0,96	0,97	0,99	0,99	0,77	0,93	1,00	**0,86**
Sunlight Control System Operation Mode	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00		1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,11	0,92	**0,94**
Glare Protection Measures	0,99	1,00	0,97	1,03	1,01	0,64	0,96	1,05	1,06	1,03	0,94	0,98	0,91	1,20	1,62	1,01	0,87	1,00	1,27	1,27	0,99	1,00	1,00		0,94	1,01	1,03	0,98	0,98	0,89	0,94	1,04	6,77	1,08	**1,16**
Implementation of Sunlight Control and Glare Protection Measures	1,11	1,10	0,30	0,95	0,10	2,44	0,86	0,70	1,25	0,92	1,03	1,02	1,03	1,02	1,08	0,99	1,37	0,99	0,71	0,71	1,01	0,99	1,00	0,94		0,99	0,97	1,04	1,05	0,69	2,68	0,96	1,08	0,99	**1,00**
Efficiency Standard (pressure loss, total system efficiency)	0,99	0,99	0,99	1,00	1,02	1,05	0,97	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,05	1,09	1,16	0,99	0,99	1,49	1,01	1,00	1,01	0,99		1,09	1,17	0,96	0,97	0,96	0,97	0,94	1,00	**1,00**
Area Cooling	0,97	0,97	0,95	1,01	1,03	1,07	0,96	1,01	1,00	1,00	1,01	1,00	1,01	1,00	1,01	1,08	1,21	1,41	0,98	0,98	0,77	1,24	1,00	1,03	0,97	1,09		-1,56	0,79	0,91	0,90	0,91	1,21	1,04	**0,91**
Lighting Control System	1,02	1,03	1,10	0,98	1,10	-0,26	1,05	0,99	1,00	1,00	0,97	1,06	0,98	0,99	0,99	1,14	-1,45	0,04	1,11	1,11	0,90	0,96	1,00	0,98	1,04	1,17	-1,56		1,08	1,22	1,17	0,26	1,04	1,00	**0,77**
Motion Detection	1,00	0,99	0,99	0,98	0,97	7,97	1,10	0,99	0,99	0,99	0,93	1,03	0,96	0,98	0,98	0,96	1,02	0,48	1,30	1,30	1,04	0,97	1,00	0,98	1,05	0,96	0,79	1,08		1,34	1,28	0,68	1,05	1,00	**1,18**
Type of Lighting	0,71	-0,30	1,05	0,51	1,11	1,23	0,92	1,05	1,01	1,03	1,02	1,01	1,02	1,02	1,02	0,97	1,01	0,85	0,95	0,95	1,06	0,99	1,00	0,89	0,69	0,97	0,91	1,22	1,34		0,53	0,89	1,11	0,99	**0,90**
Type of Light Bulb	0,94	0,92	1,19	0,93	1,44	1,12	0,94	1,14	24,75	1,17	1,02	1,01	1,02	1,03	1,04	0,97	0,95	0,81	0,96	0,96	1,04	0,99	1,00	0,94	2,68	0,96	0,90	1,17	1,28	0,53		0,86	1,07	0,99	**1,73**
Light Intensity Control	1,00	1,01	1,01	1,02	1,02	1,09	0,96	1,01	1,00	1,01	1,01	1,01	1,01	1,01	1,01	0,98	1,00	0,90	0,98	0,98	1,09	0,77	1,00	1,04	0,96	0,97	0,91	0,26	0,68	0,89	0,86		1,17	-0,57	**0,88**
Type of Ventilation	1,01	1,01	1,04	0,96	1,04	0,28	1,07	1,49	0,95	0,98	0,95	0,91	0,96	0,97	0,96	0,96	0,60	1,31	1,37	1,37	1,02	0,93	0,11	6,77	1,08	0,94	1,21	1,04	1,05	1,11	1,07	1,17		0,93	**1,14**
Ventilation Control System	1,00	1,00	1,00	1,01	1,00	0,03	1,03	1,01	1,01	1,00	1,02	0,94	1,01	1,01	1,01	1,00	0,73	0,95	0,97	0,97	1,00	1,00	0,92	1,08	0,99	1,00	1,04	1,00	1,00	0,99	0,99	-0,57	0,93		**0,88**

Figure 4.5: Interdependency Analysis of EnerCalC Parameters

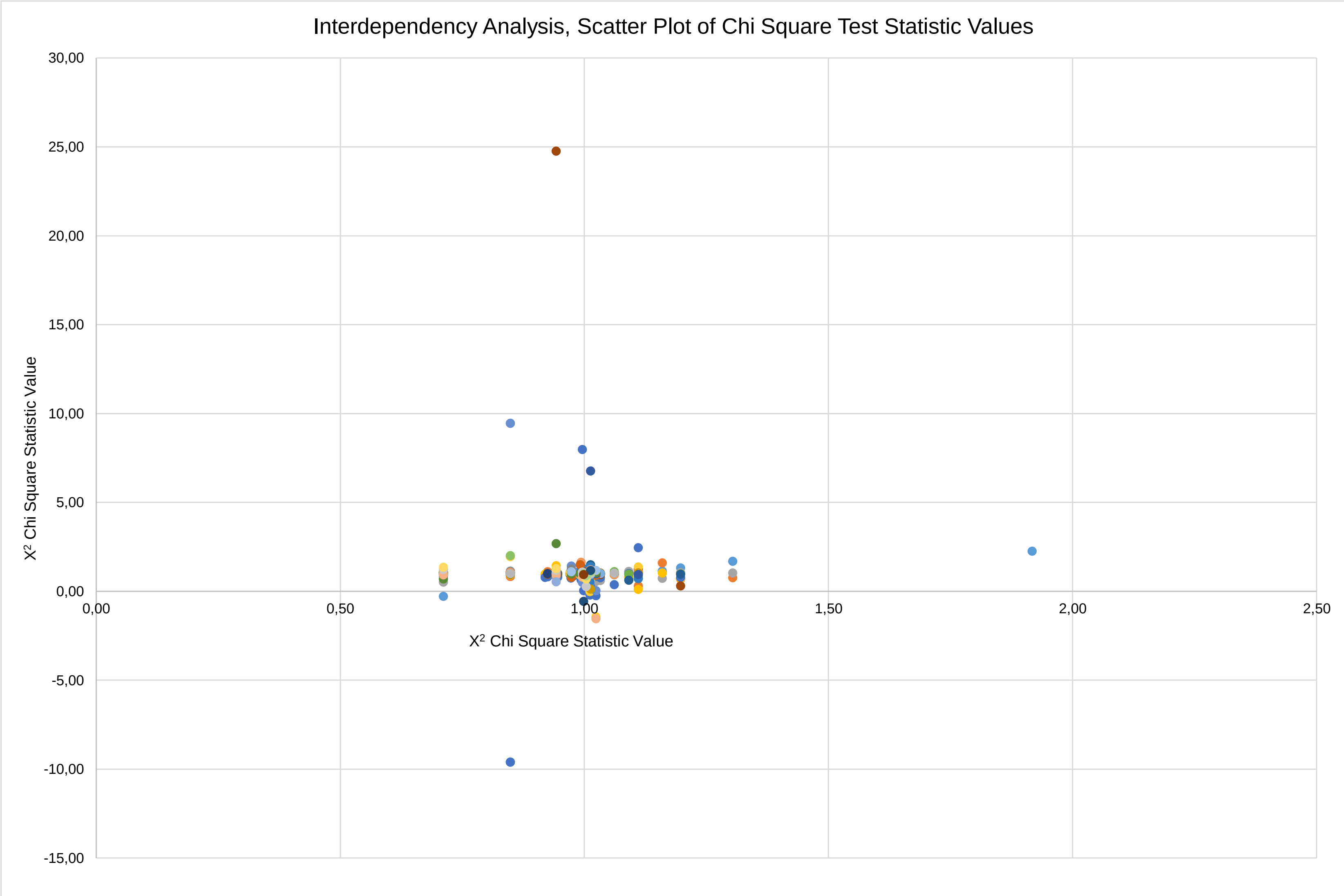


Figure 4.6: Scatter Plot of EnerCalC Parameter Interdependency

4.4 Interdependency Analysis Observations

Figure 4.5 is a table of the Pearson Chi Square Test Statistic (X^2) values. It consists of a lower triangular matrix of which the transpose has been copied and pasted on the top right to create a square matrix with a missing main diagonal. The reason for this representation is to give a coherent presentation of the average (X^2) value of each parameter at the rightmost column of the table.

Regarding the meaning of X^2 values: if the value is equal to one, it indicates that the two parameters are independent. As the value increases, so does the interdependency of the two parameters. What this means is that when the inputs of the two parameters are set to their maximum values, the increase in the net energy value output by EnerCalC will be disproportionately greater than if the two parameters had the maximum values input on a one-factor-at-a-time basis and the changes in the net energy values output for each were added together.

The average Pearson Chi Square Test Statistic value (X^2) was calculated for each parameter so as to gain a general impression of the dependency of that parameter on the others. Most parameters were found to have values close to one, indicating independence. Some parameters, like Location / Meteorology, Floor U-Value and Type of Light Bulb, were found to have an X^2 significantly greater than one, indicating stronger positive interdependence with other parameters. Some parameters have an average X^2 value that is below one, indicating a negative interdependence. Heat Recuperation of A/C units has the lowest average X^2 value, at 0,42.

The scatter plot in Figure 4.6 plots the (X^2) values of the lower triangular matrix shown in Figure 4.5. Most values can be seen clustered around the X^2 value of 1, with a few outliers that increase and/or decrease the averages displayed in Figure 4.5.

4.5 Selection of Most Relevant EnerCalC Parameters

The sensitivity analysis and to some extent the interdependency analysis indicate which parameters can be considered the most relevant for modeling the energy performance of a building.

First, with regards to the sensitivity analysis, the parameters that displayed the highest sensitivity - meaning the greatest difference between the lowest and highest net energy value output - have been selected as the most relevant parameters. The cutoff criterion is that the difference between the lowest and highest net energy value must be greater than 10%.

Thus, the selection of numerical input parameters is: Above-Ground Floor Height, Gross Floor Area to Gross Internal Area Ratio, Above-Ground Facade Length (East / West), Above-Ground Facade Length (North / South), Percent Window Area on Above-Ground Facade (North / South / East / West), Roof Area and Floor Area.

The selection of drop-down list input parameters is: Type of Light Bulb, Window Glazing Type, Airtightness, Area Cooling, Thermal Bridges, Type of Lighting, and Location / Meteorology.

4.6 Zoning

The results of the zoning procedure are given in Figures 4.7 to 4.9.

Thirty five of the forty three zone definitions given in Appendix A of Part 10 of DIN V 18599 were used to assign zones to the rooms found in buildings O.10, S.50, and O.70. A brief summary of the zoning process is given below:

- O.10, *UKE Neues Klinikum*, Martinistraße 52, 20246 Hamburg
  - Number of rooms: 3439 rooms
  - Gross Internal Area: 76.215 m^2
  - Number of DIN V 18599 zoning definitions applied: 20
- S.50, *Forschungszentrum für Molekulare Neurobiologie*, Martinistraße 84, 20246 Hamburg
  - Number of rooms: 415 rooms
  - Gross Internal Area: 10.023 m^2
  - Number of DIN V 18599 zoning definitions applied: 13
- O.70, *UKE Herzzentrum*, Martinistraße 52, 20246 Hamburg
  - Number of rooms: 642 rooms
  - Gross Internal Area: 14.052 m^2
  - Number of DIN V 18599 zoning definitions applied: 17

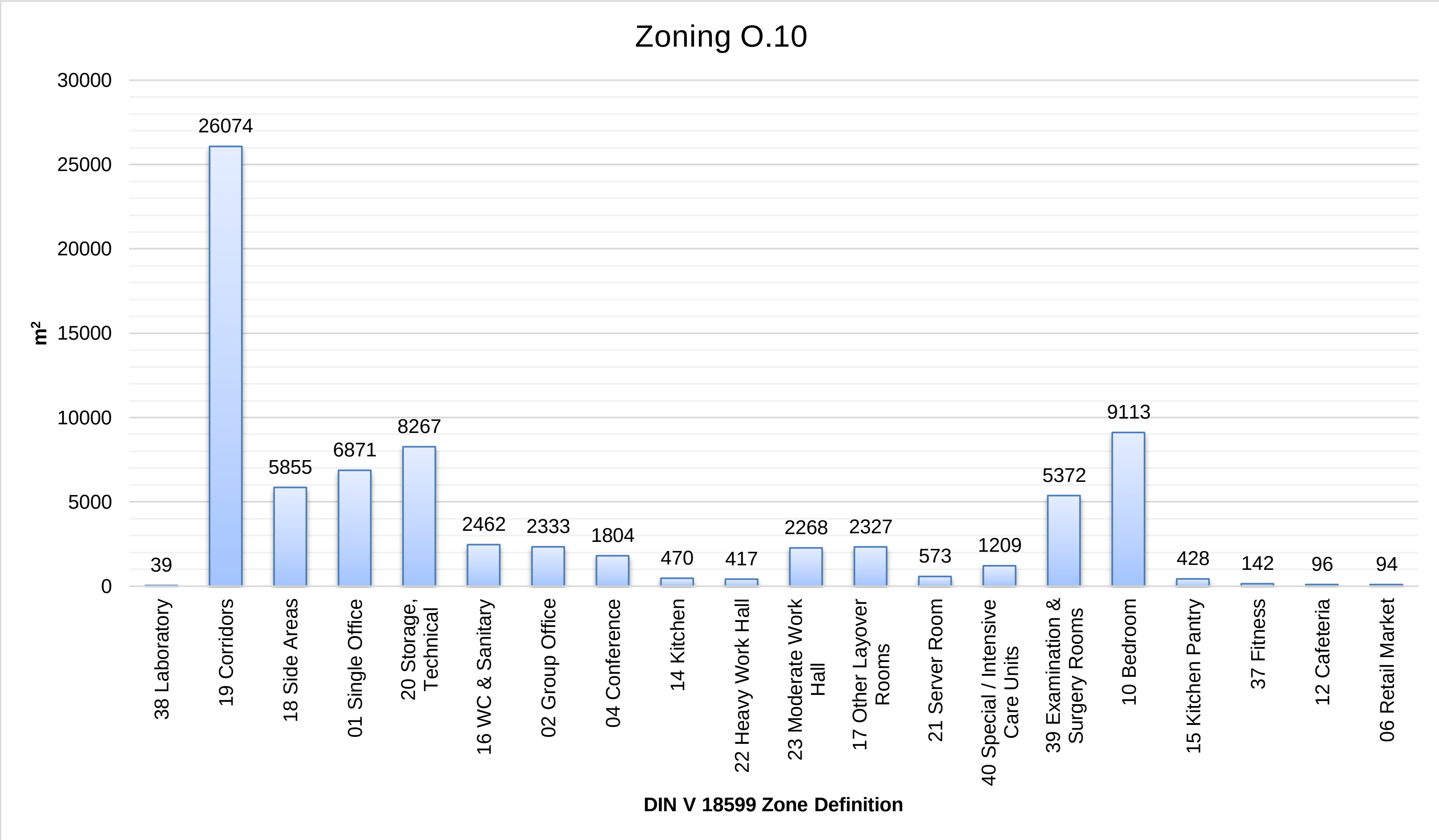


Figure 4.7: Bar graph showing the areas of the zones in O.10

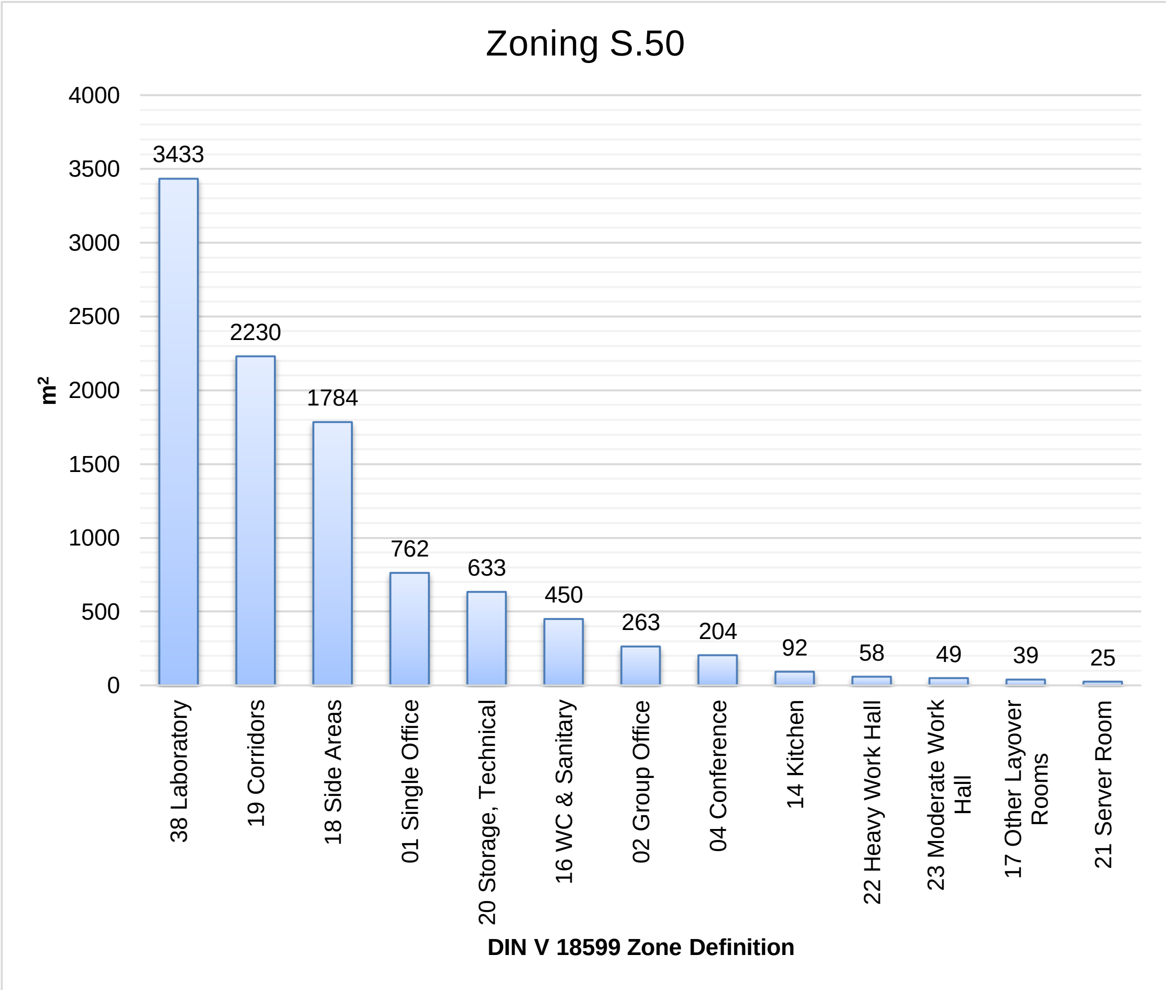


Figure 4.8: Bar graph showing the areas of the zones in S.50

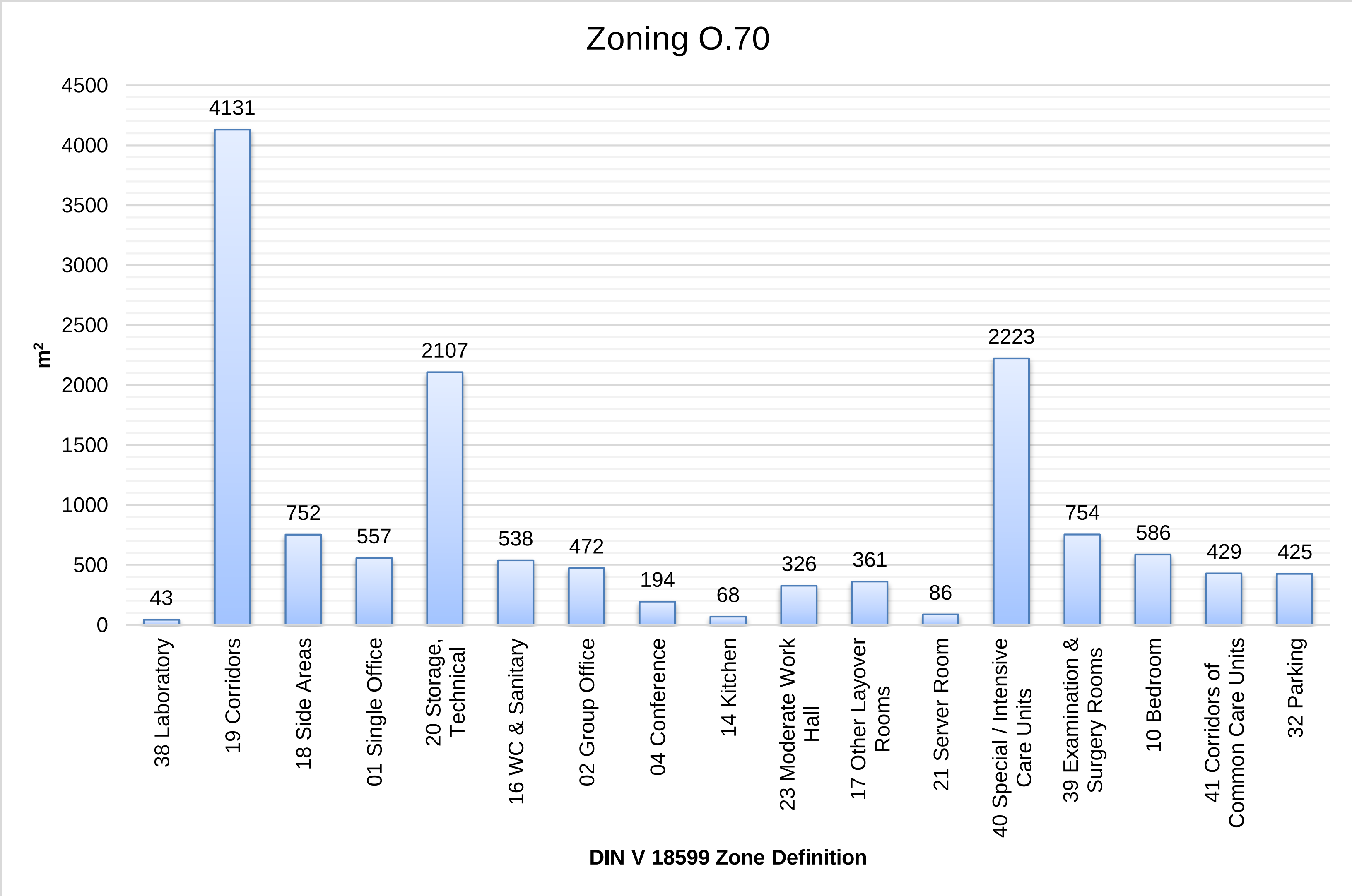


Figure 4.9: Bar graph showing the areas of the zones in O.70

4.7 Energy Performance Calculation Output & Validation

The data input into EnerCalC for each building energy performance modeling procedure can be found in 7.5.

4.7.1 O.10

EnerCalC Output		
	Energy per m² kWh/(m²M,a)	Energy per year MWh/a
Internal Heating	76,06	5533,03
Hot Water Heating	9,23	671,46
Cooling	7,20	523,55
Lighting	13,65	992,88
Ventilation	8,97	652,31
Total	115,10	8373,23

Table 4.1: O.10 EnerCalC Energy Performance Output

EnerCalC vs. Actual Data			
	EnerCalC Energy per year MWh/a	Actual Energy per year MWh/a	Accuracy
Hot Water + Internal Heating	6204,49	6022,00	103,03%
Cooling	523,55		
Lighting	992,88		
Ventilation	652,31		

Table 4.2: O.10 EnerCalC Validation

4.7.2 S.50

EnerCalC Output		
	Energy per m^2 kWh/(m^2M,a)	Energy per year MWh/a
Internal Heating	139,26	1387,02
Hot Water Heating	10,36	103,17
Cooling	7,92	78,88
Lighting	18,29	182,12
Ventilation	38,21	380,59
Total	214,00	2131,44

Table 4.3: S.50 EnerCalC Energy Performance Output

EnerCalC vs. Actual Data			
	EnerCalC Energy per year MWh/a	Actual Energy per year MWh/a	Accuracy
Hot Water + Internal Heating	1490,18	2332,00	63,90%
Cooling	78,88	156,95	50,26%
Lighting	182,12	185,42	98,22%
Ventilation	380,59	801,84	47,46%

Table 4.4: S.50 EnerCalC Validation

4.7.3 O.70

EnerCalC Output		
	Energy per m^2 kWh/(m^2M,a)	Energy per year MWh/a
Internal Heating	152,01	1972,22
Hot Water Heating	9,81	127,23
Cooling	2,24	29,07
Lighting	23,51	304,96
Ventilation	37,60	487,81
Total	225,17	2921,30

Table 4.5: O.70 EnerCalC Energy Performance Output

EnerCalC vs. Actual Data			
	EnerCalC Energy per year MWh/a	Actual Energy per year MWh/a	Accuracy
Hot Water + Internal Heating	2099,45	2569,00	81,72%
Cooling	29,07		
Lighting	304,96		
Ventilation	487,81		

Table 4.6: O.70 EnerCalC Validation

5 Discussion

5.1 Sensitivity Analysis Results

A total of forty five EnerCalC parameters are investigated in the sensitivity analysis. Seventeen of these parameters belong to the Building Envelope Area Input section of EnerCalC, found either in the "simplified" or "direct" input mode of the program (see Tables 3.1 and 3.2). Although all of these parameters feature numerical data inputs, the discrepancies in the input mode ("simplified" or "direct") of these parameters must be addressed. For the remaining parameters, the discrepancies between the numerical and drop-down list data input types for each parameter will also be discussed. This will be followed by a discussion of EnerCalC's strengths and weaknesses, the relevance of the interdependency analysis, and the implications of the results of the sensitivity analysis.

5.1.1 Direct vs. Simplified Input Mode

The "direct" building envelope input mode offers a lot more flexibility in defining the area and orientation of a building's façades than the "simplified" building envelope input mode. In the "direct" input mode, the area of each façade can be individually adjusted, for each orientation (i.e. facing north, south, east, and west). This is not the case in "simplified" mode, in which EnerCalC forces the length of the facades facing north and south, or east and west, to be equal to each other. A similar phenomenon exists for the definition of the window area; in the "direct" input mode, each window orientation (north, south, east, west) can be individually adjusted, whereas in the "simplified" mode, the parameter "Percent Window Area on Above-Ground Façade" (see Table 3.2) applies the identical percentage value to all orientations. This is the reason why the parameters in the "direct" input mode in Table 3.8 are separately listed for each orientation, whereas in the "simplified" input mode, the parameters are listed with the orientations grouped together.

What this means within the context of the results is that a parameter such as Above-Ground Facade Length (East / West), will display a greater sensitivity to changes in the input than Facade (outside, East) due to scaling discrepancies. The numerical input of the former parameter defines the length of two sides of the building's facade, whereas numerical input of the latter defines the surface area of only one face of the building's facade. So even if the building has only one floor like the reference building used for this sensitivity analysis, a 150% increase in the length of the facade facing east and west will increase the heating demand and thus the net energy value of the parameter much more than a 150% increase in the surface area of the building facade facing east only.

An approach was found very late in the research for modifying the parameters in EnerCalC's "simplified" input allowing each parameter and it's respective orientation (north, south, east, west) to be individually defined. The parameter Above-Ground Facade Length, for example, could thus be defined using four individual orientations (north, south, east, west) instead of two grouped ones (north / south, east / west). Inputting a length of 20 meters into the Above-Ground Facade Length South and 14,7 meters into the Above-Ground Facade Length West input field would lead to the corresponding Above-Ground Facade Length North and Above-Ground Facade Length East input fields to be updated with 20 and 14,7 meters as well, respectively.

In the early phases of research this automatic updating of fields was simply thought to be a feature of the "simplified" input mode, functioning on the altogether logical assumption that a building would have a quadratic shape, with parallel facades of equal length. The parameters were hence investigated in the sensitivity analysis accordingly. The late finding established, however, that modifying the value of Above-Ground Facade Length North and Above-Ground Facade Length East parameters first would not retroactively change the value of the other two, unlike in the opposite direction. This could allow for further research into the sensitivity of the parameters for each individual orientation, as opposed to grouped orientations as shown in Figure 4.1. The outstanding parameters with grouped orientations that could be investigated in this manner are Subterranean Facade Length, Above-Ground Facade Length and Percent Window Area on Above-Ground Facade Length.

The sensitivity of the parameter Above-Ground Facade Length (from the "simplified" input mode) with individually configured orientations can be inferred to be similar to changes in input of the counterpart parameter Facade, Outside (from the "direct" input mode). For example, if the Above-Ground Facade Length (South) of the reference building is increased from 20 to 30 meters (150%), and the Facade Outside (south) parameter is increased from 67 to 100,5 square meters (150%), the scale of the facades of the reference building will increase nearly identically. The reference building is configured to have a single floor with a height of 3,33 meters. An increase of facade length from 20 to 30 meters will increase the surface area of that facade from 67 to 100 square meters, which is very close to the 150% increase of the Facade Outside (south) parameter, which yields a surface area value of 100,5 square meters.

It can probably be assumed that this scaling proportionality holds for the facade lengths

/ facade surface areas of larger buildings was well, but to investigate this would confer little additional value, because at the end of the day, if a building is being modeled using EnerCalC, then the decision must be made between the "direct" or "simplified" input mode. As aforementioned, the "simplified" input mode simply offers more flexibility and was thus selected as the input mode of choice to model the energy performance of UKE buildings O.10, S.50, and O.70.

When modeling the energy performance of UKE buildings O.10, S.50, and O.70, the "simplified" input mode was actually found to have additional advantages to the "direct" input mode that were not foreseen in the sensitivity analysis. The Energieeinsparverordnung 2002 (EnEV 2002), or German energy saving regulation of 2002, requires the completion of new buildings to be supplemented with a *Wärmeschutznachweis*, or certification of thermal insulation properties of the building. These EnEV certifications are carried out by building engineers working for independent engineering consulting offices; such certifications were found in the UKE archives for buildings O.10 and O.70. The advantage of EnerCalC's "direct" input mode became obvious here, because the certifications consistently describe the buildings in terms of surface area and volume (which are features of "direct" input mode), rather than the than facade lengths. It was difficult, in fact, to find any information that could be input into EnerCalC's "simplified" input mode in these EnEV certifications. Information pertaining to EnerCalC's "simplified" input mode, i.e. facade lengths, floor heights, and so on, were more readily available in the actual building plans than in the EnEV certification.

5.1.2 Numerical vs. Drop-down List Input

As far as drop-down list input is concerned, the first point that should be made when observing Figures 4.3 and 4.4 is that just because a parameter, such as Type of Light Bulb, displays the greatest sensitivity to certain changes in input (as can be seen in Figure 4.3), it does not mean it will always behave in such a sensitive manner. It is important to note that several drop down list options exist for each parameter, and overall the parameter displays a greater sensitivity to some inputs than to others.

The main limitation of the drop-down list input parameters is that, unlike the numerical input parameters, only very discrete, homogenous choices can be made. For example, in the Type of Light Bulb parameter, only one type of light bulb can be selected. The building must thus be homogeneously equipped with light bulbs that have a similar efficiency as the type of light bulb that is input into the parameter in order for the modeling procedure to be accurate. For a building to be equipped in such a homogenous manner may not always be the case. The same issue applies for all other parameters with drop-down list inputs.

The drop-down list inputs in EnerCalC are nonetheless populated with plenty of options, so in most cases a reasonably accurate option can be found. This was also the case in this thesis when modeling the energy performance of O.10, whose window U-values were given in the EnEV certification to be around 1.60 $W/(m^2K)$. The closest option in drop-down list of the Window Glazing Type parameter had a U-value of 1.70 $W/(m^2K)$, and it was selected accordingly. It is questionable whether the magnitude of the gap between the EnerCalC drop-down list inputs and real world data is so large that it would produce significant amounts of error. In Dr.-Ing. Markus Lichtmeß Ph.D. dissertation[5], a few examples of buildings that were used to validate the function of EnerCalC are included, so it is not as though an error margin would have gone unnoticed.

5.1.3 Implications of Sensitivity Analysis Findings

Most of the numerical parameters in EnerCalC are related to input of building envelope data (surface area, volume, dimensions); these parameters are indispensable to the accurate modeling of any building. The selection of most relevant numerical parameters in Section 4.5 only holds for if the orientations of the parameters are grouped together, as in the example of parameters such as Percent Window Area on Above-Ground Facade (North / South / East / West), or Above-Ground Facade Length (East / West). But once these orientations are separated, it makes little difference whether the "direct" or "simplified" building envelope input mode is used (as discussed in Section 5.1.1). Ultimately, the same building (dimensions, surface area, volume) can be input into EnerCalC regardless of whether the "direct" or "simplified" mode is employed, as long as the building data is input correctly into each parameter. But it is preferable to define the building using the "direct" input mode since it features more inputs and is thus more flexible.

Given the ultimate lack of difference between how the building envelope is input, and given that most numerical parameters are related to building envelope input, it is the sensitivity analysis of the drop-down list parameters that merits more discussion. One of the main questions to consider when looking at Figures 4.3 and 4.4 is whether the sensitivity behavior exhibited by these parameters applies for a building that is not the reference building model defined in Section 3.3.2. It is most probably erroneous to assume that a linear relationship exists between all parameter inputs and the net energy values output by a building. Does the sensitivity of each parameter change as the building size increases? An investigation in the relationship between the scale of a building and sensitivity of parameters could be a potential direction for additional research.

That being said, certain trends can be observed in the results of the sensitivity analysis. It seems that most parameters that affect the thermal performance of a building have the highest impact on a building's energy performance. This is no surprise given that total heating (i.e. heating and hot water) routinely makes up the bulk of the energy demand, as can be seen in Figure 4.2. Five of the seven selected drop-down list input parameters - Window Glazing Type, Airtightness, Area Cooling, Thermal Bridges, and Location / Meteorology - primarily affect the thermal performance of the building. Only in some instances do other utilities affect the total net energy value of the building on such an important scale, e.g. when inefficient light bulbs are used.

5.2 Relevance of Interdependency Analysis

The interdependency analysis provided rather inconclusive results. Most parameters were found to have an average Pearson Chi Square (X^2) value close to 1. Possibly the main limitation of the interdependency analysis was the assessing interdependency by testing pairs of parameters together. It is likely that certain EnerCalC parameters are dependent on multiple other parameters, so although Figure 4.5 displays the X^2 value relationships between all pairs of parameters, it does not, for example, show how each parameter behaves when it is increased along with two (or more) other parameters, rather than only other one.

The main message that can be gleaned from the interdependency analysis is that the parameters Location / Meteorology, Floor U-Value and Type of Light Bulb, which were found to have an average X^2 value at least 40% greater than 1, to be positively dependent on the increase of other parameters. This finding is fairly supportive of the already existing selection of relevant parameters, in which Location / Meteorology and Type of Light Bulb are already present. Regarding this finding, it must be noted, however, that one outlier is enough to scale the average X^2 value in a misleading manner. This is precisely the case in the intersection between Location / Meteorology and Type of Light Bulb, which have an X^2 value of 24,75, and results in increasing the average X^2 value for both parameters. It is not entirely clear why precisely these two parameters should have such a high dependency on each other. And overall it is difficult to make any conclusive remarks about the results of the interdependency analysis, simply because most X^2 values are concentrated around 1, with the exception of a few outliers spread in both positive and negative directions.

5.3 EnerCalC: Strengths, Weaknesses, Applicability

EnerCalC currently stands as Dr.-Ing. Markus Lichtmeß interpretation and condensation of DIN V 18599 into an Excel tool. It is still in a relatively early stage of development and doesn't quite have the financial and labor-intensive backing of a commercial software solution such as ESP-r 10.1, which has been in development for twenty five years [1]. Nevertheless, the strengths of EnerCalC lies within its strong applicability to buildings in Germany, due to its compliance with DIN V 18599 (and other related DIN norms) and the inclusion of detailed climate data and climate zones for the country of Germany. Since EnerCalC can be licensed free of charge, it is particularly well suited for research in the field of building performance or energy-optimized buildings in Germany.

Certain disadvantages must be considered as well. For example, given its young age, it is not clear if EnerCalC has been used with success in other research projects or professional undertakings. And although it is based on DIN V 18599, EnerCalC essentially operates as a black box, because the source code cannot be accessed to gain an understanding of how the calculations are carried out. Furthermore, very little literature was found in which EnerCalC was either used or mentioned.

The most noteworthy functional limitations exist in the zoning capabilities of EnerCalC, in that only eleven building zones can be input, only five custom zones can be defined, and the thirty five zone definitions provided in EnerCalC by default cannot be modified. This lack of flexibility with regards to zoning is cumbersome if, for example, a user wishes to modify the usage times, lighting, climate, heat sources, and/or ventilation conditions of the zone. The unmodifiable zone utilization patterns as defined in EnerCalC are indeed faithful to the definitions given in DIN V 18599, but this does not mean that all of the rooms in buildings in Germany necessary follow these utilization conditions. It is possible that O.10, S.50, and O.70, for example, follow different usage patterns than the ones given in DIN V 18599, but there seems to be no way to input this into EnerCalC. Hence, although the energy performance calculations of EnerCalC can be considered DIN V 18599 compliant, it is important to bear in mind that reality may not always follow the definitions given in DIN V 18599.

For all these reasons, EnerCalC should probably be considered a useful tool for carrying out basic static modeling of a building's energy performance according to DIN V 18599. It is probably conceivable that more complex or detailed modeling / simulation procedures should be carried out using more established software.

5.4 Zoning

The results of the zoning procedure of O.10, S.50, and O.70 can be considered valuable for any DIN V 18599-based investigation of the energy performance of these buildings. All of the rooms in each of the buildings was matched to a certain zone definition as given in DIN V 18599. The main limitation of this procedure is that the utilization conditions of these rooms / zones were assumed to be identical to the conditions given in DIN V 18599, which may not be the case in real life. For example, in the 1 - Single Office definition in DIN V 18590, the daily utilization time is defined between 07:00 and 18:00, 250 days a year; however, it is possible for the rooms corresponding to this zone in O.10, S.50, and O.70 are utilized in different time intervals, particularly if they are within the vicinity of intensive care or post-operation rooms, which are utilized on a twenty four hour basis.

Some of the definitions given in DIN V 18599 for the zones in the healthcare / medical sector (38. Laboratory, 39. Examination and Surgery Rooms, 40. Special / Intensive Care Units) are fairly incomplete. For example, the values for the ventilation requirements are generally missing or unclear, and EnerCalC compounds this problem by condensing air conditioning requirements into very few parameters. One of the main parameters for ventilation in the EnerCalC "utilization" page is *Mindestaußenluftvolumenstrome für Gebäude (Klasse II Schadstoffarm nach DIN EN 15251)*, which essentially defines the minimum external air volume stream, but for the building, and only as a Class II pollutant free air stream. The air conditioning requirements of laboratories and especially examination and surgery rooms and special / intensive care units are significantly more demanding than that, as defined in DIN 1946-4 (Ventilation in buildings and rooms of health care). First, to maintain a sterile internal environment, the air needs to be sterile rather than pollutant-free, and second, the minimum external air volume stream cannot be defined in terms of the building only, as some sections of building have greater air intake requirements than others. These limitations in modeling ventilation requirements do not seem to extend to the heating, hot water, lighting and/or cooling requirements of zones in the healthcare / medical sector.

Overall, the zoning results provide an insight into the internal constitution of O.10, S.50, and O.70 by assigning DIN V 18599 definitions to each of the rooms found in the buildings. The number of square meters occupied by each zone is shown in Figures 4.7 through 4.9 and these results can be utilized in any other context where a DIN V 18599-based zoning procedure of these buildings is required.

5.5 Energy Performance Calculation Results

The energy performance calculations of O.10, S.50, and O.70 provided mixed results. The total heating values of the three buildings were modeled with an accuracy between 63% and 103%. The difficulty of gathering data on the other utilities led to only S.50's energy performance being fully modeled, with cooling, lighting, and ventilation being modeled with an accuracy of 50%, 98%, and 47%, respectively.
This energy performance calculation is limited in many ways. First of all, due to the eleven zone limit in EnerCalC, not all of the zones present in each building could be input, but the input of the first eleven zones usually covered at least 90% of the total net internal area of the building. Second, referencing the architectural plans of each building was done in such a way to get a generalized idea of the dimensions and surface area of the building. Not all of the details of the architectural plans were accounted for in modeling the dimensions and surface area of the building. Third, regarding the zoning procedure, the rooms in the buildings might not always comply with the zone definitions given in DIN V 18599, which may lead to a margin of error in energy performance calculation if the rooms are used differently than as is defined in DIN V 18599.

One of the main problems with the energy performance calculation is being able to obtain real-world data to validate EnerCalC's output. As can be seen in the results given in Section 4.7, few real world figures on the net energy values of O.10, S.50, and O.70 could be obtained. So although the output of EnerCalC's calculated energy performance values are shown, it was only for S.50 that the all five utility energy requirements could be validated. The modeling of cooling and ventilation requirements displays a rather poor accuracy, which indicates the need for more precise definition of these requirements in EnerCalC, particularly in the zoning "utilization" page.

5.6 Literature Review

The design and operation of buildings plays a critical role in improving their thermal performance and reducing their energy consumption. The current economic and environmental constraints on energy resources has yielded scientific literature addressing a variety of topics centered around modeling and/or simulating the energy performance of buildings. Although much of this literature is not focused on the DIN V 18599, EnerCalC, or complex hospitals per se, research on strategies for improving the energy performance of other categories of buildings can nevertheless still be considered applicable to buildings constituting a complex hospital.

5.6.1 Modeling vs. Simulation

Two key concepts must be identified and distinguished from each other before proceeding with the literature review. These two concepts are modeling vs. simulating a building's energy performance. Although both concepts involve using computers to recreate how a building utilizes energy input, key differences exist between both procedures. Modeling is a static procedure that refers to real-world physical data to recreate real-world scenarios e.g. the energy balancing behavior of a building using EnerCalC. Simulation, on the other hand, tends to be dynamic, allowing for the recreation of entire real-world building scenarios without requiring much, if any input, of real-world data. Since modeling requires collection of real-world data to a greater extent than simulation (thus limiting the validity of the results to the subject being investigated), simulation software seems to be the preferred method of researching building energy optimization methods in current scientific literature.

A good first example of the prevalence of simulation software in the research of building energy optimization is a paper by Crawley et al., in which twenty major building energy simulation programs are compared and contrasted [1]. In this paper, Crawley makes quite clear the advantages of simulation software over modeling, as it offers increased flexibility and is not dependent on the input of real-world data.

6 Conclusion

This thesis focuses on performing a statistical sensitivity and interdependency analysis of the parameters in Dr.-Ing. Markus Lichtmeß's tool EnerCalC to find the tool's most important input parameters when modeling energy performance, and, with this knowledge, to model the energy performance of UKE buildings O.10, S.50, and O.70.

The sensitivity and interdependency analyses investigated the behavior of the parameters when their inputs were changed so as to gain an understanding of which parameters affect the net energy values output by EnerCalC the most. A selection of the parameters most relevant to carrying out an energy performance calculation was made based upon the results of these analyses. Real world data about the UKE buildings O.10, S.50, and O.70 was input into these selected parameters to model the energy performance of the said buildings.

The energy performance calculations of O.10, S.50, and O.70 provided mixed results. The total heating values of the three buildings were modeled with an accuracy between 63% and 103%. The difficulty of gathering data on the other utilities led to only S.50's energy performance being fully modeled, with cooling, lighting, and ventilation being modeled with an accuracy of 50%, 98%, and 47%, respectively.

7 Appendix

7.1 EnerCalC Parameter Translation

1) Eingabe der Gebäudehüllefläche (Building Envelope Area Input)

EnerCalC Parameter (English)	EnerCalC Parameter (German)
Facade (outside), South	Fassaden (Außen), Süd
Facade (outside), West	Fassaden (Außen), West
Facade (outside), North	Fassaden (Außen), Nord
Facade (outside), East	Fassaden (Außen), Ost
Window, South	Fenster, Süd
Window, West	Fenster, West
Window, North	Fenster, Nord
Window, East	Fenster, Ost
Floor	Boden
Roof	Dach
Building Volume	Gebäudevolumen
Above-Ground Façade Length, North/-South	Fassadenlänge über Erdreich (Sud / Nord)
Above-Ground Façade Length, East-/West	Fassadenlänge über Erdreich (Ost / West)
Percent Window Area on Above-ground Façade, N/S/E/W	Anteil der Fensterfläche über Erdreich
Gross Floor Area to Gross Internal Area Ratio	Brutto-Netto-Flächenverhältnis
Above-Ground Floor Height	Geschosshöhe

Table 7.1: EnerCalC Parameter Translation

2) Eingabe gebäudebezogene Parameter (Building Parameter Input), Eingabe zonebezogene Parameter (Building Zone Input)

EnerCalC Parameter (English)	EnerCalC Parameter (German)
Location / Meteorology	Standort/Wetterdaten
Construction Weight Type	Bauschwere
Airtightness	Luftdichtheit
Thermal bridges	Wärmebrücken
Window Glazing Type, Ug	Verglasungsart, Ug
Window Frame U-Value, Uf	U-Wert Rahmen, Uf
Window Spacer Bar U-Value, Y	Rahmenverbundwert, Y
External Wall U-Value	U-Wert Außenwände
Roof U-Value (Fx=1)	U-Wert Dach (Fx=1)
Floor U-Value (Fx=0,6)	U-Wert Boden (Fx=0,6)
Double-skin Façade	Glasdoppelfassade
Shadowing (Horizon)	Verschattung Horizont
Shadowing (Vertical / Overhang)	Verschattung Uberhang
Sulight Control System	Sonnenschutz
Sunlight Control System Operation Mode	Steuerung Sonnenschutz
Glare Protection Measures	Berücksichtigung Blendschutz
Implementation of Sunlight Control and Glare Protection Measures	Ausführung Sonnen- und Blendschutz
Efficiency Standard (pressure loss, total system efficiency)	Effizienzstandard (Druckverluste, Wirkungsgrad)
Heat Recuperation of A/C Units	Wärmerückgewinnungsgrad der Anlage/n
Area Cooling	Bereich gekühlt
Window Architrave (height from ceiling)	Ø Fenstersturz (ab UK Decke), hSt in m
Window Height	Ø Fensterhöhe, hFe in m
Lighting Control System	Beleuchtungssteuerung
Motion Detection	Präsenzerfassung
Type of Lighting	Beleuchtungsart
Type of Light Bulb	Lampenart
Light Intensity Control	Konstantlichtregelung
Type of Ventilation	Art der Lüftung
Ventilation Control System	Lüftungssteuerung (Teil 100)

Table 7.2: EnerCalC Parameter Translation

7.2 Sensitivity Analysis VBA Code

7.2.1 Preambles

```
Sub Preamble_Direct_Input_Mode()

Workbooks.Open Filename:="c:\Program Files (x86)\EnerCalC\EnerCalc.xlsm"
Worksheets("Eingabe").Activate
Application.Run "EnerCalc.xlsm!Hülle_Direkte_Eingabe"

Dim counter As Integer
Dim x As Workbook
Dim y As Workbook

Set x = Workbooks("Sensitivity Analysis.xlsm")
Set y = Workbooks("EnerCalC.xlsm")

'Direct Input Mode

'outer facade areas
y.Sheets("Eingabe").Range("E24").value = "67" 'south
y.Sheets("Eingabe").Range("F24").value = "49" 'west
y.Sheets("Eingabe").Range("G24").value = "67" 'north
y.Sheets("Eingabe").Range("H24").value = "49" 'east

'window areas
y.Sheets("Eingabe").Range("E25").value = "27" 'south
y.Sheets("Eingabe").Range("F25").value = "20" 'west
y.Sheets("Eingabe").Range("G25").value = "27" 'north
y.Sheets("Eingabe").Range("H25").value = "20" 'east

'wall (against unheated / earth)
y.Sheets("Eingabe").Range("E27:H27").value = "0"

'floor & roof area
y.Sheets("Eingabe").Range("I28").value = "321" 'floor
y.Sheets("Eingabe").Range("I29").value = "321" 'roof

'building volume
y.Sheets("Eingabe").Range("I30").value = "1071"

'Zone Definition

'removal of all of EnerCalC's default zones except first one
y.Sheets("Eingabe").Range("F82:K84,F86:K86").ClearContents

'net area of first zone
y.Sheets("Eingabe").Range("E83").value = 294

'zone height
y.Sheets("Eingabe").Range("E84").value = 2.75

End Sub
```

Figure 7.1: VBA Preamble for EnerCalC's Direct Input Mode

```
Sub Preamble_Simplified_Input_Mode()

Workbooks.Open Filename:="c:\Program Files (x86)\EnerCalC\EnerCalc.xlsm"
Worksheets("Eingabe").Activate
Application.Run "EnerCalc.xlsm!Hülle_Vereinfachte_Eingabe"

Dim counter As Integer
Dim x As Workbook
Dim y As Workbook

Set x = Workbooks("Sensitivity Analysis.xlsm")
Set y = Workbooks("EnerCalC.xlsm")

'Simplified Input Mode

'subterranean facade lengths
y.Sheets("Eingabe").Range("E15:H15").value = "0"

'roof type
y.Sheets("Eingabe").[A_DAchtyp].value = "Flachdach"

'no. of subterranean floors / footprint / height
y.Sheets("Eingabe").Range("E20,G20,I20").value = "0"

'no. of above-ground heated floors
y.Sheets("Eingabe").Range("E21").value = "1"

'percent of building footprint
y.Sheets("Eingabe").Range("G21").value = "100%"

'Zone Definition

'removal of all of EnerCalC's default zones except first one
y.Sheets("Eingabe").Range("F82:K84,F86:K86").ClearContents

'net area of first zone
y.Sheets("Eingabe").Range("E83").value = 294

'zone height
y.Sheets("Eingabe").Range("E84").value = 2.75

End Sub
```

Figure 7.2: VBA Preamble for EnerCalC's Simplified Input Mode

The preambles described in Figures 7.1 and 7.2 were called upon in the subsequent data production macros to generate data for the sensitivity analysis. Each macro input a range of values into a selected building parameter and copied the data produced by EnerCalC into a separate Excel sheet.

7.2.2 Building Envelope Parameters, Direct/Simplified Mode

1) Building Envelope Area Input, Direct Mode

```
Sub DirectInput_FacadeSouth()

Application.Run "Preamble_Direct_Input_Mode"

Dim counter As Integer
Dim x As Workbook
Dim y As Workbook

Set x = Workbooks("Sensitivity Analysis.xlsm")
Set y = Workbooks("EnerCalC.xlsm")

counter = 9

Do While counter < 20

    x.Sheets("Sheet1").Cells(counter, "C").Copy

    y.Sheets("Eingabe").Range("E24").PasteSpecial xlPasteValues

    y.Sheets("Gesamtbilanz").Range("Q8,Q12,Q16,Q19,Q20").Copy

    x.Sheets("Sheet1").Cells(counter, "D").PasteSpecial xlPasteValues,
        Transpose:=True

    counter = counter + 1

    Loop

End Sub
```

Figure 7.3: VBA Data Production Macro for EnerCalC's Direct Input Mode, Facade South Parameter

```
Sub DirectInput_WindowWest()

Application.Run "Preamble_Direct_Input_Mode"

Dim counter As Integer
Dim x As Workbook
Dim y As Workbook

Set x = Workbooks("Sensitivity Analysis.xlsm")
Set y = Workbooks("EnerCalC.xlsm")

counter = 84

Do While counter < 95

    x.Sheets("Sheet1").Cells(counter, "C").Copy

    y.Sheets("Eingabe").Range("F25").PasteSpecial xlPasteValues

    y.Sheets("Gesamtbilanz").Range("Q8,Q12,Q16,Q19,Q20").Copy

    x.Sheets("Sheet1").Cells(counter, "D").PasteSpecial xlPasteValues,
        Transpose:=True

    counter = counter + 1

    Loop

End Sub
```

Figure 7.4: VBA Data Production Macro for EnerCalC's Direct Input Mode, Window West Parameter

The data production macros given in Figures 7.3 and 7.4 are examples of how data was produced for the EnerCalC parameters given under the Building Envelope Area Input, Direct Mode. The first line in the Do-While loop copied the range of 50% to 150% of the parameter's reference value into the corresponding input field in EnerCalC, defined in the second line of the Do-While loop. The net energy values output by EnerCalC for each variation of the parameter's reference value (50%, 60%, 70%, .. to 150%) was then copied into a separate worksheet.

For all of the other EnerCalC parameters given under the Building Envelope Area Input, Direct Mode, the only change made was the parameter input values copied in the first line of the Do-While loop - always corresponding to a 50% to 150% variation of the reference value, in 10% increments - and the target parameter input field in EnerCalC, defined in the second line of the Do-While loop.

2) Building Envelope Area Input, Simplified Mode

```
Sub SimplifiedInput_AboveGroundFacadeNS()

Application.Run "Preamble_Simplified_Input_Mode"

Dim counter As Integer
Dim x As Workbook
Dim y As Workbook

Set x = Workbooks("Sensitivity Analysis.xlsm")
Set y = Workbooks("EnerCalC.xlsm")

counter = 177

Do While counter < 188

    x.Sheets("Sheet1").Cells(counter, "C").Copy

    y.Sheets("Eingabe").Range("E16").PasteSpecial xlPasteValues

    y.Sheets("Gesamtbilanz").Range("Q8,Q12,Q16,Q19,Q20").Copy

    x.Sheets("Sheet1").Cells(counter, "D").PasteSpecial xlPasteValues,
        Transpose:=True

    counter = counter + 1

    Loop

End Sub
```

Figure 7.5: VBA Data Production Macro for EnerCalC's Simplified Input Mode, Above-Ground Facade North/South Parameter

```
Sub SimplifiedInput_WindowArea()

Application.Run "Preamble_Simplified_Input_Mode"

Dim counter As Integer
Dim x As Workbook
Dim y As Workbook

Set x = Workbooks("Sensitivity Analysis.xlsm")
Set y = Workbooks("EnerCalC.xlsm")


counter = 207

Do While counter < 218

    y.Sheets("Eingabe").[A_Fe_Anteil_nord].value = Range([A_Fe_Anteil_nord
        ].Validation.Formula1)((counter - 203)).value

    y.Sheets("Gesamtbilanz").Range("Q8,Q12,Q16,Q19,Q20").Copy

    x.Sheets("Sheet1").Cells(counter, "D").PasteSpecial xlPasteValues,
        Transpose:=True

    counter = counter + 1

    Loop

End Sub
```

Figure 7.6: VBA Data Production Macro for EnerCalC's Simplified Input Mode, Percent Window Area N/S/E/W Parameter

The macros given in Figures 7.5 and 7.6 produce sensitivity analysis data for two of the building envelope input parameters given in EnerCalC's simplified input mode. Figures 7.3 through 7.5 all featured numerical input types, Figure 7.6, however, is the first example of how data was input from a drop-down list (the drop-down list in this case being the list of options for percent window area of the above-ground facade).

7.2.3 Remaining Parameters

```
Sub Parameter_Meteorology()

Application.Run "Preamble_Simplified_Input_Mode"

Dim counter As Integer
Dim x As Workbook
Dim y As Workbook

Set x = Workbooks("Sensitivity Analysis.xlsm")
Set y = Workbooks("EnerCalC.xlsm")

counter = 258

Do While counter < 275

    y.Sheets("Eingabe").[G_Wahl_Klima].value = Range([G_Wahl_Klima].
        Validation.Formula1)((counter - 257)).value

    y.Sheets("Gesamtbilanz").Range("Q8,Q12,Q16,Q19,Q20").Copy

    x.Sheets("Sheet1").Cells(counter, "D").PasteSpecial xlPasteValues,
        Transpose:=True

    counter = counter + 1

    Loop

End Sub
```

Figure 7.7: VBA Data Production Macro for EnerCalC's Meteorology Parameter

```
Sub Parameter_WindowFrameUValue()

Application.Run "Preamble_Simplified_Input_Mode"

Dim counter As Integer
Dim x As Workbook
Dim y As Workbook

Set x = Workbooks("Sensitivity Analysis.xlsm")
Set y = Workbooks("EnerCalC.xlsm")

counter = 330

Do While counter < 341

    x.Sheets("Sheet1").Cells(counter, "C").Copy

    y.Sheets("Eingabe").Range("E56").PasteSpecial xlPasteValues

    y.Sheets("Gesamtbilanz").Range("Q8,Q12,Q16,Q19,Q20").Copy

    x.Sheets("Sheet1").Cells(counter, "D").PasteSpecial xlPasteValues,
        Transpose:=True

    counter = counter + 1

    Loop

End Sub
```

Figure 7.8: VBA Data Production Macro for EnerCalC's Window Frame U-Value Parameter

Figures 7.7 and 7.8 are examples of the macros used to produce data for the remaining parameters in EnerCalC, meaning all of the parameters selected for the sensitivity analysis found in EnerCalC's Building Parameter Input and Zone Parameter Input sections. Figure 7.7 is an example of a data production macro for a parameter with a drop-down list input type (meteorology), and Figure 7.8 is an example for a parameter with a numerical input type.

For these remaining parameters, only the Simplified Input Preamble was run to define the building envelope area. This was done for the sake of consistency; running the Direct Input Preamble for each macro would impact the data output by EnerCalC, since both preambles were configured to define precisely the same reference building.

7.3 Interdependency Analysis VBA Code

```
Sub InterdependenceE1MaxE2Max()

Application.Run "Preamble_Direct_Input_Mode"

Dim counter As Integer
Dim x As Workbook
Dim y As Workbook

Set x = Workbooks("Sensitivity Analysis.xlsm")
Set y = Workbooks("EnerCalC.xlsm")


Dim ParameterArray(33) As String

'Fassadenlänge über Erdreich (Sud / Nord)
ParameterArray(0) = "E16"

'Fassadenlänge über Erdreich (Ost / West)
ParameterArray(1) = "F16"

'Anteil der Fensterfläche über Erdreich
ParameterArray(2) = "E17"

'Brutto-Netto-Flächenverhältnis
ParameterArray(3) = "E19"

'Geschosshohe
ParameterArray(4) = "I21"

'Standort/Wetterdaten
ParameterArray(5) = "E48"

'Bauschwere
ParameterArray(6) = "E49"

'Luftdichtheit
ParameterArray(7) = "E50"

'Warmebrucken
ParameterArray(8) = "E51"

'Verglasungsart, Ug
ParameterArray(9) = "E54"

'U-Wert Rahmen, Uf
```

```
ParameterArray(10) = "E56"

'Rahmenverbundwert , y
ParameterArray(11) = "E57"

'U-Wert Außenwände
ParameterArray(12) = "E59"

'U-Wert Dach (Fx=1)
ParameterArray(13) = "E60"

'U-Wert Boden (Fx=0,6)
ParameterArray(14) = "E61"

'Glasdoppelfassade
ParameterArray(15) = "E64"

'Verschattung Horizont
ParameterArray(16) = "E65"

'Verschattung Uberhang
ParameterArray(17) = "E66"

'Sonnenschutz
ParameterArray(18) = "E67"

'Steuerung Sonnenschutz
ParameterArray(19) = "E69"

'Berücksichtigung Blendschutz
ParameterArray(20) = "E70"

'Ausführung Sonnen- und Blendschutz
ParameterArray(21) = "E71"

'Effizienzstandard (Druckverluste, Wirkungsgrad)
ParameterArray(22) = "E74"

'Wärmerückgewinnungsgrad der Anlage/n
ParameterArray(23) = "E75"

'Bereich gekühlt
ParameterArray(24) = "E86"

'Ø Fenstersturz (ab UK Decke), hSt in m
ParameterArray(25) = "E96"
```

```
'∅ Fensterhöhe, hFe in m
ParameterArray(26) = "E97"

'Beleuchtungssteuerung
ParameterArray(27) = "E99"

'Präsenzerfassung
ParameterArray(28) = "E100"

'Beleuchtungsart
ParameterArray(29) = "E101"

'Lampenart
ParameterArray(30) = "E102"

'Konstantlichtregelung
ParameterArray(31) = "E103"

'Art der Lüftung
ParameterArray(32) = "E106"

'Lüftungssteuerung (Teil 100)
ParameterArray(33) = "E107"


Dim VariableArrayRef(33) As String

'Fassadenlänge über Erdreich (Sud / Nord)
VariableArrayRef(0) = x.Sheets("Sheet4").Range("B4").value

'Fassadenlänge über Erdreich (Ost / West)
VariableArrayRef(1) = x.Sheets("Sheet4").Range("B5").value

'Anteil der Fensterfläche über Erdreich
VariableArrayRef(2) = Range([A_Fe_Anteil_süd].Validation.Formula1)
(x.Sheets("Sheet4").Cells(6, "E")).value

'Brutto -Netto - Flächenverhältnis
VariableArrayRef(3) = x.Sheets("Sheet4").Range("B7").value

'Geschosshohe
VariableArrayRef(4) = x.Sheets("Sheet4").Range("B8").value

'Standort/Wetterdaten
VariableArrayRef(5) = Range([G_Wahl_Klima].Validation.Formula1)
(x.Sheets("Sheet4").Cells(9, "E")).value
```

```
'Bauschwere
VariableArrayRef(6) = Range([G_Bauschwere].Validation.Formula1)
(x.Sheets("Sheet4").Cells(10, "E")).value

'Luftdichtheit
VariableArrayRef(7) = Range([G_Luftdichtheit].Validation.Formula1)
(x.Sheets("Sheet4").Cells(11, "E")).value

'Warmebrucken
VariableArrayRef(8) = Range([G_Wärmebrücken].Validation.Formula1)
(x.Sheets("Sheet4").Cells(12, "E")).value

'Verglasungsart , Ug
VariableArrayRef(9) = Range([G_glas_süd].Validation.Formula1)
(x.Sheets("Sheet4").Cells(13, "E")).value

'U-Wert Rahmen, Uf
VariableArrayRef(10) = x.Sheets("Sheet4").Range("B14").value

'Rahmenverbundwert, y
VariableArrayRef(11) = x.Sheets("Sheet4").Range("B15").value

'U-Wert Außenwände
VariableArrayRef(12) = x.Sheets("Sheet4").Range("B16").value

'U-Wert Dach (Fx=1)
VariableArrayRef(13) = x.Sheets("Sheet4").Range("B17").value

'U-Wert Boden (Fx=0,6)
VariableArrayRef(14) = x.Sheets("Sheet4").Range("B18").value

'Glasdoppelfassade
VariableArrayRef(15) = Range([G_GDF_süd].Validation.Formula1)
(x.Sheets("Sheet4").Cells(19, "E")).value

'Verschattung Horizont
VariableArrayRef(16) = Range([G_shade_hor_süd].Validation.Formula1)
(x.Sheets("Sheet4").Cells(20, "E")).value

'Verschattung Uberhang
VariableArrayRef(17) = Range([G_shade_überhang_süd].Validation.Formula1)
(x.Sheets("Sheet4").Cells(21, "E")).value

'Sonnenschutz
VariableArrayRef(18) = Range([G_SS_süd].Validation.Formula1)
(x.Sheets("Sheet4").Cells(22, "E")).value
```

```
'Steuerung Sonnenschutz
VariableArrayRef(19) = Range([G_Steuerung_SS].Validation.Formula1)
(x.Sheets("Sheet4").Cells(23, "E")).value

'Berücksichtigung Blendschutz
VariableArrayRef(20) = Range([G_Steuerung_Blendschutz].Validation.Formula1)
(x.Sheets("Sheet4").Cells(24, "E")).value

'Ausführung Sonnen- und Blendschutz
VariableArrayRef(21) = Range([G_Ausführung_Blendschutz].Validation.Formula1)
(x.Sheets("Sheet4").Cells(25, "E")).value

'Effizienzstandard (Druckverluste, Wirkungsgrad)
VariableArrayRef(22) = Range([G_Effizienz_Lüftung].Validation.Formula1)
(x.Sheets("Sheet4").Cells(26, "E")).value

'Wärmerückgewinnungsgrad der Anlage/n
VariableArrayRef(23) = x.Sheets("Sheet4").Range("B27").value

'Bereich gekühlt
VariableArrayRef(24) = Range([Z_cool_1].Validation.Formula1)
(x.Sheets("Sheet4").Cells(28, "E")).value

'Ø Fenstersturz (ab UK Decke), hSt in m
VariableArrayRef(25) = x.Sheets("Sheet4").Range("B29").value

'Ø Fensterhöhe, hFe in m
VariableArrayRef(26) = x.Sheets("Sheet4").Range("B30").value

'Beleuchtungssteuerung
VariableArrayRef(27) = Range([Z_Bel_Steuerung_1].Validation.Formula1)
(x.Sheets("Sheet4").Cells(31, "E")).value

'Präsenzerfassung
VariableArrayRef(28) = Range([Z_Präsenz_1].Validation.Formula1)
(x.Sheets("Sheet4").Cells(32, "E")).value

'Beleuchtungsart
VariableArrayRef(29) = Range([Z_Bel_Art_1].Validation.Formula1)
(x.Sheets("Sheet4").Cells(33, "E")).value

'Lampenart
VariableArrayRef(30) = Range([Z_Bel_Typ_1].Validation.Formula1)
(x.Sheets("Sheet4").Cells(34, "E")).value

'Konstantlichtregelung
VariableArrayRef(31) = Range([A_Bel_Konstlicht_1].Validation.Formula1)
```

```
(x.Sheets("Sheet4").Cells(35, "E")).value

'Art der Lüftung
VariableArrayRef(32) = Range([Z_Lüft_1].Validation.Formula1)
(x.Sheets("Sheet4").Cells(36, "E")).value

'Lüftungssteuerung (Teil 100)
VariableArrayRef(33) = Range([Z_Lüft_Regel_1].Validation.Formula1)
(x.Sheets("Sheet4").Cells(36, "E")).value


Dim VariableArrayMax(33) As String

'Fassadenlänge über Erdreich (Sud / Nord)
VariableArrayMax(0) = x.Sheets("Sheet4").Range("C4").value

'Fassadenlänge über Erdreich (Ost / West)
VariableArrayMax(1) = x.Sheets("Sheet4").Range("C5").value

'Anteil der Fensterfläche über Erdreich
VariableArrayMax(2) = Range([A_Fe_Anteil_süd].Validation.Formula1)
(x.Sheets("Sheet4").Cells(6, "G")).value

'Brutto -Netto - Flächenverhältnis
VariableArrayMax(3) = x.Sheets("Sheet4").Range("C7").value

'Geschosshohe
VariableArrayMax(4) = x.Sheets("Sheet4").Range("C8").value

'Standort/Wetterdaten
VariableArrayMax(5) = Range([G_Wahl_Klima].Validation.Formula1)
(x.Sheets("Sheet4").Cells(9, "G")).value

'Bauschwere
VariableArrayMax(6) = Range([G_Bauschwere].Validation.Formula1)
(x.Sheets("Sheet4").Cells(10, "G")).value

'Luftdichtheit
VariableArrayMax(7) = Range([G_Luftdichtheit].Validation.Formula1)
(x.Sheets("Sheet4").Cells(11, "G")).value

'Warmebrucken
VariableArrayMax(8) = Range([G_Luftdichtheit].Validation.Formula1)
(x.Sheets("Sheet4").Cells(12, "G")).value

'Verglasungsart , Ug
VariableArrayMax(9) = Range([G_glas_süd].Validation.Formula1)
```

```
(x.Sheets("Sheet4").Cells(13, "G")).value

'U-Wert Rahmen, Uf
VariableArrayMax(10) = x.Sheets("Sheet4").Range("C14").value

'Rahmenverbundwert, y
VariableArrayMax(11) = x.Sheets("Sheet4").Range("C15").value

'U-Wert Außenwände
VariableArrayMax(12) = x.Sheets("Sheet4").Range("C16").value

'U-Wert Dach (Fx=1)
VariableArrayMax(13) = x.Sheets("Sheet4").Range("C17").value

'U-Wert Boden (Fx=0,6)
VariableArrayMax(14) = x.Sheets("Sheet4").Range("C18").value

'Glasdoppelfassade
VariableArrayMax(15) = Range([G_GDF_süd].Validation.Formula1)
(x.Sheets("Sheet4").Cells(19, "G")).value

'Verschattung Horizont
VariableArrayMax(16) = Range([G_shade_hor_süd].Validation.Formula1)
(x.Sheets("Sheet4").Cells(20, "G")).value

'Verschattung Uberhang
VariableArrayMax(17) = Range([G_shade_überhang_süd].Validation.Formula1)
(x.Sheets("Sheet4").Cells(21, "G")).value

'Sonnenschutz
VariableArrayMax(18) = Range([G_SS_süd].Validation.Formula1)
(x.Sheets("Sheet4").Cells(22, "G")).value

'Steuerung Sonnenschutz
VariableArrayMax(19) = Range([G_Steuerung_SS].Validation.Formula1)
(x.Sheets("Sheet4").Cells(23, "G")).value

'Berücksichtigung Blendschutz
VariableArrayMax(20) = Range([G_Steuerung_Blendschutz].Validation.Formula1)
(x.Sheets("Sheet4").Cells(24, "G")).value

'Ausführung Sonnen- und Blendschutz
VariableArrayMax(21) = Range([G_Ausführung_Blendschutz].Validation.Formula1)
(x.Sheets("Sheet4").Cells(25, "G")).value

'Effizienzstandard (Druckverluste, Wirkungsgrad)
VariableArrayMax(22) = Range([G_Effizienz_Lüftung].Validation.Formula1)
```

```
(x.Sheets("Sheet4").Cells(26, "G")).value

'Wärmerückgewinnungsgrad der Anlage/n
VariableArrayMax(23) = x.Sheets("Sheet4").Range("C27").value

'Bereich gekühlt
VariableArrayMax(24) = Range([Z_cool_1].Validation.Formula1)
(x.Sheets("Sheet4").Cells(28, "G")).value

'∅ Fenstersturz (ab UK Decke), hSt in m
VariableArrayMax(25) = x.Sheets("Sheet4").Range("C29").value

'∅ Fensterhöhe, hFe in m
VariableArrayMax(26) = x.Sheets("Sheet4").Range("C30").value

'Beleuchtungssteuerung
VariableArrayMax(27) = Range([Z_Bel_Steuerung_1].Validation.Formula1)
(x.Sheets("Sheet4").Cells(31, "G")).value

'Präsenzerfassung
VariableArrayMax(28) = Range([Z_Präsenz_1].Validation.Formula1)
(x.Sheets("Sheet4").Cells(32, "G")).value

'Beleuchtungsart
VariableArrayMax(29) = Range([Z_Bel_Art_1].Validation.Formula1)
(x.Sheets("Sheet4").Cells(33, "G")).value

'Lampenart
VariableArrayMax(30) = Range([Z_Bel_Typ_1].Validation.Formula1)
(x.Sheets("Sheet4").Cells(34, "G")).value

'Konstantlichtregelung
VariableArrayMax(31) = Range([A_Bel_Konstlicht_1].Validation.Formula1)
(x.Sheets("Sheet4").Cells(35, "G")).value

'Art der Lüftung
VariableArrayMax(32) = Range([Z_Lüft_1].Validation.Formula1)
(x.Sheets("Sheet4").Cells(36, "G")).value

'Lüftungssteuerung (Teil 100)
VariableArrayMax(33) = Range([Z_Lüft_Regel_1].Validation.Formula1)
(x.Sheets("Sheet4").Cells(37, "G")).value
```

```
Dim q As String

For i = 0 To 33

y.Sheets("Eingabe").Range(ParameterArray(i)) = VariableArrayMax(i)

    For j = i + 1 To 33

    y.Sheets("Eingabe").Range(ParameterArray(j)) = VariableArrayMax(j)

    q = Application.Sum(y.Sheets("Gesamtbilanz").Range("Q8,Q12,Q16,Q19,Q20"))

    x.Sheets("Sheet4").Cells(j + 4, i + 9).value = q

    y.Sheets("Eingabe").Range(ParameterArray(j)) = VariableArrayRef(j)

    Next j

y.Sheets("Eingabe").Range(ParameterArray(i)) = VariableArrayRef(i)

Next i

End Sub
```

Three arrays are defined above. The first, VariableArrayRef, contains all of the inputs (either numerical or drop-down list entries) necessary for each of the parameters analyzed in the sensitivity analysis to produce their respective reference values. The second, VariableArrayMax, contains all of the numerical / drop-down list entries necessary for each parameter to yield its maximum values. The “input” or third array, ParameterArray, defines the location of all of the parameter inputs in EnerCalC.

By cycling either the reference (VariableArrayRef) or maximum (VariableArrayMax) parameter value arrays through the “input” array (ParameterArray) using a nested loop, four 34 x 34 matrices are generated. The matrices correspond to the values output when both arrays are at their reference values (E1refE2ref), one at maximum and one at reference (E1maxE2ref / E1refE2max), and both arrays set at maximum values (E1maxE2max). The above example shows the nested loop code necessary to produce E1maxE2max.

7.4 Custom Zones in EnerCalC

			38 Laboratory	39 Examina	40 Special	41 Corridor	42 Doctors
Nutzungs- und Betriebszeiten	**Einheit**	**Symbol**					
Nutzung Begin	[Uhr]	-	7:00	7:00	0:00	0:00	8:00
Nutzung Ende	[Uhr]	-	18:00	18:00	24:00	24:00	18:00
tägliche Nutzungsstunden	[h/d]	$t_{nutz,d}$	11	11	24	24	10
jährliche Nutzungstage	[d/a]	$d_{nutz,a}$	250	250	365	365	250
jährliche Nutzungsstunden zur Tagzeit	[h/a]	t_{Tag}	2543	2543	4407	4407	2346
jährliche Nutzungsstunden zur Nachtzeit	[h/a]	t_{Nacht}	207	207	4353	4353	154
tägliche Betriebsstunden RLT und Kühlung	[h/d]	$t_{v,op,d}$	24	13	24	24	12
jährliche Betriebstage RLT, Kühlung und Heizung	[d/a]	$t_{RLT\text{-}Betrieb}$=d	250	250	365	365	250
tägliche Betriebsstunden Heizung	[h/d]	$t_{h,op,d}$	13	13	24	24	12
Beleuchtung							
Wartungswert der Beleuchtungsstärke	[lx]	E_m	500	500	300	125	500
Höhe der Nutzebene	[m]	h_{Ne}	1,00	0,80	0,80	0,20	0,80
Minderungsfaktor Bereich Sehaufgabe	[-]	k_A	0,92	1,00	1,00	1,00	1,00
relative Abwesenheit	[-]	C_A	0,30	0,00	0,00	0,80	0,00
Raumindex	[-]	k	1,25	1,20	1,20	1,00	1,20
Teilbetriebsfaktor der Gebäudebetriebszeit für Beleuchtung	[-]	F_t	1,00	1,00	0,80	1,00	1,00
Wartungsfaktor Beleuchtung nach 18599 (pauschal)	[-]	WF	0,67	0,67	0,67	0,67	0,67
Wartungsfaktor für Beleuchtung nach EnEV 2009	[-]	WF	0,80	0,80	0,80	0,80	0,80
Anpassung Strombedarf Tabellenverfahren nach EnEV 2009	[-]	WF-Fak	0,84	0,84	0,84	0,84	0,84
Konstantlichtregelung nach EnEV 2009	[-]	Kon-Fak	0,90	0,90	0,90	0,90	0,90
Raumklima							
Feuchteanforderung	[Typ]	-	-	-	-	-	-
Mindestaußenluftvolumenstrom	[m³/(h m²)]	V'_A	25,0	30,0	30,0	25,0	25,0
Mindestaußenluftvolumenstrom - reduz. Betrieb	[m³/(h m²)]	V'_A	0	0	0	0	0
Wärmequellen (negative Werte => Senken)							
Personen - mittel	[Wh/(m²d)]	$q_{I,p}$	36	84	144	-	72
Arbeitshilfen - mittel	[Wh/(m²d)]	$q_{I,fac}$	108	35	228	-	25
Personen - hoch	[Wh/(m²d)]	$q_{I,p}$	54	105	192	-	90
Arbeitshilfen - hoch	[Wh/(m²d)]	$q_{I,fac}$	378	50	312	-	35
Personen - Absenkbetrieb	[Wh/(m²d)]	$q_{I,p}$	0	0	0	0	0
Arbeitshilfen - Absenkbetrieb	[Wh/(m²d)]	$q_{I,fac}$	0	0	0	0	0
Raumlufttemperatur							
Raum-Solltemperatur Heizung	[°C]	$\vartheta_{i,h,soll}$	22	22	22	20	22
Temperaturabsenkung reduzierter Betrieb	[K]	$\Delta\theta_{i,NA}$	4	4	4	4	4
Raum-Solltemperatur Kühlung	[°C]	$\vartheta_{i,c,soll}$	24	24	24	24	24
Minimaltemperatur Auslegung Heizung	[°C]	$\vartheta_{i,h,min}$	20	20	20	20	20
Maximaltemperatur Auslegung Kühlung	[°C]	$\vartheta_{i,c,max}$	26	24	24	26	26

Figure 7.9: EnerCalC Custom Zone Definitions (1/2)

			38 Laboratory	39 Examina	40 Special	41 Corridor	42 Doctors
weitere Randbedingungen							
Tagesmittel Außentemperatur Auslegungstag Heizung	[°C]	$\vartheta_{e,min}$	-12	-12	-12	-12	-12
Tagesmittel Außentemperatur Auslegungstag Juli Kühlung	[°C]	$\vartheta_{e,max,Jul}$	24,6	24,6	24,6	24,6	24,6
Tagesmittel Außentemperatur Auslegungstag September Kühlung	[°C]	$\vartheta_{e,max,Sep}$	18,9	18,9	18,9	18,9	18,9
Abminderungsfaktor infolge von Verschmutzung	[-]	F_V	1,0	1,0	1,0	1,0	1,0
Verschmutzungsfaktor	[-]	k_2	1,0	1,0	1,0	1,0	1,0
Zuordnung Kennwert-Tabelle Kälteerzeugung							
Nummer der Kennwerte-Tabelle gem. DIN 18599 - Teil 7	[Typ]	-					
Trinkwarmwasser Nichtwohngebäude (siehe Tabelle 6)							
Anzahl der Spitzenzapfungen am Tag	[-]	n_{Sp}					
spezifische Raumgeometrien (aus Teilkennwertemethode)							
typische Raumhöhe	[m]	h_R	3,0	3,0	3,0	3,0	3,0
typische Raumbreite	[m]	b_R	6,0	6,0	6,0	6,0	12,0
typische Raumtiefe	[m]	a_R	6,0	6,0	6,0	6,0	12,0
Bodenfläche	[m²]	$A_{n,R}$	36	36	36	36	144
Volumen	[m³]	$V_{n,R}$	108	108	108	108	432
Anordnungstyp im Gebäude	-	F_{Type}					
Daten für Schnittsltelle - Energiebenchmark IWU							
Wandfläche je Zonenfläche	[m²/m²]	A_{wa}	0,34313725	0,343137	0,343137	0,343137	0,343137
Fensterfläche je Zonenfläche	[m²/m²]	A_{fe}	0,24509804	0,245098	0,245098	0,245098	0,245098
Dachfläche je Zonenfläche	[m²/m²]	A_{da}	0,22166667	0,221667	0,221667	0,221667	0,221667
Bodenfläche je Zonenfläche	[m²/m²]	A_{fb}	0,22166667	0,221667	0,221667	0,221667	0,221667
Bilanztemperatur Heizen	[°C]	$\vartheta_{i,h,soll}$	21	22	22	21	20
Bedarfsgesteuerte Lüftung							
Mindestaußenluftvolumenstrome für Gebäude (Klasse II Schadstoffarm nach DIN EN 15251)	[m³/(h m²)]	$V_{A,Geb}$	25,0	40,0	40,0	25,0	2,5
Relative Abwsenheit RLT	[-]	C_{RTL}		0,3			0,3
Teilbetriebsfaktor der Gebäudebetriebszeit RLT	[-]	F_{RTL}		0,7			0,7
Manuelle und zeitabhängige Steuerung	[m³/(h m²)]	$V_{d,c}$	25,0	30,0	30,0	25,0	25,0
Präsenzmelder (integriert in der Lüftungsautomation)	[m³/(h m²)]	$V_{d,c}$	25,0	33,0	40,0	25,0	18,3
Personenzähler (integriert in der Lüftungsautomation)	[m³/(h m²)]	$V_{d,c}$	25,0	35,1	40,0	25,0	13,5
Gassensoren (CO2, VOC, Mischgas)	[m³/(h m²)]	$V_{d,c}$	25,0	35,1	40,0	25,0	13,5

Figure 7.10: EnerCalC Custom Zone Definitions (2/2)

7.5 EnerCalC input tables

7.5.1 O.10

Building Parameter Input		
Building Envelope		
Facade (outside), North	10419	m^2
Facade (outside), South	10449	m^2
Facade (outside), East	8687	m^2
Facade (outside), West	8687	m^2
Window, North	5200	m^2
Window, South	5200	m^2
Window, East	4350	m^2
Window, West	4350	m^2
Floor	16458	m^2
Roof	16458	m^2
Building Volume	277400	m^3
Other Selected Parameters		
Type of Light Bulb	LSL stab EVG	
Window Glazing Type	WSV2:U= 1,7	
Airtightness	mit Dichtheitstest und raumlufttechnischer Anlage	
Area Cooling	(unknown)	
Thermal Bridges	pauschal - gering (DIN 4108 Beiblatt 2)	
Type of Lighting	direkt/indirekt	
Location / Meteorology	Region 2, Hamburg	

Table 7.3: O.10, EnerCalC Building Parameter Input Values

Zoning		
19 Corridors	26074	m^2
10 Bedroom	9113	m^2
20 Storage, Technical	8267	m^2
01 Single Office	6871	m^2
18 Side Areas	5855	m^2
39 Examination & Surgery Rooms	5372	m^2
16 WC & Sanitary	2462	m^2
02 Group Office	2333	m^2
17 Other Layover Rooms	2327	m^2
23 Moderate Work Hall	2268	m^2
04 Conference	1804	m^2
Sum of Area of First 11 Zones	72747	m^2
Total Gross Internal Area	76215	m^2
Percent Coverage	95,45%	

Table 7.4: O.10, EnerCalC Zoning Input Values

7.5.2 S.50

Building Parameter Input		
Building Envelope		
Facade (outside), North	1164	m^2
Facade (outside), South	1164	m^2
Facade (outside), East	792	m^2
Facade (outside), West	792	m^2
Window, North	466	m^2
Window, South	466	m^2
Window, East	317	m^2
Window, West	317	m^2
Floor	2488	m^2
Roof	2488	m^2
Building Volume	38320	m^3
Other Selected Parameters		
Type of Light Bulb	LSL stab EVG	
Window Glazing Type	WSV2:U= 1,7	
Airtightness	mit Dichtheitstest und raumlufttechnischer Anlage	
Area Cooling	(unknown)	
Thermal Bridges	pauschal - gering (DIN 4108 Beiblatt 2)	
Type of Lighting	direkt/indirekt	
Location / Meteorology	Region 2, Hamburg	

Table 7.5: S.50, EnerCalC Building Parameter Input Values

Zoning Input		
38 Laboratory	3433	m^2
19 Corridors	2230	m^2
18 Side Areas	1784	m^2
01 Single Office	762	m^2
20 Storage, Technical	633	m^2
16 WC & Sanitary	450	m^2
02 Group Office	263	m^2
04 Conference	204	m^2
14 Kitchen	92	m^2
22 Heavy Work Hall	58	m^2
23 Moderate Work Hall	49	m^2
Sum of Area of First 11 Zones	9960	m^2
Total Gross Internal Area	10023	m^2
Percent Coverage	99,37%	

Table 7.6: S.50, EnerCalC Zoning Input Values

7.5.3 O.70

Building Parameter Input		
Building Envelope		
Facade (outside), North	1577	m^2
Facade (outside), South	1200	m^2
Facade (outside), East	541	m^2
Facade (outside), West	541	m^2
Window, North	631	m^2
Window, South	480	m^2
Window, East	216	m^2
Window, West	216	m^2
Floor	2819	m^2
Roof	2819	m^2
Building Volume	34338	m^3
Other Selected Parameters		
Type of Light Bulb	LSL stab EVG	
Window Glazing Type	WSV2:U= 1,7	
Airtightness	mit Dichtheitstest und raumlufttechnischer Anlage	
Area Cooling	(unknown)	
Thermal Bridges	pauschal - gering (DIN 4108 Beiblatt 2)	
Type of Lighting	direkt/indirekt	
Location / Meteorology	Region 2, Hamburg	

Table 7.7: O.70, EnerCalC Building Parameter Input Values

Zoning		
19 Corridors	4131	m^2
40 Special / Intensive Care Units	2223	m^2
20 Storage, Technical	2107	m^2
39 Examination & Surgery Rooms	754	m^2
18 Side Areas	752	m^2
10 Bedroom	586	m^2
01 Single Office	557	m^2
16 WC & Sanitary	538	m^2
02 Group Office	472	m^2
41 Corridors of Common Care Units	429	m^2
32 Parking	425	m^2
Sum of Area of First 11 Zones	12974	m^2
Total Gross Internal Area	14051	m^2
Percent Coverage	92,33%	m^2

Table 7.8: O.70, EnerCalC Zoning Input Values

Bibliography

[1] Drury B. Crawley et al. "Contrasting the capabilities of building energy performance simulation programs". In: *Building and Environment* 43.4 (2008). Part Special: Building Performance Simulation, pp. 661 –673. ISSN: 0360-1323. DOI: http://dx.doi.org/10.1016/j.buildenv.2006.10.027. URL: http://www.sciencedirect.com/science/article/pii/S0360132306003234.

[2] ENOB Research for Energy Optimized Building. *EnerCalC – Simplified energy balancing to DIN V 18599*. 2014. URL: http://www.enob.info/en/software-and-tools/projects/details/enercalc-simplified-energy-balancing-to-din-v-18599/.

[3] Beuth Verlag GmbH. *VORNORM DIN V 18599-1 Berichtigung 1:2013-05*. 2014. URL: http://www.beuth.de/de/vornorm/din-v-18599-1-berichtigung-1/179953082.

[4] Beuth Verlag GmbH. *VORNORM DIN V 18599-1:2011-12*. 2014. URL: http://www.beuth.de/de/vornorm/din-v-18599-1/142650957.

[5] Dr.-Ing. Markus Lichtmeß. "Vereinfachungen für die energetische Bewertung von Gebäuden". PhD thesis. Bergische Universität Wuppertal, Germany, 2014.

[6] European Parliament and Council of the European Union. "Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002". In: *Official Journal of the European Communities* (2003). URL: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:001:0065:0065:EN:PDF.

[7] Sonja Puhl. *University Medical Center Hamburg-Eppendorf Home Page*. 2014. URL: http://www.uke.de/index_ENG.php.

[8] Hamburg University of Technology. *Minimierung der Klimagasemissionen bei der Energieversorgung komplexer Krankenhäuser*. 2014. URL: http://www.tuhh.de/iue/projekte/krankenhaeuser.html.