Towards zero energy hospital buildings: a polyclinic building as case study.

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Abstract. The need for (nearly) Zero Energy Buildings (nZEBs) becomes increasingly important due to climate change and increasing energy prices. Considering that, on average the existing hospitals use 3.5 times more energy than the nZEB requirement, reaching zero energy a very challenging task. However, monitoring hospitals' energy flows together with a holistic view on building functions and occupancy can contribute to achieving potential energy savings, which is lacking in the current hospital buildings.

Therefore, in this study, the energy saving potentials of a polyclinic building of a hospital in the Netherlands was investigated through a holistic inspection of the building and its occupancy. The analysis is performed in order to investigate the building characteristics, energy supply and demand. It was found that the number of people present was considerably lower than the full capacity, with 30% average occupancy in the medical facilities and 70% for the administrative areas. The air supply of the current ventilation system was found to be constant irrespective of the number of people present in these rooms. Furthermore, a discrepancy of 30-50% was found between designed and installed lighting systems. The analysis of the polyclinic showed possible energy-saving measures with controlled ventilation rates and lighting according to the occupancy.

1 Introduction

In the developed countries the building sector is currently one of the major energy consumers, with consumption between 20% and 40% of total Primary Energy (PE). For example, in 2010 the Dutch built environment consumed up to 41% of the entire energy consumption of the Netherlands [1]. For these reasons, in May 2010, the EU has launched the Energy Performance of Buildings Directive (EPBD)[2]. It is a directive which presents targets for nearly Zero Energy Buildings (nZEB) regulation and implementation of legislation of EU Member States (MS) by 2020. The EPBD states a general definition for nZEB buildings that has to be further defined by MS for different building types. In general, from January 1st 2019, new buildings occupied by the government have to be nZEB and all other new buildings (residential and utility) have to fulfil nZEB regulation from January 1st 2020.

The Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA) published a paper [3] where nZEBs are defined in a uniform way.

"Technically reasonable achievable national energy use of > 0 kWh/(m² a) primary energy achieved with best practice energy efficiency measures and renewable energy technologies which may or may not be cost optimal."

Currently, in the Netherlands, no definitive nZEB definition has been specified for 2020. The Dutch

government has published the *National Plan to promote nZEBs* [4] which describes a plan to reduce energy consumption in the built environment.

Previous research [5] shows, from the total energy consumption of the built environment the healthcare sector is responsible for 1.64% in the Netherlands. Within the total of 120 hospitals in the Netherlands, eight of them are academic hospitals [6, 7]. Academic hospitals, also known as University Medical Centers (UMCs), form a special group with a combination of basic healthcare, highly specialized medical facilities and educational functions [8]. Moreover, approximately 64% of healthcare energy demand is consumed by these eight UMCs [5]. UMCs are aware of the current and increasing problems due to energy consuming activities and the increasing energy demand and costs. They are concerned about taking energy reduction measures in order to increase energy efficiency, besides the necessity to move toward nZEBs due to legislation.

In the case of the Netherlands, the methodologies and performance requirements that private and public buildings have to comply with have been published in September 2012 [9]. The performance of the buildings is currently indicated by the Energy Performance Coefficient (EPC) which is described in the NEN 7120 [10]. The EPC is related to a specific function of the building. Hospitals are usually characterized by three functions, and their EPC are presented in Table 1.

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	EPC [2015]	nZEB requirements			
Function		Energy demand	Primary Energy Use	Renewable Energy	
		[kWh/m ² y]	[kWh/m ² y]	[%]	
Healthcare with bed-area	1.8	65	120	50	
Healthcare other than bed-area	0.8	03			
Office	0.8	50	25	50	

Table 1 EPC factors and preliminary nZEB requirements per function

The EPC and NEN7120 method are currently in use and will be used until 1st January 2020, until the nZEB requirements will come into force. Table 1 also presents the preliminary nZEB requirements additional to EPC [2, 11].

In light of the changes in this last decade and the new requirements, all eight Dutch UMCs agreed upon a Multi-Year-Energy Efficiency Agreement 2001-2020 (MJA3) to reach an average energy reduction of 2% every year, compared to 2005. The agreement is sponsored and supported by the Dutch Civil Service for Entrepreneur (RVO) [12]. However, as stated by RVO [13], the UMCs' energy demand kept increasing instead of the necessary decrease, in the first years after signing MJA3. This trend is caused by several reasons, but it mainly highlights that UMCs have problems in determining strategies and measures to accomplish the goals they set back in 2001. According to Capperucci et al.[14], the major difficulty of the process is detecting inefficiencies due to the complexity of these types of buildings. Furthermore, the relation between energy consumption and its influencing parameters is not easily recognizable due to the multiplicity of its relations [14]. Aside from the complexity of the problem, monitoring activities of energy streams and consumers are limited. Monitoring of UMCs energy streams together with a holistic view of the building functions and its occupant's behavior can contribute to filling the current lack of knowledge and consequently enable the identification of energy-saving measures based on reliable data. A polyclinic building of a UMC has been chosen as the case study for this analysis. In the next sections of this paper, the methodology followed by the analysis of the case study building, results analysis, discussion and the conclusions sections are presented respectively.

2 Methodology

The main objective of the research is to identify possibilities for energy reduction through multi-faceted analysis of the building's energy consumptions, functions and occupancy. The study is based on the so-called 5 step approach, which is developed from the Trias Energetica [15, 16] and illustrated in Figure 1. During this study, the focus is kept to the first two steps of the five-step approach: user demand and behavior and the reduction of energy demand.

In order to fulfill the research objective, the methodology was divided into three main sections (Figure 2). First, a literature review was executed to provide an overview of previous studies about nZEB Hospitals and

future visions of hospital organizations. The literature research was based on four different sources: previous thesis studies, internal UMC reports, academic literature about the state of the art and normative regarding energy requirements (NEN 7120).



Figure 1 Modified five-step approach from Trias Energetica.



Figure 2 Schematic representation of the research method.

Next, a case study analysis was executed in three steps. In the first step, the case study building's EPC factor has been assessed in order to identify how the building performs compared to the restrictions established by NEN 7120. The EPC calculation is performed with ENORM V3.50 software. This shows how the building performs, highlighting the most energy consuming technical systems in the entire building. Then, a functional analysis is carried out, focusing on the impact of each function in the total energy consumption of the building. Based on the results of the EPC calculation, two technical systems were selected to be inventoried at the room level. This reveals which functions and specific rooms consume most of the energy in the polyclinic. The functional analysis was based on the information retrieved from the UMC organization. Not all required information could be retrieved accurately from the UMC organization. Therefore an audit analysis was performed, to validate the retrieved information. Concurrently, other information about user behavior were gathered, giving attention to the occupancy levels of the building.

Then, the identification of energy saving measures (scenarios) was carried out. Lastly, the impact on the overall energy performance of the building was evaluated for these different scenarios.

3 Results

3.1 Case study building

The case study building, constructed around 1985, is used as a daily care outpatient clinic. It is distributed in six layers where three of them present outpatient functions only. The other layers are used for energy distribution throughout the building itself and connecting the UMC's other buildings. Figure 3 shows all the incoming and outgoing energy streams through the building. While the solid arrows indicate the supply streams, the dashed arrows illustrate the return streams. To the building, the only streams that do not arrive from the energy plant are tap water with a local storage system installed on the underground layer and the local electricity production from the photovoltaic panels installed on the rooftop.



Figure 3 Polyclinic energy streams schematization.

Even though the energy streams are well known, the monitoring of these energy streams resulted insufficient, creating an unclear overview of the energy supply to the polyclinic. The Building Energy Management System records every 15 minutes four flows out of the eight total incoming flows. However, the retrieved measurement results are also found to be either incomplete or inconsistent, disabling the clear understanding of the building's current energy use.

In Figure 4, the macro-function distribution of the three outpatient floors is presented. The distribution areas span almost a third of the entire gross floor area (GFA) of the polyclinic (total \approx 12190m²). Then, medical facilities and administrative areas are the most present functions in the building.



Figure 4 Polyclinic macro-function Gross Floor Area (GFA) distribution (excluding technical levels).

An in-depth analysis was carried out to identify the occupancy levels of the most spanned macro-functions presented in Figure 4. In order to detect the occupancy, the full rooms' capacity was recorded first. Then, for some selected rooms, according to availability, the daily activities during a week-day was recorded. The registration of the daily occupancy enabled to draw an average occupancy pattern per function. The capacity of a room is defined as the total number of sits present in the room itself. Table 2 highlights the available square meter per person in each analyzed function.

 Table 2 Average capacity per function.

Macro-function	Specific capacity	
	[m ² /person]	
Distribution areas	12,7	
Administrative areas	2,8	
Medical facilities	2,5	
I) Treatment/Chat room	5,2	
II) Waiting room	1,4	

It is notable that the distribution areas present a higher specific capacity compared to administrative rooms and medical facilities. However, for different medical facilities, it is necessary to show separate results as given in Table 2. The occupancy measurements took place in administrative areas and treatment/chat rooms only. The waiting rooms and distribution areas have not been included due to the absence of permanent staff that could perform the recording. Figure 5 plots the profile of the occupancy rate of the different treatment and chat rooms. Among the seven different recordings, it is difficult to observe a common pattern. It is notable how the starting and the end of the working days differ between cases, resulting in unpredictable occupancy patterns. However, a major observation from occupancy measurements of treatment/chat rooms is that the peak occupancy level never reaches 80% in all considered days. This lead to an average occupancy of a maximum of 40% around 13h00 (black solid line in Figure 5).



Figure 5 Daily occupancy rate of treatment and chat rooms.

Differently from the medical facilities' occupancy rate, Figure 6 shows the occupancy rate of administrative areas in the polyclinic. It shows consistent measurements during working days. In this case, the considered offices have a full capacity between four to five people. The resulting graph shows that the usual working day is from 07h00 to 17h00. Even though the occupancy rate stayed constant throughout the day, the observation still holds without exceeding 80% of the full capacity.



Figure 6 Daily occupancy rate of office and reception rooms.

These results are in line with findings of [17]. Brunia [17] found a similar trend for consultancy rooms, with a maximum average capacity of 40% and with a sudden decrease around lunch time. On the other hand, also the steady occupancy of the administrative rooms is comparable with the results presented by [17].

3.1.1 EPC analysis

To understand the current performance of the policlinic building, the EPC factor is derived from a calculation based on the NEN 7120. Guerra-Santin et al. [18] explain the EPC calculation taking into account the space heating, space cooling, tap water, heating and electricity needed for lighting and mechanical ventilation. However, energy used for cooking and electricity consumption for appliances (white and brown goods) are excluded because they are not directly related to the building itself. Figure 7 below, presents the results of the EPC calculation. The figure shows lighting, ventilation and heating as the main energy consuming systems in the polyclinic. The polyclinic results in consuming around 225 kWh_{prim}/m^2 according to the EPC calculation.



differentiated by source (ENORM V3.50).

While the lighting requires almost half of the primary energy of the entire building, ventilation and heating need another 40% of the total. It is interesting to notice that electricity is the highest used energy source in the building. From EPC analysis it was noticed the lighting and ventilation system are responsible for 70% of the energy consumptions of the polyclinic building. For this reason, the focus of further research will be on lighting and ventilation only.

3.1.2 Functional analysis

The functional analysis enabled to understand the most responsible functions for lighting and ventilation present in the polyclinic building. The analysis focused on inventorying the equipment/systems present in rooms. The selection of the rooms for the inventory was randomly distributed throughout the building. 224 rooms out of 418 were selected for the inventory. At least 3 rooms per function were selected. The ventilation and lighting inventory was based on the mechanical and electrical drawings respectively.

The maximum capacity per inlet and exhaust ventilation was calculated per room assuming a utilization time of 14 hours per day, and the opening of the polyclinic during the week. Knowing the kW consumption of the fans, the consumption per cubic meter of exhaust and supply has been evaluated. Assuming 52 weeks/year of operation, the consumption for the supply was assessed to be 3,23 kWh/m³ year, while for the exhaust it is 1,44 kWh/m³ year. On the other hand, the lighting assessment was based on the inventory of the lighting installed power per luminaires, retrieving the consumption of square meter per function. Assuming the operation hours presented in Table 3 below, the consumption per square meter per year was obtained. Being both ventilation and lighting systems supplied by the energy plant of the campus (CHP), the yearly consumption was divided by the efficiency of generation system to obtain the primary energy consumptions. Therefore, the conversion factor of 2,56 kWh_{prim}/kWh_e was used [10], [19].

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Function	Day [h/day]	Year [h/year]				
Distribution areas	14	3640				
Technical rooms	2	520				
Administrative areas	10	2600				
Medical facilities	8	2080				
Specialization rooms	8	2080				
Several functions	5	1300				

 Table 3 Assumed operation hours per lighting system

 inventory

Figure 8 describes the total primary energy consumption per year of every macro-function. These results are obtained by multiplying the specific density consumption by the total floor surface of each function.



Figure 8 Macro-functions' consumption per technical facility.

It can be observed that the specialization rooms, which have the highest value of specific consumption density (\approx 320kWh_{prim}/m² year), represents the lowest when the whole polyclinic is taken into account. For lighting and ventilation, Figure 8 highlights the medical facilities, distribution areas and administrative areas as the most relevant consuming functions, accounting for 81% of the entire yearly consumption. For this reason, a more indepth look has been taken considering the specific rooms of these three functions. Figure 9 plots the results of the more detailed functional analysis showing the most consuming rooms of distribution areas, medical facilities and administrative areas regarding lighting and ventilation systems.



Figure 9 Functions' consumption per technical facility.

In Figure 9, the presented functions are responsible for 77% of the entire ventilation and lighting energy consumption of the building. The treatment rooms, chat rooms and offices together are responsible for almost 43% of the lighting and ventilation energy consumption of the building. It is important to underline that this calculation was based on inventories collected from mechanical and technical drawings of UMC. To validate the obtained results and to verify the reliability of the results, an on-site assessment was carried as the next step.

3.1.3 Audit analysis

In this section, the distribution areas, medical facilities and administrative rooms are further investigated. Lighting conditions have been listed according to the currently installed lights in the building. Afterward, a comparison with the installed lighting power with the design information has been performed. Similarly, the ventilation has been recorded, where possible, with a *Flow Finder* based on the zero pressure principle. In total, 33 different spaces have been investigated. However, only in 8 of them the ventilation measurements have been carried out due to logistic limitations.

Regarding the ventilation, a difference between the designed and operational flows was identified. While the inlet presents an average difference of -15%, the exhaust has an average decrease of -5% compared to the design situation. Regarding the lighting system in 30 different rooms, a gap between installed and operational power density was found. While the distribution areas' operational lighting is 35% less than the electrical drawings; for medical facilities and administrative areas, the operational is more than half compared to the indication of the drawings. Due to the differences between design and operational state of the systems, an updated version of the comparison between macro-functions' technical systems energy consumption is presented in Figure 10.



■ Ventilation consumption ■ Lighting consumption × Difference design & present

Figure 10 Macro-functions' updated comparison per technical facility.

While the ventilation modification has been applied in all cases, the lighting differences have been applied only on the three macro-functions which have been investigated. Even after considering the differences between design and operation, the medical facilities, administrative areas and distribution areas are still the leading energy-consuming facilities.

3.2 Energy saving measures

After identifying the energy consuming functions and relevant rooms, the next step is to observe to what extent the relevant parameters influence the building energy demand through a sensitivity analysis. From the results of such analysis, the implementation of energy saving measures can be carried out. However, in order to conduct the analysis, a new calculation tool has been selected, being ENORM not suitable for parameter variations due to its black box nature. Contrarily, the MS-Excel based tool developed by RHDHV [20] named Advanced Energy Exchange Calculation Tool (AEECT), can be transparently seen and modified. Successively to the tool validation, various parameters' impact on the building energy demand is investigated. According to [21], the influencing parameters should include the building envelope, Internal Heat Loads (IHLs) and HVAC system. Additionally, the relative humidity is also taken into account. During the analysis, the impact of the parameters is evaluated on the overall energy demand of the building. The scope of the analysis is to grade the impact of all parameters modifying the input and observing the relative change in the overall energy use. The input parameters are divided into building characteristics, internal heat loads and building services. Building characteristics include the thermal resistance of the building envelope (floor, roof and walls). While internal heat loads include the specific heat generated by people, lighting and equipment; the building services group includes the relative humidity, air supply and temperature set point for heating and cooling. In all cases, a modification of $\pm 20\%$ has been applied to each parameter.

3.2.1 Sensitivity analysis

The results of the relative sensitivity analysis are presented in Figure 11. In this case, all the Rc values have been grouped into one single parameter called Rc building. For the other cases, the single relative impact of each parameter is illustrated. In the case of the building characteristics (oblique lines), it is interesting to observe that the most impacting are the Rc values and infiltration



Figure 11 Relative sensitivity analysis for polyclinic building.

rate. In the case of the internal heat loads (vertical lines), the installed lighting present a really high impact compared to the people and equipment. The building services (net pattern) present on average the highest impact on building energy consumption. Besides them, lighting, equipment, Rc values and the infiltration rate seems to have a considerable influence on the building energy demand.

3.2.2 Measures implementation

Findings from the sensitivity analysis lead to the realization of energy saving measures. The analysis of the energy saving measure is carried out with ENORM tool.

- 1. Firstly, improvements regarding the building shell are implemented (Opaque elements and fenestrations). The opaque components present an enhancement of thermal resistances and infiltration rates. On the other hand, fenestration was substituted with a lower U-value.
- 2. Secondly, a sweep pulse switching in combination with daylight control level is lighting implemented for the system. Additionally, a decrease of the installed lighting power to 9 W/m² per function has been implemented in the whole building. In this way, the high-efficiency lighting effect is assessed. Regarding the ventilation system, a CO₂ level was implemented. control Making the ventilation system responsive to the occupancy level of the building.
- 3. Thirdly, a PV façade is implemented ideally installing it on the south and east façade of the building on a strip of 3 m high which is situated at the same height of the building layer which does not present any transparent openings for a total surface of 400 m².
- 4. The fourth and last scenario represents a combination of all these three energy saving measures.

The results obtained are shown in Table 4. The first three rows of the table show the EPC and nZEBs requirements for the polyclinic building and the results of the polyclinic design and operation scenarios respectively (Table 4). Underneath, the four scenarios' results are presented. It is notable that in all cases, the EPC requirement is not fulfilled. However, some of the measures (1-2-4) fulfill the energy demand requirement from the nZEB. None of the scenarios reach the minimum share of renewable energy. Only for scenarios 2 and 4 the primary energy use requirement is fulfilled.

4 Discussion

The polyclinic can be seen as a sample building of the healthcare sector, hosting the outpatient-care functions and being operative during weekdays. The building hosts mainly administrative areas and treatment and chatrooms. It was found that even though the present energy streams to and from the Polyclinic building are well

Scenario		nZEB requirements			
	EPC [2015]	Energy demand	Primary Energy use	Renewable energy	
	[-]	[kWh/m ² y]	[kWh/m ² y]	[%]	
Polyclinic requirements	0,8	61	94	50	
Polyclinic design	2,94	82	123	26	
Polyclinic operation	2,29	65	112	30	
1) Building shell	2,06	51	96	22	
2) Occupancy strategies	1,73	54	87	33	
3) PV facade	2,18	65	104	32	
4) Combination	1,32	38	61	29	

Table 4 Energy saving measures results with ENORM compared with EPC and nZEB requirements.

known, the monitoring of these energy streams resulted inefficient and incomplete, creating a partial overview of the energy supply to the polyclinic. Therefore, a multifaceted analysis was performed to identify the energy saving measures and to assist the renovation process of the building towards nZEB standards.

First, the study allowed to understand building energy use and occupant behavior. The occupancy measurements highlighted that in the analyzed rooms the full capacity is never reached. The presence of users resulted to be considerably lower than the full capacity of the rooms in the building, with a 30% average occupancy in the medical facilities and 70% for the administrative areas.

Second, the EPC calculation drew an overview of the overall polyclinic's energy consumption and showed where it is positioned compared to the EPC and nZEB requirements (Table 4), besides identifying the most energy-intensive technical systems. In the building, medical facilities and administrative areas have been identified as the most energy-intensive macro-functions and lighting and ventilation resulted as the most impacting energy systems. From the analysis, a discrepancy from 30-50% was found between designed and installed lighting system. On the other hand, in the ventilation system, a decrease of 15% and 5% was detected between the designed and operational inlet and exhaust air supply at the room level respectively. However, the ventilation decrease does not affect the building ventilation demand seeing the current user behavior.

5 Conclusion

The above discussed findings lead to the realization of some potential energy saving measures that could be implemented.

During this study, no occupancy sensors or lighting control strategies have been detected inside the building. The focus on the occupancy detection strategies seems a good opportunity to decrease the energy demand of the building. Seen the unpredictability of the occupancy, especially in the medical facilities' spaces, an occupancy detection strategy could bring valuable improvement in the lighting energy consumption. On the other hand, a similar strategy can be thought for the administrative spaces as well since the full occupancy capacity is never reached in the measurements. Additionally, room for improvement was identified in the ventilation system. In relation to the Dutch building regulation [22], the air supply in a healthcare function other than bed area has to be a minimum of 43,3 m³/h per person. The analysis found that the actual state of the ventilation rate is in line with the requirements from the normative. The air supply of the current ventilation system is constant irrespective of the number of people present in a room. If the ventilation rates can be controlled according to the occupants present in the room, this could be seen as a possible energy consumption reduction method for this building.

Calculations performed in this research aim to provide recommendations for possible energy saving measures only but, not to investigate their effectivity in detail. With a view to the future renovation of the polyclinic building, it is important to investigate further the energy saving measures using the knowledge gathered from this study. Furthermore, the creation of an inventory of equipment and installed lighting is suggested observing the relevant impact that these factors have on the building energy Management System is recommended in order to record the energy supplied to the building and to retrieve the actual energy consumption of the building. This enables the identification of future consumption inefficiencies.

References

- EIA, "World energy demand and economic outlook," *Int. Energy Outlook 2011*, vol. 0484, no. 2010, pp. 1–11, 2011.
- [2] EU, Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast). 2010, pp. 13–35.
- [3] REHVA, "REHVA EPBD recast, Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast), Official Journal of the European Union, (2010)," 2010.
- [4] Dutch governments, "Nationaal Plan voor het bevorderen van Bijna-EnergieNeutrale Gebouwen (BENG) in Nederland," 2012. .
- [5] Ministerie van Volkshuisvesting, "Ruimtelijke Ordening en Milieubeheer," 2010.

- [6] Zurghulpatias, "Overzicht algemene ziekenhuizen in Nederland," a, 2015. [Online]. Available: http://www.zorghulpatlas.nl/zorg-innederland/ziekenhuiszorg/algemene-enacademische-ziekenhuizen/overzicht-algemeneziekenhuizen-in-nederland/. [Accessed: 17-Dec-2017].
- [7] Zurghulpatias, "Academische ziekenhuizen in Nederland," b, 2015. [Online]. Available: http://www.zorghulpatlas.nl/zorg-innederland/ziekenhuiszorg/algemene-enacademische-ziekenhuizen/academischeziekenhuizen-in-nederland/. [Accessed: 17-Dec-2017].
- [8] W. J. Bos, H. P. J. Koevoets, and A. Oosterwaal, "Ziekenhuislandschap 20/20: Niemandsland of Droomland?," 2011.
- [9] Subvention, "'Nationaal Plan bijnaenergieneutrale gebouwen' - Dutch national Plan to promote nZEBs," 2013. [Online]. Available: http://www.subvention.nl/specialismen/bouwand-investeringsprojecten/nieuws-bouw-andinvesteringsprojecten/nieuwsarchief-bouw-andinvesteringen/nationaal-plan-bijnaenergieneutrale-gebouwen/.
- [10] D. S. Institute, NEN 7120 2012. 2012, p. 506.
- [11] S. Blok, "Voortgang energiebesparing gebouwde omgeving.," 2015.
- [12] RVO, "Rijksdienst voor ondernemend."[Online]. Available: www.rvo.nl. [Accessed: 22-Jun-2018].
- [13] RVO, "MJA-Sectorrapport 2014," 2015.
- [14] R. Capperucci, W. Zeiler, and W. Maassen, "Roadmap to Nearly Zero Energy Hospitals case study, Policlinic VU Medical Center Amsterdam," Eindhoven, 2015.
- [15] E. Lysen, *The Trias Energetica: Solar Energy Startegies for Developing Countries.* 1996.
- [16] B. Entrop, J. Brouwers, and A. Van der Veen, "Model voor duurzaam ruimtegebruik gemeenten," *J. Build. Apprais.*, vol. 5, pp. 293– 310.
- [17] S. Brunia, "Bezettingsgraadmeting," Delft, 2009.
- [18] O. Guerra-Santin, L. Itard, and H. Visscher, "Effects of the dutch energy performance regulations on energy savings in dwellings," *14th Eur. Roundtable Sustain. Prod. Consum.*, pp. 1–13, 2010.
- [19] Utrecht UMC, "Energy Efficiency Plan UMC Utrecht," Utrecht, 2016.
- Utrecht," Utrecht, 2016.
 [20] RHDHV, "Royal HaskoningDHV," 2018.
 [Online]. Available: www.royalhaskoningdhv.com/.
- [21] M. Rasouli, G. Ge, C. J. Simonson, and R. K. Besant, "Uncertainties in energy and economic performance of HVAC systems and energy recovery ventilators due to uncertainties in building and HVAC parameters," *Appl. Therm. Eng.*, vol. 50, pp. 732–742, 2012.
- [22] Bouwbesluit, "Ministerie van volkshuisvesting, ruimtelijke ordening en milieubeheer. Technische bouwvoorschriften uit het oogpunt

van gezondheid.," 2013.