Operational Energy Performance assessment and benchmarking of TU/e campus buildings for campus 2020

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ABSTRACT

In the current building scenario, sustainability assessment is inevitable and energy efficiency is considered the 1st step towards sustainability assessment. This recommends an investigation on the current operational energy performance of buildings in TU/e campus, as it plans to undergo a renovation to become known as a science park with emphasis on providing sustainable, world class living, working and learning environment by 2020. Here, the research tries to assess the operational energy performance of different TU/e buildings, and later it is used for future energy prediction and for benchmarking with buildings of similar type. The research also compares the green building labelling schemes relevant in the current scenario that could be applied to the TU/e campus buildings.

For comparisons/benchmarking, a new methodology is applied particularly for TU/e campus buildings by calculating the “comparable energy”. Even though many building benchmarking tools have been available worldwide, they hold a lot of constraints. Buildings cannot be compared in the whole building level as it includes multiple uses. For example; TU/e buildings are equipped with office space, laboratories, kitchen etc. and at different ratios. Currently available methods allow comparisons of buildings mainly on its use type. It makes the comparison difficult when multiple features/uses are included in the building. Here, the comparable energy represents the energy that is consumed in the office space/uses, and that makes it comparable with typical office building energy utility index (EUI).

The main results include, 1) 4 green building labelling are shortlisted based on ‘scope’ (LEED-Leadership in Energy & Environmental Design, BREEAM-Building Research Establishment Environmental Assessment), ‘uniqueness of financial aspect’ (DGNB) and ‘severity’ (LBC-Living Building Challenge). On comparing it qualitatively, it is found that financial aspects, regional aspects and net zero energy aspects are of high significance in the scenario of building sustainability assessment. So DGNB & LBC are found relevant for applying to the TU/e campus buildings. 2) The “comparable energy” shows that building “Vertigo” & “Traverse” are the energy efficient buildings of the TU/e campus with EUI of $167\frac{kWHR}{m^2*Yr}$ and $169\frac{kWHR}{m^2*Yr}$, “Cyclotron” & “Spectrum” are found low in energy efficiency with EUI of $1240\frac{kWHR}{m^2*Yr}$ and $998\frac{kWHR}{m^2*Yr}$. 3) On comparing the past performance (year 2004, 2005, 2006) and present performance (2010, 2011, 2012, & 2013) of buildings, an increase in EUI is found in all the TU/e campus buildings. Matrix building shows the highest percentage increase in EUI with 37%. 4) For TU/e campus buildings, the “comparable energy” of “Traverse and Vertigo” can be taken for cross sectional benchmarking as it shares the advantages of same location. Moreover, it is suggested that, “EnoB (Energy Optimized Building)” monitored energy efficient buildings (Average EUI of
$110 \frac{KW\cdot H}{m^2\cdot yr}$ can be taken as a benchmark for Vertigo and Traverse building. Finally 5) 2 extreme scenarios in heating degree days are taken for energy prediction in 2020. In the low heating degree day scenario, it is found that, in most of the TU/e campus buildings, the advantage gained in space heating, is overcome by degradation in electrical energy efficiency.

The results show that the calculation of comparable energy of TU/e campus buildings makes the comparison with typical office buildings meaningful. Further, energy consumption is certainly going to increase in the future, so energy efficiency improvement plans of the existing building stock should be the prime focus for campus 2020 plans. It will enhance the opportunities to become a more sustainable campus with low environmental footprint for the year 2020.
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1 Introduction

The latest IPCC report shows that, buildings accounted for 32% of the total global final energy use and approximately 1/3rd of the black carbon emissions. By the end of mid-century, it is predicted that this figures of energy use and emissions may double or even triple[1]. Currently, in the European region, about 35% of the buildings are over 50 years old [2] and considering the fact that, buildings are generally built expecting to stay longer, a large proportion of the today’s existing building stock will still exist for another 30-40 year period in developed countries. But like any other system, building’s performance or energy efficiency degrades over time, and it is expected to play a crucial factor in the future global energy consumption and carbon emission figures.

By improving the energy efficiency of buildings, it is estimated that a reduction in total EU energy consumption by 5% to 6% and CO2 emissions by about 5% is possible by 2020[2]. The importance of energy efficiency in existing building performance is underscored with the rise in building energy benchmarking tools and energy rating tools (like Energy star, Energy IQ, Calc arc, bEQ etc.). Further, Considering the fact that energy efficiency is considered the most important category among all globally available green building labelling schemes with an average weight percentage of 25%[3], it should be considered the first step towards sustainability assessment in existing buildings and organization. Good energy efficiency supports buildings to control rising energy costs, reducing environmental footprints, increasing the value of building and thereby increase the overall sustainability of the building.

1.1 Project Background:

In this context, “Technical University of Eindhoven (TU/e)” plans to undergo renovation to become known as a science park with emphasis on providing sustainable, world class living, working and learning environment by 2020 (campus 2020). So an evaluation on the current operational energy performance of University campus buildings is in demand. This evaluation of the current operational energy performance of buildings can be used to benchmark with similar good performing buildings and predict the future energy performance to support the design making of “future TU/e Campus buildings, which eventually supports to make plans to achieve high energy efficiency/good performing campus buildings. Moreover, the performance of TU/e campus buildings in terms of sustainability are also considered important as part of the “campus 2020” plans. The availability of a number of green building
labelling schemes can create confusion to any investor. Hence, a study on green building labelling schemes, that could be applied to the TU/e campus buildings are also in demand.

Hence the below study is conducted on various green building labelling schemes and on operational energy performance of selected TU/e campus buildings.

1.2 Literature Survey

*Benefits, critics on Green building labeling schemes:* Literatures suggest that the usage of sustainability assessment tools in the building sector are inevitable [4],[5],[6]. Many Green building labels tried to address many sustainability issues related to building and they have succeeded to an extent in creating awareness about criteria & objectives of sustainability among the building community [3]. The certified green buildings offer high comfort level, healthy indoor climate while banking on regenerative energies & resources that allow low operating costs [7]. Nowadays it can be seen that a competition in the building industry to get green building certification, which in turn increases the transparency in data, updates & quality of schemes etc. [6]. The main drawbacks of green building labelling schemes is that the same building which is termed green with one labeling scheme termed “not green” with other schemes [8]. It questions the criteria that need to be considered for the assessment. Further, environmental issues are mainly qualitative and they cannot be measured using the market-based approach of these schemes. Finally, there is no clear logical or common basis for the way in which the maximum number of points is awarded to each criterion, described in the schemes [5].

Even though green building labelling schemes have some drawbacks, the benefits show that, it can be taken as a framework of reference for any project, as it addresses a number of sustainability issues and helps in reducing the impact of a building to its surrounding.

*Whole building Operational Energy Performance Benchmarking:* In buildings, the term “benchmark” is used to refer the standard or reference point in which the buildings performance can be compared[9]. For whole building energy benchmarking activity, the data sets of energy use, energy costs, peak demand, time-of-use data, building characteristics, and non-energy performance features can be included. The Comparison data sets can include: Similar buildings, past performance of the same building (historical data), similar systems or components.
Benchmarking strategies: There are mainly four types of strategies used for benchmarking: 1) statistical comparisons, 2) point-based rating systems, 3) simulated model-based techniques, and 4) hierarchical end use performance metrics [10].

In Statistical approaches, larger data sets of similar buildings are required, to generate a benchmark for which the building EUI is compared. Many building benchmarking tools like “Energy Star”, “Cal arc” etc. are generated based on this approach. The idea of Hierarchal end-use metrics is to begin the analysis at the whole building level and gradually move down to the lower levels of systems and components level to find the performance data. For example, the highest level data can be the total energy consumed by the building, the middle level can be the main end uses (heating, cooling total electricity etc.) and the third level can be the total lighting load (comes under total electricity). However, the type of data required is usually not readily available, as it involves more details. Sub-metering is one of the strategies that can be employed to get data of the system and component loads. Simulation model-based approaches are common nowadays and it calculates energy benchmarks based on an idealized model of building performance. “Energy Plus” is one of many energy modeling tools that is used in simulation based approaches. Point-based system provides standards and guidelines to measure how efficient and environmentally friendly a facility is, as they do not allow comparisons with other buildings. “LEED” rating system is an example for this point based system [11],[10].

Among the strategies, the statistical data is the easier way to start with, as many benchmarking tools are readily available providing datasets of the various buildings but are unlikely to be effective for comparing the buildings in Netherlands. As most of the currently available benchmarking tools are based on United States, and there are a lot of barriers associated in comparing a building with another one, considering the fact that each building is unique in its own way.

Barriers to whole building benchmarking: Buildings are different in a lot of ways, different uses (offices, Universities etc.), different working hours (shifts in operation), different occupancy rate (workers in office, students in school), different sizes, rooms in, different geographic regions (oceanic climate, tropical climate) etc. The most significant challenge in building energy performance benchmarking is to ensure that the data are being compared in the most meaningful way as possible. The benchmarks may mislead due to not fully understanding the end-uses of various buildings properly[7].

Because of these barriers, new methodologies are adopted for benchmarking according the need. Even though many building benchmarking tools have been
available worldwide, they hold a lot of constraints. Buildings cannot be compared in the whole building level as it includes multiple uses. For example; TU/e buildings are equipped with office space, laboratories, kitchen etc. and at different ratios. Currently available methods allow comparisons of buildings mainly on its use type. It makes the comparison difficult when multiple features/uses are included in the building. Otherwise, it is wise to benchmark the buildings on comparable terms.

1.3 Objective

The main objective of this research paper is to analyze the current operational energy performance of TU/e campus buildings, and to use that information for benchmarking with buildings of similar type and to predict future energy performance. To extend the scope of sustainability, it also focuses on the relevant green building schemes that could be applied to the TU/e campus buildings in the present scenario.

Thus the main research questions are

a) Which green building labelling schemes (aspects of sustainability) are relevant in the current scenario?

b) What is the operational energy performance of TU/e campus buildings that could be used for benchmarking and predicting future energy performance?

1) What is the operational energy performance of TU/e campus buildings?
2) What are the building benchmarks that could be applied for the TU/e campus buildings?
3) What is the predicted energy performance of TU/e campus buildings for “campus 2020”?

2 Methodology

To support TU/e’s “campus 2020” plans, a qualitative study on the various green building labelling schemes and an approach to assess and benchmark the operational energy performance of TU/e’s campus building is conducted. The qualitative study on the green building labelling schemes is done by comparing the strengths and weaknesses of various schemes. The evaluation of TU/e campus building’s operational energy performance is primarily based upon the hourly energy data, sensor data, annual energy report and space distribution data, which is collected from TU/e real estate department and from TU/e campus buildings.
In the first part, the green building labelling schemes that are relevant in the current scenario are shortlisted and it is compared qualitatively. In the second part, a methodology is applied to assess the operational energy performance of the building in comparable terms. The total energy consumption of different TU/e campus buildings are compared in terms of $\text{of} \frac{kW\cdot h}{(m^2 \cdot a)}$. By segmenting the energy use in TU/e buildings that has been used for office use, laboratory use and other use, the comparable operational energy performance are compared. The comparable energy represents the energy that is consumed in the office space/uses, which allows it to benchmark with typical office building benchmarks/databases. The third part involves benchmarking of TU/e campus building’s comparable energy with typical office buildings, and finally energy prediction for the selected TU/e buildings in 2020 by considering different climate scenarios.

The general methodology, used in this research project is represented schematically in Figure 1. This is explained in detail in the following paragraphs.

![Figure 1: Representation of the adopted methodology that is used in this research](image)
2.1 Selection of relevant Green building rating schemes

To upsurge the distribution of sustainability in buildings and cities, the usage of sustainability assessment tools in the building environment are considered inevitable. Sustainable development principles are taking on an increasingly important role in real estate applications, particularly by forward-looking developers. In the current scenario it is observed that more than 600 sustainability assessment rating tools are available worldwide[6]. It includes all green building labelling schemes, Energy rating schemes, energy benchmarking schemes etc. Green building labelling tools tried to address many sustainability issues but none of them have emerged as a universal measure check. It often creates confusion among decision makers for choosing a particular tool for their building.

In the context of TU/e’s modernization plans, initially (step 1) the research started by collecting the list of various green building labelling schemes (Appendix A1). Literature study is conducted in order to understand the advantages and disadvantages of each green building labelling scheme. From the listed labelling schemes, the green building labelling schemes which are relevant in the current scenario are outlined based on scope, uniqueness and severity, see Figure 2. Finally, the comparison of the selected green building labelling schemes are done qualitatively (step 6).

Figure 2: Shortlisted green building labelling schemes
Among the green building rating systems, energy efficiency is always considered the most important category (weight average of 25.5%), followed by Indoor Environment Quality (17.7%), waste and pollution (15.9%), sustainable site (13.2%) and material and resources (11.5%). In the case of “Living Building Challenge”, importance is given to make their certified building in to a “net zero energy” building. This significance for energy in the green building labelling schemes underscores the decision to evaluate the operational energy performance of the TU/e campus buildings. Because it is considered as the first step to make strategic plans for attaining better energy efficient buildings.

2.2 TU/e building’s total Energy and comparable energy

In order to calculate the total energy consumption (step 2) in different TU/e campus buildings, initially the sensor data is collected from the TU/e real estate department. Later, Seven year hourly energy data of selected TU/e campus buildings (Table 1) are collected. The mean, median standard deviation, maximum and minimum data points are interpreted (step 6) for assessing the total energy performance of TU/e campus buildings.

The selection of TU/e campus buildings are based on the years in which last renovation happens. During years 1999-2003, many of the TU/e campus buildings underwent some major renovation works, so two sects of TU/e campus buildings are chosen for assessment in order to compare the newly renovated building (T2) with the buildings which have not been renovated buildings (T1). It is expected that T2 building will perform better than the T1 buildings.

<table>
<thead>
<tr>
<th>BUILDINGS -T1</th>
<th>YEAR</th>
<th>BUILDINGS -T2</th>
<th>YEAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matrix</td>
<td>1960</td>
<td>Gemini-North</td>
<td>1999</td>
</tr>
<tr>
<td>Auditorium</td>
<td>1966</td>
<td>Cyclotron</td>
<td>2001</td>
</tr>
<tr>
<td>Gemini-South</td>
<td>1974</td>
<td>Vertigo</td>
<td>2002</td>
</tr>
<tr>
<td>Traverse</td>
<td>1985</td>
<td>Kennisport</td>
<td>2002</td>
</tr>
<tr>
<td>Helix</td>
<td>1996</td>
<td>Spectrum</td>
<td>2002</td>
</tr>
</tbody>
</table>

Table 1: Selected TU/e campus buildings with year of last major renovation (TU/e, diensten, 2014)

One of the initial assumptions for this project is that, the building performance or energy efficiency of a building will deteriorate over years. So out of seven year energy
data collected, three of the buildings annual energy data are taken from year 2004, 2005 and 2006, which represent the past performance of the building and the remaining four years, are 2010, 2011, 2012 and 2013, which represents the recent performance. It was expected that the energy performance will be better during the past years when compared to recent year energy performance. This past performance of TU/e campus buildings is compared with recent performance (step 5).

2.2.1 Distribution of sensors (energy meters) in TU/e campus buildings

The basic energy sensor distribution to TU/e campus buildings are represented schematically in figure 3. The total electricity is basically distributed through the TU/e campus buildings through two main connections, the main line connection and the emergency connection (sensor ES1). The total electricity load (TE) of the building can be categorized as constant loads, semi-fluctuating loads and fluctuating loads. Lighting is considered relatively constant is measured by constant load sensor ES2. The power for working of computers, open ports and laboratories comes under semi-fluctuating sensor ES3 and finally the power required for kitchen, ventilation, elevators and heat-pump is measured by fluctuating load sensor ES4. The component level metering is not available as the metering is not advanced.

Figure 3: Basic sensor distribution in TU/e campus Buildings [13]
The natural gas supply is mainly for boiler heating, then supply to laboratories and for the purpose of compressed air supply. This natural gas supply is represented by sensors GS1, GS2 and GS3 respectively. TU/e has a Heat and Cold Storage (ATES) installation which is one of the biggest of its kind in Europe. There are two sensors measuring ATES thermal energy supply inside TU/e campus buildings, AS2 represents cooling and AS1 represents heating.

Data Validation: obtained hourly energy data in MS Excel is verified by comparing the data with annual energy consumption report issued by TU/e real estate department. In the annual energy report, details regarding total electricity consumption, total Natural gas consumption, ATES Heating and ATES cooling are available. It is compared against summation of electricity sensors (TE-kWH/a), Natural gas sensors (TNG-m$^3$/a) and ATES sensors (AS1, AS2-kWHTh/a). Details regarding electricity sensor distribution in TU/e campus and selected sensor-list for this project are listed in appendix A3 and appendix A4 respectively. The annual energy consumption report of TU/e campus buildings, for the selected years is listed in appendix A5.

The annual energy consumption of buildings in TU/e campus is the summation of Annual electricity load (TE), Annual Natural gas Usage (TNG) and Annual energy used from Aquifer thermal energy storage (ATES). Here, for interpretations the building’s energy use is expressed as a function of its size. And are calculated by using the below mentioned formulas and conversion factors.

\[
E_{site}(EUI) = \frac{kWHT}{m^2*a} = \frac{(TE + TNG + ATES)}{FUA} \]

Where,

\[
TE(kW) = TE(kW) \quad \text{(No conversion applied on the hourly readings)}
\]

\[
TNG(kW) = 10.5^a \times TNG(m^3) \quad a \quad [-14]
\]

\[
ATES (kW) = ATES (kWth) \quad \text{(Assumption)}
\]

FUA Or functionally useful areas of TU/e campus buildings are detailed in Table 2.
<table>
<thead>
<tr>
<th><strong>TU/e Campus Buildings</strong></th>
<th><strong>Office Space (m²)</strong></th>
<th><strong>Laboratory Space (m²)</strong></th>
<th><strong>Other Space (m²)</strong></th>
<th><strong>Functionally Useful Area (m²)</strong></th>
<th><strong>Gross Floor Area (m²)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Auditorium</td>
<td>497.96</td>
<td>0</td>
<td>5366.04</td>
<td>5864</td>
<td>13407</td>
</tr>
<tr>
<td>Cyclotron</td>
<td>1662.03</td>
<td>2561.5</td>
<td>802.47</td>
<td>5026</td>
<td>10578</td>
</tr>
<tr>
<td>Gemini-South</td>
<td>5014.9</td>
<td>1746.52</td>
<td>5002.58</td>
<td>11764</td>
<td>21084</td>
</tr>
<tr>
<td>Gemini-North</td>
<td>770.8</td>
<td>3980.47</td>
<td>4074.63</td>
<td>8825.9</td>
<td>12712</td>
</tr>
<tr>
<td>Helix</td>
<td>5337</td>
<td>6821</td>
<td>3966</td>
<td>16124</td>
<td>30372</td>
</tr>
<tr>
<td>Kennisport</td>
<td>0</td>
<td>0</td>
<td>6708</td>
<td>6708</td>
<td>12384</td>
</tr>
<tr>
<td>Matrix</td>
<td>1142.23</td>
<td>1121.62</td>
<td>1396.15</td>
<td>3660</td>
<td>7005</td>
</tr>
<tr>
<td>Spectrum</td>
<td>247.62</td>
<td>3900.26</td>
<td>283.75</td>
<td>4431.63</td>
<td>4431.63</td>
</tr>
<tr>
<td>Traverse</td>
<td>2802.3</td>
<td>1370.7</td>
<td>4173</td>
<td>7291</td>
<td>7291</td>
</tr>
<tr>
<td>Vertigo</td>
<td>3613</td>
<td>3458.76</td>
<td>9026.61</td>
<td>16098.37</td>
<td>26009</td>
</tr>
</tbody>
</table>

Table 2: Floor space Usage in TU/e Campus Buildings, b-(TU/e, diensten, 2014)

Information regarding primary energy and the emissions caused due to the energy consumption in buildings is also useful in energy planning. So in addition to site energy calculation, the primary energy consumed \( (EUI_{source}) \) by electricity and gas and finally the \( \text{CO}_2 \) emissions resulted from this energy consumption is calculated based on the conversion factors listed in Table 3. ATES, being considered as highly efficient and is used for energy conservation, the primary energy consumption in terms of ATES is taken as zero.

\[
EUI_{source} - \text{kWh/m}^2 * \text{a} \quad \text{Emissions} - \text{kgCO}_2/\text{m}^2*\text{a}
\]

<table>
<thead>
<tr>
<th>Electricity</th>
<th>(2.56^{c}) TE/FUA</th>
<th>(0.455^{e}) TE/FUA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural gas</td>
<td>(1.047^{d}) TNG/FUA</td>
<td>(0.1691^{f}) TNG/FUA</td>
</tr>
</tbody>
</table>

Table 3: Conversion factors: c-(Molenbroek, Stricker, & Boermans, 2011), d-(TU/e, Building Performance, 2014), e,f-(Milieubarometer, CO2 factors, 2010)

### 2.2.2 Assessing Comparable Energy Consumption

The comparable energy calculation (step 3) of TU/e campus buildings mainly aims to remove the energy use in the laboratories, and the fluctuating loads (energy use in Kitchen and elevators) to make it comparable in terms of energy used in the office space. Further, it allows the TU/e campus buildings to compare with typical office buildings for cross sectional benchmarking, since it is known that, rather than comparing the total energy including multiple features/uses, comparison on single
feature/use communicates, how well a building's operational energy performance in comparison with other building benchmarks.

Figure 4 depicts how the functionally useful area is distributed in TU/e campus buildings. This depiction confirms the need to compare the buildings in relative terms. For example, in Spectrum building, 88% of the FUA is occupied by laboratories versus 21% in Vertigo. The energy use in laboratories and the fluctuating loads will differ largely with buildings, as the purpose of each building is different.

<table>
<thead>
<tr>
<th>Building</th>
<th>Office Space</th>
<th>Laboratory Space</th>
<th>Other Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertigo</td>
<td>22%</td>
<td>21%</td>
<td>56%</td>
</tr>
<tr>
<td>Traverse</td>
<td>67%</td>
<td>33%</td>
<td></td>
</tr>
<tr>
<td>Spectrum</td>
<td>6%</td>
<td>88%</td>
<td>6%</td>
</tr>
<tr>
<td>Matrix</td>
<td>31%</td>
<td>31%</td>
<td>38%</td>
</tr>
<tr>
<td>Konijnport</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Helix</td>
<td>33%</td>
<td>42%</td>
<td>25%</td>
</tr>
<tr>
<td>Gemini-North</td>
<td>9%</td>
<td>45%</td>
<td>46%</td>
</tr>
<tr>
<td>Gemini-South</td>
<td>43%</td>
<td>16%</td>
<td>43%</td>
</tr>
<tr>
<td>Cyclotron</td>
<td>33%</td>
<td>51%</td>
<td>16%</td>
</tr>
<tr>
<td>Auditorium</td>
<td>8%</td>
<td>92%</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4: Functionally useful area distribution in TU/e campus buildings

So the energy utility index of TU/e campus buildings in comparable terms is calculated using the below formula

\[
EUL_{site-C} \left( \frac{kW/H}{m^2\cdot Yr} \right) = TE \ - \ ES4 \ + \ ES5 \ + \ E\cdot Ventilation \ + \ 10.5 \cdot GS1 \ + \ AS1 \ + \ AS2
\]

Energy consumed for ventilation in a typical Dutch residential home is \( \frac{2.4kW}{m^2\cdot Yr} \) [15], so here for TU/e campus buildings it is taken as \( \frac{3kW}{m^2\cdot Yr} \) as it is assumed that more
ventilation load is expected in an office building than residential buildings. The details of electricity consumed in the laboratories are not available separately as there is no separate sensor to monitor that. It is one of the drawbacks of this comparison.

2.3 Building Energy Performance Benchmarking

The building energy benchmarks are considered as an important tool to promote the efficient use of energy in office buildings. But the challenge here is to find the suitable benchmarks that could be applied for TU/e campus buildings, as each building is unique in its own way and energy consumption in a building depends on number of factors. So here in this section (step 4), the general factors that need to be considered for benchmarking TU/e campus buildings with typical office buildings are identified initially. It is of significant importance, as most commercial benchmarking tools (Energy Star, Energy IQ, Cal-Arch, Oak Ridge etc.) that are currently available are from different regions of the world (especially United States). And finally the EUI data sources that are taken for cross sectional benchmarking are listed.

2.3.1 Factors envisaged for building EUI comparisons

The factors on a macro scale that needs to be considered are

- Climate zones (Figure 5)
- Energy consumption per capita with different regions (See appendix A9)
- Annual working hours (See appendix A10)
- Expectations of comfort (set points) varies with different regions
- Occupancy rate inside the building
- Building benchmark calculations available in terms of GFA, sometimes in FUA
- The function of a building

Because of these factors, the benchmarks from the neighboring countries of Netherlands based on similar climate zone will be a sensible choice. This choice has been further motivated by the similarity in World energy per capita consumption of the selected countries. The annual working hours in the selected countries also shows similar numbers, when it is compared to United States and other regions. It is assumed that the expectations of comfort will be a lot similar in these selected regions, and the effect of occupancy rate is neglected. The data that are available in GFA is converted to FUA, by assuming $FUA = 0.9 \times GFA$. 
2.3.2 Comparable energy benchmarking with typical office buildings

TU/e campus buildings come under commercial buildings. But under commercial buildings, different categories were identified such as Public buildings, Warehouse, Educational buildings, Health care, Lodgings, office buildings etc. Since, the comparable energy represents mainly the energy consumed for office usage; it is benchmarked with typical office buildings of the selected countries.

2.3.3 EUI Data sources for benchmarks

The EUI data sources used for building benchmarking are listed below

- **ULI – Urban Land Institute**

  The ULI Greenprint Center for Building Performance is a nonprofit research and education organization supported by its members. It focuses in generating real estate solutions that improve the
environment through energy efficiency while demonstrating the correlation with increased property values.

EUI of typical office building properties located in different countries (France, Germany, United Kingdom etc.) is collected from here. These data’s are not directly comparable but offer meaningful comparisons for office benchmarks. [17]

- **EnOB-Research for energy optimized building**

  The research in EnOB is sponsored by the German Federal Ministry of Economics and Technology, involves research in buildings that have minimal primary energy requirements and high occupant comfort, with moderate investment costs and significantly reduced operating costs.

  During the EnOB initiative, 50 individual office buildings in Germany have been investigated for more than two years. Even though these buildings don’t allow direct comparison with the TU/e campus buildings, the comparable energy of the selected buildings can be benchmarked with “EnOB” monitored buildings, as it represents high energy efficiency.

- **Data hub for the energy performance of buildings**

  BPIE is an online database of energy consumption data across Europe. BPIE began collecting facts and figures on the European building stock in 2010 in the context of preparing its major study “Europe’s Buildings under the Microscope”, released in October 2011. BPIE includes technical data on building performance and can set search criteria.

  Typical Office Building EUI for France, commercial building average for Belgium, United Kingdom, and Germany are collected from this data source.
2.4 Energy prediction

A demonstration on, how the TU/e campus building’s perform in the future (year 2020) with the existing building stocks, is invaluable to initiate any strategic plans for design making. A lot of factors need to be considered for building energy predictions, macro factors ranging from climate change to micro factors like component efficiency. Here, two main factors are considered for energy predictions:

- System Efficiency for electricity consumption
- Heating Degree Days for Heating energy consumption

Here initially the base case year is identified for each end use for different TU/e campus buildings. For electricity, the year 2013 is taken as the base year energy consumption, as system efficiency is the only parameter considered for prediction. And it is known that it will only deteriorate. For heating, cooling and other end uses the median energy performance of the available readings are taken as the base case (Table 4). Since heating and cooling load inside a building is more a reflection of heating and cooling degree days, than the system efficiency.

<table>
<thead>
<tr>
<th></th>
<th>Base Year</th>
<th>Electricity ( \frac{kWh}{m^2*Yr} )</th>
<th>Base Year</th>
<th>Heating ( \frac{kWh}{m^2*Yr} )</th>
<th>Base Year</th>
<th>Cooling ( \frac{kWh}{m^2*Yr} )</th>
<th>Base Year</th>
<th>Other ( \frac{kWh}{m^2*Yr} )</th>
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<td>2013</td>
<td>284</td>
<td>2012</td>
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<td>177</td>
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<td>0</td>
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<td><strong>Auditorium</strong></td>
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<td>2005</td>
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<td>2012</td>
<td>32</td>
<td>-</td>
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<tr>
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<td>2005</td>
<td>238</td>
<td>2012</td>
<td>98</td>
<td>2005</td>
<td>286</td>
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<tr>
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<td>2005</td>
<td>76</td>
<td>2012</td>
<td>32</td>
<td>-</td>
<td>0</td>
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<tr>
<td><strong>Helix</strong></td>
<td>2013</td>
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<td>2006</td>
<td>347</td>
<td>2013</td>
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<td>-</td>
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<tr>
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<td>454</td>
<td>2006</td>
<td>35</td>
<td>2006</td>
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<td>2012</td>
<td>314</td>
<td>2005</td>
<td>300</td>
<td>2010</td>
<td>142</td>
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<tr>
<td><strong>Vertigo</strong></td>
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<td>140</td>
<td>2005</td>
<td>76</td>
<td>2011</td>
<td>33</td>
<td>2006</td>
<td>93</td>
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<tr>
<td><strong>Kennisport</strong></td>
<td>2013</td>
<td>149</td>
<td>2011</td>
<td>66</td>
<td>2010</td>
<td>35</td>
<td>-</td>
<td>0</td>
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<tr>
<td><strong>Spectrum</strong></td>
<td>2013</td>
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<td>2010</td>
<td>67</td>
<td>2010</td>
<td>537</td>
<td>-</td>
<td>0</td>
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</tbody>
</table>

Table 4: Base case year and end use energy consumption of TU/e campus buildings

From the KNMI weather data ([18]), it is observed that on a micro scale, that the effect of climate change on ambient temperature and the number of heating degree days are
not linear. It is further motivated by globally averaged CO₂ concentration trend observed at Mauna Loa (appendix A1). So, for the year 2020 energy predictions, two extreme scenarios of the last 10 year heating degree days are considered.

Scenario 1: Maximum HDD experienced over the last 10 years= 3191

Scenario 2: Minimum HDD experienced over the last 10 years= 2473

Assuming the heating demand in a building is a function of heating degree days, for scenario 1 and scenario 2 the percentage increase/decrease in HDD of the base year with respect to the extreme conditions are taken as the respective increase/decrease in the heating energy demand. For both cases the cooling energy demand and energy used for “Other” is taken as the median year performance. Because, the calculated CDD are too low for an effective comparison (Appendix A12) and clear prediction is not possible with energy usage in the laboratory and the fluctuating loads. The percentage change in electricity usage is based on extrapolation of the previous years.
### Table 5: Increase in energy demand in 2020 compared to 2014

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Electricity Increase</th>
<th>Heating Increase</th>
<th>Total Increase</th>
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<td>SCENARIO 1</td>
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<tr>
<td>Matrix Auditorium</td>
<td>15%</td>
<td>14%</td>
<td>12%</td>
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<tr>
<td>Gemini-South</td>
<td>8%</td>
<td>8%</td>
<td>8%</td>
</tr>
<tr>
<td>Traverse</td>
<td>9%</td>
<td>19%</td>
<td>8%</td>
</tr>
<tr>
<td>Helix</td>
<td>16%</td>
<td>19%</td>
<td>14%</td>
</tr>
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<td>10%</td>
<td>25%</td>
<td>15%</td>
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<td>9%</td>
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<td>Vertigo</td>
<td>8%</td>
<td>14%</td>
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<tr>
<td>Kennisport</td>
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<tr>
<td>Spectrum</td>
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<td>1%</td>
<td>3%</td>
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### Table 6: Qualitative comparison of relevant green building rating schemes

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<th>Parameters</th>
<th>LEED (O+M)</th>
<th>BREEAM (IN-USE)</th>
<th>DGNB (Existing Offices)</th>
<th>LIVING BUILDING CHALLENGE</th>
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<td>Scope</td>
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<td>+1</td>
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<td>CO2 Emissions</td>
<td>x1</td>
<td>+2</td>
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<td>Financial aspects</td>
<td>x4</td>
<td>-</td>
<td>-</td>
<td>+3</td>
</tr>
<tr>
<td>Beauty and Awareness</td>
<td>x3</td>
<td>+1</td>
<td>+1</td>
<td>+1</td>
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<td>Sustainability</td>
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<td>+1</td>
<td>+1</td>
<td>+1</td>
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<tr>
<td>Suitability in Netherlands</td>
<td>x3</td>
<td>+1</td>
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<td>+3</td>
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<tr>
<td>Annual Expenses on Energy</td>
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<td>+3</td>
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<tr>
<td>Energy Benchmarking/Net zero energy building</td>
<td>x3</td>
<td>+2</td>
<td>+1</td>
<td>+1</td>
</tr>
<tr>
<td>Base case building performance (simulation)</td>
<td>x1</td>
<td>+2</td>
<td>+3</td>
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</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>34</td>
<td>36</td>
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</table>

#### 3 Results and Discussion

#### 3.1 Relevant green building rating schemes
At present BREEAM and LEED are the most widely used labelling scheme with more than 260000 and 200000 certifications respectively. This global acceptance of these two schemes is considered an important parameter for the choice of these two schemes. The nucleus of BREEAM is mainly concentrated in reducing emissions of CO₂ caused by energy consumption in buildings, on the other hand LEED put its emphasis in reducing annual expenses on energy in buildings [19]. Living building challenge gave high significance to make all their certified buildings have zero impact to the surroundings, by giving aspirational goals to the building community like net zero energy, net zero water and net zero waste. And that makes Living Building Challenge a more sustainable friendly scheme compared to the other schemes.

The absence of financial aspects in the evaluation framework of BREEAM, LEED and Living Building Challenge undermines the schemes and makes it less attractive from the investor point of view. Since financial return is considered the basis to all the projects, the resulting project may be environmentally performing good, but at the outflow of high investment cost. For example, installing more windows to allow for passive ventilation and more daylight by replacing an existing ventilation system may be difficult, as it may be very expensive to facilitate [5] This makes the DGNB system an attractive one, as both financial concerns and environmental issues are going hand in hand to a certain level.

The regional acceptance is also an important factor to consider because each labelling scheme has been adapted to suit the region of origin in which they are to be used [6]. Because it is sensible to assume that the labelling schemes will not give a fair judgment, if it is used in other regions of the world. For example, a quick comparison of ASHRAE 90.1 and UK Building Regulations suggest that some targets for energy efficiency are lower in the US than in the UK. So, DGNB, based from Germany, has that regional advantage alongside BREEAM, as BREEAM-NL is the adapted version of BREEAM in Netherlands.

In terms of Building Performance Simulation, a study by [20] shows that BREEAM’s ‘Notional building’ consumes 18% less energy than LEED’s ‘Baseline building’ which may result in a standard level LEED building (Silver or Gold) is considered to have low performance under BREEAM (Between “Pass” and “Very good. Considering the recent importance of Building Performance Simulation in the design, operation and management of the building, this percentage difference in assessment clearly shows the weaknesses of these conventional systems. And altogether, it is considered the largest disadvantage of all these (LEED, BREEAM & DGNB) different green rating tools, the same building is evaluated ‘green’ with some tools might “not be green” with
other tools”[8]. In this terms, the philosophy of Living Building challenge, Net zero impact, stands unique. And their certification is based on actual performance of the building. The importance that “Living Building Challenge “ is giving on beauty, awareness and the social dimension of sustainability is appreciable, in fact, DGNB and other multi-criteria systems poorly consider the social dimension of sustainability [3].

Legally defined critical values for energy consumption are generally below those required for Green Buildings. These critical values are usually set in a manner that allows for marketable products to be used. But with the directive, 2010/31/EU [21], even the laws are aiming for “net zero energy buildings” for the future. And this importance towards net zero energy buildings are highly visible in Living Building Challenge. After all, for existing buildings, operational energy is the prime factor to be considered, since it is one of the measurable quantities.

3.2 Results for current Operational energy performance of TU/e campus Buildings

Here the performance indicator for TU/e campus building’s energy efficiency are represented in two ways, the total operational energy performance (Figure 7) and the comparable energy performance (Figure 8), and the outcome is presented with the help of box plots. The mean and median are denoted in the box plots, to show the average energy performance of the TU/e campus buildings and where the mid-points are located. The amounts of variation in the data points (selected years) are represented in the form of standard deviation, it is shown on either sides of the mean point, taking the mean as the mid-point. The advantage of putting median in these plots is that it gives a fair idea about where most of the data points are located. In addition to this, the maximum and the minimum of these data points are also illustrated at both ends of the box plot for the selected years.
In terms of total energy consumption, it can be noted that from Figure 7, Cyclotron and Spectrum building are having the highest of $EUI_{site}$ with $1398 \frac{kWh}{m^2\cdot yr}$ and $1351 \frac{kWh}{m^2\cdot yr}$ respectively, against Traverse, Kennisport and Vertigo buildings with smallest $EUI_{site}$ of $182 \frac{kWh}{m^2\cdot yr}$, $291 \frac{kWh}{m^2\cdot yr}$ and $325 \frac{kWh}{m^2\cdot yr}$ respectively. As it can be noted that (from appendix A17), this high value of $EUI_{site}$ in Cyclotron and Spectrum building is mainly because of the high consumption rate in electrical energy, $593 \frac{kWh}{m^2\cdot yr}$ and $791 \frac{kWh}{m^2\cdot yr}$ respectively. Comparatively Stable performance (low standard deviation and lower consumption rate) is observed in Traverse, Vertigo and Kennisport, in all segments of energy uses (appendix A17, A18 and A19).

The above readings provide the basis for total energy consumption rate in the TU/e campus buildings, but the total energy consumption cannot be considered as an “energy efficiency performance indicator” for comparison between buildings. Since the end-uses of energy are different in different campus buildings, i.e. the purpose of each building is different. For example, the traverse building represents a typical office building, whereas Spectrum and Cyclotron building’s $FUA$ are distributed with 51% and 88% of laboratory space respectively (Figure 4). That means the energy has been
used for different purposes. So the relative performance of the building in terms of “comparable energy performance” is of significance.

In terms of comparable energy (Figure 8), “Vertigo” (178 $kWh/m^2\cdot yr$) and “Traverse” (169 $kWh/m^2\cdot yr$) is found as energy efficient in the selected list of buildings. Even though “Cyclotron” and “Spectrum” building are from “Type 2” buildings list (T2-relatively new buildings, Table 1), the $EUI_{site-c}$ is found higher with 1240 $kWh/m^2\cdot yr$ and 998 $kWh/m^2\cdot yr$ respectively. It means one of the initial assumption that the “T2 building perform better than the T1 buildings” is found contradicting here. Further, the Matrix building and Helix building are also found to be less energy efficient.

One of the main difference in comparing Figure 7 and Figure 8 is that, the standard deviation of the buildings has been reduced except for Matrix and Cyclotron. For Gemini-North, the decrease in standard deviation is found as 65% (appendix A8). This clarifies that the energy use in the laboratories and the fluctuating loads are highly varying, and this further express the significance of “comparable energy” comparisons.
But, the presence of electricity used in the laboratories (Figure 3) in comparable energy calculation of TU/e campus buildings, makes the comparison weak here. With sub-metering, detailed comparisons are possible.

From Figure 9, the building performance or energy efficiency of a building is decreasing with years. Even though there are factors other than energy efficiency, which determines the energy consumption in a building, the increase of 34% in electrical energy consumption and 46% in heating energy in Cyclotron building, 33% of heating energy consumption in Helix building is worth investigating. The overall increase of 37% in matrix and 19% in Spectrum makes it one of the first buildings that need to be monitored for modernization purposes. Considering Cyclotron & Spectrum is from the T2 sect of building, its performance is also considered very low and needs to be checked next to matrix building. With Sub-metering to the systems level, where exactly the energy efficiency is decreasing can be found out.
3.3 Cross Sectional Benchmarking of TU/e campus buildings

Here in this section, the “comparable energy” (Mean) of TU/e campus buildings are benchmarked with typical office building average in the selected countries (Figure 5). Regarding energy efficiency of the buildings, the comparable energy performance is considered important in this report. But with the use of Aquifer Thermal Energy Storage, certain amount of energy is conserved in most of the TU/e campus buildings. The energy use in TU/e campus buildings can be viewed as, Comparable energy, Comparable energy without energy consumption from ATES and the total energy consumed.

![Figure 10: Building Energy Benchmarks (01): Average energy consumption in office buildings in the same region](image-url)
In Figure 10, typical office building average across the selected countries is used for comparing with TU/e campus buildings. It is observed that TU/e campus buildings “comparable energy” is far above the average of this typical office building averages obtained from “BPIE” [22]. Even with good energy conservation from ATES, the average is found to be higher than the typical office building averages.

For benchmarking energy performance of TU/e campus buildings, the “comparable energy” of “Traverse and Vertigo” itself is a good initial benchmark for the other campus buildings, as it shares the advantages of same location. In Figure 11, “ULI”[17] and “EnoB” monitored buildings, which represents high energy efficiency buildings are taken for comparison with Vertigo and Traverse building. These buildings especially “EnoB” monitored buildings integrate many energy efficient technologies like night ventilation with ambient air, discharged heat stored in internal building mass by the use of natural heat sinks and the usage of novel materials like capillary-active interior insulation, vacuum insulation etc. In addition, many tools are developed in automated data processing, visualization and fault detection [23]. So, for the comparable energy performance of Vertigo and Traverse building, “EnOB” monitored buildings (Average EUI of $110\frac{kWh}{m^2*at}$) can be taken as a benchmark, as it represents high energy efficient buildings.
3.4 Energy prediction for campus 2020

In Figure 12 and Figure 13, the first column represents the base-line energy consumption and the second column represents the scenarios for the year 2020. It is found that the pattern of building energy consumption is different for different campus buildings, but in majority of the TU/e campus buildings, the space heating is the most energy-intensive end-use, followed by electricity usage comprising lighting, computer, open ports, ventilation etc. In Cyclotron, vertigo, Kennisport and Spectrum, the electricity usage is the most energy-intensive end-use. It is interesting to see that in both high consuming buildings Cyclotron and Spectrum, space-cooling energy consumption is a lot higher than the space-heating consumption, considering Heating Degree Days days in Eindhoven are high compared to the Cooling Degree Days.

Figure 12: Scenario 1, Predicted energy performance of TU/e campus buildings
Figure 13: Scenario 2: Predicted energy performance of TU/e campus buildings

In column 2 representing scenario 1, explains that the total energy consumption of all TU/e campus buildings will increase. While, in column 2 representing scenario 2, explains that even with the lowest case of HDD there is no reduction can be expected in the base-line scenario. It means that the increase in total energy consumption with the existing building stock is unavoidable. In scenario 2, in terms of energy efficiency, only deterioration in electricity consumption is considered, but in most buildings it overcomes the advantage gained by the low number of Heating Degree Days. Further, the effect of change in cooling degree days is not considered for this study, as it was found very low for any prediction (appendix A12), it will certainly have an important effect in future, as it is also an indicator of climate change [24].

Energy prediction for multi end use buildings like TU/e campus buildings depends on wide variety of factors; these 2 extreme scenarios in HDD are considered to show the importance of energy efficiency in the future scenario. With these existing buildings in TU/e campus, the energy consumption is certainly going to increase in the future, so energy efficiency improvement plans of the existing building stock should be the prime focus for campus 2020 plans.
4 Conclusion & Recommendations

Keeping “TU/e campus 2020” plans in mind, the main findings of this project and conclusions are listed below

1) From a long list of green building labelling schemes, four schemes are shortlisted “LEED” & “BREEAM” based on scope, DGNB based on its uniqueness in financial aspects and “Living Building Challenge”, presently the most rigorous assessment of sustainability. On comparison between these selected schemes, it is found that financial aspects, regional aspects and net zero energy aspects are of high significance in the present scenario. So “DGNB “and “Living Building Challenge” are the best suitable schemes for the future campus plans of TU/e campus buildings.

2) The “comparable energy” shows that building “Vertigo” & “Traverse” are the high energy efficient buildings with EUI of 167 $\frac{\text{KWH}}{m^2 \cdot \text{Yr}}$ and 169 $\frac{\text{KWH}}{m^2 \cdot \text{Yr}}$ “Cyclotron” & “Spectrum” are found low energy efficient with EUI of 1240 $\frac{\text{KWH}}{m^2 \cdot \text{Yr}}$ and 998 $\frac{\text{KWH}}{m^2 \cdot \text{Yr}}$. Considering “Cyclotron” and “Spectrum” are from the T2 sect of buildings (new buildings), this buildings energy performance should be monitored alongside Matrix and Helix building.

3) On comparing the past performance and present performance of TU/e campus buildings, it is found that the energy efficiency of the TU/e campus buildings are deteriorating. Matrix building shows the highest in energy efficiency deterioration with a percentage increase in EUI of 37%.

4) For the TU/e campus buildings, the comparable energy performance of “Traverse and Vertigo” is taken as a benchmark as it shares the advantages of same location. Moreover, it is suggested that, “EnOB” monitored energy efficient buildings (Average EUI of 110 $\frac{\text{KWH}}{m^2 \cdot \text{Yr}}$) can be taken as a benchmark for Vertigo and Traverse building.

5) 2 extreme scenarios in heating degree days are taken for energy prediction in 2020. In the low heating degree day scenario, it is found that, in most of the TU/e campus buildings, the advantage gained in space heating, is overcome by degradation in electrical energy efficiency. So, the increase in total energy consumption with the existing building stock is unavoidable.
From the results, the calculation of comparable energy of TU/e campus buildings make the comparison with typical office buildings meaningful. With sub-metering (especially for electricity consumed in the laboratories) the comparable energy calculations will become accurate for benchmarking with typical office buildings. Further, energy consumption is certainly going to increase in the future, so energy efficiency improvement plans of the existing building stock should be the prime focus for campus 2020 plans. It will enhance the opportunities to become a more sustainable campus with low environmental footprint for the year 2020.

5 References


## Appendix

### 6.1 A1- Green Building Labelling schemes

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<th>COUNTRY</th>
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<th>AUTHORIZING MANAGEMENT</th>
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<td>Canada-GBC</td>
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<td></td>
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<td>Australian Green Building Council</td>
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<td>NABERS <em>(National Australian Building Environmental Rating Scheme)</em></td>
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<td>SBAT <em>(Sustainable Building Assessment Tool)</em></td>
<td>CSIR <em>(Council for Scientific and Industrial Research)</em></td>
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Table 7: List of green building labelling schemes [25],[26], [27]
6.2 A2-Description of selected rating schemes

The BREEAM was planned at the beginning of the 1990s by UK- Green Building Council and was the first multi-criterion system for sustainability assessment. The evaluation is based on performance of a building related to energy and water use, the internal environment (health and well-being), pollution, transport, materials, waste, ecology and management processes. BREEAM –In USE is a scheme to help building managers reduce the running costs and improve the environmental performance of existing buildings.

Figure 14: BREEAM IN-USE category weightage for building sustainability assessment

LEED is developed by the US Green Building Council (USGBC) in 2000. LEED provides verification for the design, construction and operation for green buildings. The evaluation is based on performance of a building related to location and transportation, sustainable sites, water efficiency, energy and atmosphere, materials and resources, the indoor environment quality, innovation, regional priority and integrative process.
The German Sustainable Building Council (DGNB – Deutsche Gesellschaft für Nachhaltiges Bauen) was founded in 2007. The evaluation is based on a set of criteria covering six topics related to sustainable construction, comprising: 1) Environmental Quality 2) Economic Quality 3) Sociocultural and Functional Quality 4) Technical Quality 5) Process Quality 6) Site Quality.
Living Building Challenge is founded by Cascadia Green Building Council and is considered the most rigorous and broadminded Green building system in the world. It has 7 performance areas named as petals, apart from other conventional rating systems beauty, inspiration and education are included for assessment.
6.3 A3 Electricity Sensor distribution in TU/ campus buildings

Electricity Main line connections
Figure 19: Electricity Main line connection to the TU/e campus buildings
Electricity Emergency line connections

Figure 20: Electricity emergency connection to the TU/e campus buildings
6.4 A4-List of selected sensors

- Energy data collected for these below mentioned sensors.
- HNLK-Electricity, Emergency supply, Sensor ES1
- HLK-Electricity Constant load, Sensor ES2
- HRK-Electricity, Semi fluctuating, Sensor ES3
- HOK/HVK-Electricity, Fluctuating, Sensor ES4
- HP- Electricity, Heat pump, Sensor ES5
- High pressure-Gas, Sensor GS1
- Low pressure-Gas, Sensor GS2

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<th>Sensors</th>
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<tr>
<td>1. Sportcentrum</td>
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<tr>
<td>a. 07GAS-xxxxxx-DAT-COL (Low Pressure)</td>
</tr>
<tr>
<td>b. 07GAS-xxxxxx-DAT-COL (Low Pressure) (Swimming pool)</td>
</tr>
<tr>
<td>c. 07EL-030602-DAT-COL</td>
</tr>
<tr>
<td>i. 07ELT-040301-DAT-COL (Sportcentrum)</td>
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<tr>
<td>ii. 07ELT----------DAT-COL (Sportcentrum+Tenrispaviljoen)</td>
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<tr>
<td>iii. 07EL-031501-DAT-COL</td>
</tr>
<tr>
<td>1. 07EL2--------DAT-COL (Swimming pool extra)</td>
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<tr>
<td>2. 07EL------------ (Control cabin)</td>
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<tr>
<td>3. 07EL-081002-DAT-COL (Change rooms)</td>
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<td>4. 07EL-080801-DAT-COL (HP1)</td>
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<td>5. 07EL-080901-DAT-COL (HP2)</td>
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<td>6. 07EL-081502-DAT-COL (HVAC swimming pool)</td>
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<td>d. 07NK-030702-DAT-COL (emergency)</td>
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<td>2. Auditorium</td>
</tr>
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<tr>
<td>b. 13GAS-030701-DAT-COL (High Pressure)</td>
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<tr>
<td>c. 13EL-070602-DAT-COL (HLK)</td>
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<tr>
<td>d. 13EL-070901-DAT-COL (HLK)</td>
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<td>e. 13NK-070701-DAT-COL (minus 1 below)</td>
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<td>f. 51EL-020801-DAT-COL (HR1K)</td>
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<td>g. 51EL-020702-DAT-COL (emergency power)</td>
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<td>c. 55GAS-xxxxxx-DAT-COL (High Pressure)</td>
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<td>i. 54ELT-031301-DAT-COL (Gaslab)</td>
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<td>a. 82GAS2-1P76-8_DAT_COL (Low pressure)</td>
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<tr>
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<td>b. 82GAS-xxxxxxx_DAT_COL (High pressure)</td>
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<td>c. 81ELT-061201-DAT-COL (HRK)</td>
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<tr>
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| Figure 21: List of selected sensors |
### Bijlage 7: Verbruiken per gebouw

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**In 2005**

- Ceres: 1,200,000 kWh (January - December)
- Verpins: 2,400,000 kWh (January - December)

**In 2006**

- Ceres: 1,400,000 kWh (January - December)
- Verpins: 2,600,000 kWh (January - December)

**In 2007**

- Ceres: 1,600,000 kWh (January - December)
- Verpins: 2,800,000 kWh (January - December)

**In 2008**

- Ceres: 1,800,000 kWh (January - December)
- Verpins: 3,000,000 kWh (January - December)

**In 2009**

- Ceres: 2,000,000 kWh (January - December)
- Verpins: 3,200,000 kWh (January - December)

**In 2010**

- Ceres: 2,200,000 kWh (January - December)
- Verpins: 3,400,000 kWh (January - December)

**In 2011**

- Ceres: 2,400,000 kWh (January - December)
- Verpins: 3,600,000 kWh (January - December)

**In 2012**

- Ceres: 2,600,000 kWh (January - December)
- Verpins: 3,800,000 kWh (January - December)

**In 2013**

- Ceres: 2,800,000 kWh (January - December)
- Verpins: 4,000,000 kWh (January - December)

**In 2014**

- Ceres: 3,000,000 kWh (January - December)
- Verpins: 4,200,000 kWh (January - December)

**In 2015**

- Ceres: 3,200,000 kWh (January - December)
- Verpins: 4,400,000 kWh (January - December)
### Figure 22: Annual Energy consumption report-2004

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<th>Gebouwnaam</th>
<th>Energieconsumptie (hda)</th>
<th>Energieproductie (hda)</th>
<th>Energieverbruik (hda)</th>
<th>Opmerkingen</th>
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<tbody>
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<td>81</td>
<td>W Hoog</td>
<td>15.026</td>
<td>2.775</td>
<td>12.251</td>
<td>In 2003 is het gebouw overgegaan op decenteelstroom</td>
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<tr>
<td>82</td>
<td>W Land</td>
<td>4.120</td>
<td>1.502</td>
<td>2.618</td>
<td>In 2003 is het gebouw overgegaan op decenteelstroom</td>
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<td>83</td>
<td>Laplace</td>
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<td>Studentencentrum</td>
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<td>Totaal gas maandelijks 28.170 GJ.</td>
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### Bijlage 7: Verbruik per gebouw

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*Note: Year in the header indicates data is for the year 2004.*

**Figure 23: Annual Energy Consumption Report-2005**
### Bijlage 7: Verbruik per gebouw

**Overzicht energieverbruiken per gebouw 2005**

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*Figuur 26: Jaaroverslag 2011-2013*
6.6 A6-Total Energy/Comparable energy consumption (Site Energy)

- Total Energy = Other Energy + Energy Heating + Energy cooling + Energy Electricity
- Comparable Energy = Energy Heating + Energy cooling + Energy Electricity
- The orange colored cells are the corrected reading after verifying with Annual energy report.

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Table 8: Total Energy /Comparable energy consumption of TU/e campus buildings
### 6.7 A7-Primary Energy (Electricity and Gas)

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Vertigo-(FUA=4173m)

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Table 9: Primary energy consumption (Electricity & Gas) in TU/e campus buildings
### Table 10: Mean, Median, SD, Maximum & Minimum of Total/Comparable energy consumption

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6.9 A9- Annual Energy per capita consumption

Figure 27: World Annual energy consumption per capita[28]

6.10 A10-Average Annual Working Hours (OECD)

Figure 28: Average annual working hours per worker[29]
6.11 A11-Monthly Mean CO$_2$ at Mauna Loa

Figure 29: Monthly mean CO$_2$ at Mauna LOA [30]

6.12 A12-Cooling Degree Days-Eindhoven

Figure 30: Cooling degree days in Eindhoven[18]
6.13 A13-Process of certification in Green building rating schemes

Figure 31: Process of certification in the selected rating schemes

6.14 A14-(U-Values) of buildings in the neighbouring countries

Figure 32: U-Values of different building component in the selected neighboring countries of Netherlands [22]
6.15 A15-Annual Primary Energy consumption in the TU/e campus Buildings

Figure 33: Annual primary energy consumption in the TU/e campus buildings

6.16 A16-Annual CO₂ Emissions from the TU/e campus Buildings

Figure 34: Annual CO₂ emissions per square meter from the TU/e campus buildings
6.17 A17-Annual Electrical Energy per square meter of TU/e Campus Buildings

Figure 35: Annual electricity energy consumed per square meter in the TU/e campus buildings
6.18 A18-Annual heating Energy Consumption in TU/e campus Buildings

Figure 36: Annual electricity energy consumed per square meter in the TU/e campus buildings
6.19 A19-Annual Energy consumption without ATES

Figure 37: Annual Energy consumption without ATES