HOTEL AMSTELKWARTIER
Towards nearly-Zero Energy Hotel by applying Renewable Energy Technology

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HOTEL AMSTELKWARTIER
Towards nearly-Zero Energy Hotel by applying Renewable Energy Technology

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ABSTRACT
This master-thesis is a co-operation between the Technical University of Eindhoven and the company Wolter & Dros, specialist in the field of building services in the Netherlands. The study presents an analysis of the economical and environmental feasibility of applying renewable energy technology (RET) in the hotel Amstelkwartier. Assessment criteria comprised life cycle cost (LCC) and renewable fraction (RF). Difference in life cycle cost (dLCC) is used for comparison with respect to the original state of the energy supply system, where a negative dLCC represents money saving. The RET software HOMER (National Renewable Energy Laboratory, US) was utilized as the assessment tool with modeling. A prediction of the required hourly energy load data is made, as a part of the current study. The current energy supply system contains a combined heat and power (CHP) system running on bio-oil, leading to an expected RF of 57.5%.

RET improvement options as wind turbine and photovoltaic (PV) packages in addition to the current energy supply system are evaluated. Three types of PV packages are taken into consideration: PV panels installed on the own roof, the southern façade of the hotel and PV packages installed on a nearby building by renting an external roof. Installing 500 m² of PV panels on a nearby building, and 240 m² PV at the own roof is the cost optimal solution, resulting in an expected difference in LCC of -€ 41,452 over 25 years and an increased RF from 57.5% to 67.6%. The installation of PV panels on the southern façade is highly visible and will contribute to the 'green' image of the hotel, but doesn’t appear to be profitable. The economical feasibility of installing PV panels on neighbor buildings strongly depends on the roof rental cost. When considering annual roof rental cost of 5 €/m², the cost optimal area of nearby PV is 500 m². Higher roof rental cost lead to an unprofitable PV system for installation on neighbor buildings.

The installation of a wind turbine under default settings in HOMER not profitable. However, one can wonder about the reliability of this prediction. The uncertainty of the expected wind speed above the building can lead to wrong conclusions concerning the economical viability. This requires further research in the wind behavior above the building for a reliable decision making concerning the installation of a wind turbine.

Keywords: hotel; renewable energy technology; wind; photovoltaic; biomass; life cycle cost; renewable fraction; optimization software.
**NOMENCLATURE**

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<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Notes</th>
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<tbody>
<tr>
<td>Base-case</td>
<td>: reference-case. In this study: the current situation of the hotel's energy system</td>
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<tr>
<td>BIPV</td>
<td>: building integrated photo voltaic</td>
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<tr>
<td>CHP</td>
<td>: combined heat and power</td>
<td></td>
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<tr>
<td>COP</td>
<td>: coefficient of performance</td>
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<tr>
<td>CRF</td>
<td>: capital recovery factor</td>
<td></td>
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<td>DHW</td>
<td>: domestic hot water</td>
<td></td>
</tr>
<tr>
<td>GHG</td>
<td>: green house gases</td>
<td></td>
</tr>
<tr>
<td>HOMER</td>
<td>: hybrid optimization of multiple energy resources, simulation software used for renewable energy modeling</td>
<td></td>
</tr>
<tr>
<td>i</td>
<td>: real discount rate</td>
<td></td>
</tr>
<tr>
<td>LCC</td>
<td>: life cycle cost</td>
<td></td>
</tr>
<tr>
<td>dLCC</td>
<td>: difference in life cycle cost</td>
<td></td>
</tr>
<tr>
<td>LEED</td>
<td>: leadership in energy and environmental design</td>
<td></td>
</tr>
<tr>
<td>nZEB</td>
<td>: nearly-zero energy building</td>
<td></td>
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<tr>
<td>nZEH</td>
<td>: nearly-zero energy hotel</td>
<td></td>
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<tr>
<td>OC</td>
<td>: operating cost</td>
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</tr>
<tr>
<td>PV</td>
<td>: photo voltaic</td>
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<td>RET</td>
<td>: renewable energy technology</td>
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<tr>
<td>RF</td>
<td>: renewable fraction</td>
<td></td>
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<tr>
<td>U-value</td>
<td>: coefficient of heat transmission</td>
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<td>USGBC</td>
<td>: U.S. Green Building Council</td>
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1 INTRODUCTION

1.1 BACKGROUND

The rapidly growing world energy consumption is leading to exhaustion of energy resources and heavy environmental impacts as global warming, climate change etc. Buildings contribute on a global scale between 20% and 40% of the energy consumption and also have a great part in the global emission of carbon dioxide, with an estimated share of 30% [1,2].

More specifically, the energy consumed by hotels is higher than the energy consumption of other commercial buildings. A typical hotel’s annual power consumption ranges from 250 to 350 kWh/m$^2$. For large hotels (>100 beds) it ranges from 450 to 700 kWh/m$^2$, versus a typical commercial building’s power consumption between 30 and 152 kWh/m$^2$ [3,4]. Moreover, hotel buildings have a unique energy profile. Specific hotel sector characteristics are [5]:

- 24-h operation;
- Higher degree of comfort provision;
- Low tolerance for failure;
- Two daily load peaks.

These characteristics necessitate a separate assessment of studies as RET viability in the hotel sector. Renewable energy technology (RET) in buildings contributes in reducing the environmental impact. Besides the environmental incentive, a well designed RET system can lead to economical benefit. Moreover, the ‘green’ image makes the hotel more attractive for customers.

Building certification systems provide third-party verification about improving performance in energy savings, water efficiency, CO$_2$ emission reduction and improved indoor environmental quality. LEED is one of the main certification instances, developed by the U.S. Green Building Council (USGBC). LEED certifies buildings as ‘certified’, ‘Silver’, ‘Gold’ or ‘Platinum’. Buildings can receive a LEED certification for the building design, construction and the commissioning of the building. The requirements of the LEED certification increase in time under the influence of the development of new technologies and governmental regulations. RET can help buildings in meeting new requirements to the LEED certificate in the future.

The annual and daily pattern of energy flows in hotel buildings is extensively evaluated in a Korean study [6]. A RET assessment for a large-scale grid connected hotel in Australia concluded that wind turbines and PV in combination with grid-supply resulted in a competitive life cycle cost (LCC) in comparison with grid-only [16]. A comparable conclusion is shown in a Greek research [7], where an energy supply mix of renewable sources and conventional sources leads to a reduction of the total energy cost. Bakos and Sourcos [8] reported a successful PV set-up for a small/medium-scale tourist operation (450 kWh/day) in Greece, concluding that the configuration was not viable at the current grid-electricity prices. Two other studies examined the technical feasibility of building integrated PV in hotels, concluding that different design options have varying results in performance [9,10] but neither conducted economic assessments. The different findings of the several studies indicate the necessity of a separate assessment of RET in any case-study.
1.2 THE CURRENT STUDY

The company Wolter & Dros is a specialist in the field of building systems and is part of TBI, active on the Dutch market. This master thesis is a co-operation between Wolter & Dros and the Technical University of Eindhoven in the sphere of renewable energy systems for hotels.

This study concerns the upcoming new hotel Amstelkwartier, which construction will be completed by the end of 2015. The TBI enterprises J.P. van Eesteren, Croon Elektrotechniek and Wolter & Dros are responsible for the realization of the building. Hotel Amstelkwartier will be the first hotel in Europe awarded with a LEED platinum certificate for building operation. The award is mainly merit of the hotel’s expected low energy consumption, grey water system, green roof area, renewable energy generation by the CHP system and the use of sustainable materials. The low expected thermal energy demand is mainly caused by the adaptable façade, which adapts under influence of the weather conditions by increasing the overall U-value and regulating the sun admittance.

Wolter & Dros will be responsible for the commissioning of the building, where the platinum LEED certificate for building operation needs to be retained. Applying RET can help to meet the expected increasing requirements of the LEED certificate. Therefore a research towards applying RET in hotel Amstelkwartier is conducted, formulated by the following design question:

- Is it economically and environmentally feasible to apply renewable energy technology in the current energy supply system of hotel Amstelkwartier?

To examine these issues, a case-study analysis was conducted for the hotel Amstelkwartier in Amsterdam.

Mismatch between renewable energy production and consumption is the biggest drawback in RET applications, necessitating a prediction of the hourly energy consumption of the hotel. The hourly energy load data is estimated using various techniques. Modeling software for distributed power was used to examine the research aims. HOMER, software produced by the National Renewable Energy Laboratory, US [11] was chosen as the primary application for this study due to its extensive use in precious RET case studies [12,13] and RET validation tests [14,15].

The structure of the report follows the methodology as described in Figure 1. The applied methodology is shown in section 2, while section 3 contains the case-study of the hotel Amstelkwartier (phase 1, 2 and 3 in the methodology). The results and discussion, including a LCC based decision making and sensitivity analysis is shown in section 4, after which recommendations are given in section 5.
2 METHODOLOGY

The proposed methodology to assess the application of RET in hotel Amstelkwartier is described in section 2. An overview of the methodology, consisting of 4 research phases, is shown in Figure 1.

Mismatch in renewable energy supply and consumption is the biggest drawback in RET systems, requiring data about the hourly electrical load. Phase 1 of this research consists of the collecting of all relevant building and system information and is described in section 2.1. Phase 2 consists of the energy performance prediction and is described in section 2.2. Phase 3 defines the improvement options and offers for further evaluation in HOMER and is described in section 2.3. The cost optimality analysis and the sensitivity analysis (phase 4) is described in section 2.4.
2.1 **Phase (1) Collecting building and system information**

The objective of phase 1 is to obtain full understanding of the hotel’s design and energy system. Wolter & Dros provided the information about the hotel, the energy system and the prediction of the energy performance. The energy performance predictions are obtained by calculations and simulations with the program 'VABI114', resulting in annual data about the predicted energy performance. The annual data of predicted energy consumption is used to predict the hourly data and to validate simulations performed with the building simulation tool IES VE for the heating and cooling demand.

2.2 **Phase (2) Energy performance prediction**

For the evaluation of improving the current energy supply system by applying RET, a prediction of the hourly electrical load data is necessary. The objective of phase 2 is to predict of the hourly electricity load from the grid.

In the energy system of the hotel, the different types of energy demands as space heating, space cooling, DHW and electricity all influence the resulting electricity demand from the grid. Therefore a prediction of these energy demands of the hotel is required, resulting in an energy need prediction from the grid. Section 2.2.1 describes the prediction of the heating and cooling demand, section 2.2.2 describes the estimation of the DHW demand while in section 2.2.3 the plug-load and lighting demand is estimated. Section 2.2.4 explains how the resulting electricity need from the grid is predicted.

2.2.1 **Heating and cooling prediction**

The heating and cooling demand of the hotel is mainly supplied by a heat pump which electricity consumption contributes for a significant part to the total electricity consumption. The heating and cooling demand is predicted with the simulation software IES VE. The IES VE results of the heating and cooling demand are scaled up to reach the annual heating and cooling demand as predicted by Wolter & Dros (Figure 4). The simulations of IES VE result in hourly thermal load data of the hotel. The thermal load is converted into electrical consumption of the heat pump using the COP of the supply system, according to equation 1:

\[
E_h^d = \frac{Q_h^d}{\text{COP}_{\text{sys}}} \quad (1) \quad [6]
\]

Where:
- \(E_h^d\) = electrical demand on the h-th hour of the d-th day;
- \(Q_h^d\) = heating or cooling demand on the h-th hour of the d-th day;
- \(\text{COP}_{\text{sys}}\) = coefficient of power of the thermal energy supply system.

In case of the ground source heat pump, the \(\text{COP}_{\text{sys}}\) is a function of the part load.

2.2.2 **DHW estimation**

The estimation of the DHW demand of the building is based on statistics. In a Korean research about energy consumption of hotels [6] several energy flow profiles as DHW and electricity consumption are evaluated. The daily profile of the DHW consumption in this research is used to estimate the DHW demand of hotel Amstelkwartier. The values are scaled up to reach the annual DHW consumption as predicted by Wolter & Dros (Figure 4). The typical profiles of energy flows in Korean hotels are shown in Appendix 1.
The heating power is to meet the DHW demand is calculated according to equation 2:

\[ P_{\text{DHW}} = \rho \times c \times \Delta T \times q_v \]  

Where:  
\( P_{\text{DHW}} \) = heating power [kW]  
\( \rho \) = density [kg/l];  
\( c \) = specific heat water (= 4.18 kJ/kg*K);  
\( \Delta T \) = temperature difference between ingoing and outgoing water flow;  
\( q_v \) = volume flow [l/s].

The energy consumption for heating is calculated out of the heating power:

\[ Q_{\text{DHW}} = \int_0^t P_{\text{DHW}} \, dt \]  

Where:  
\( Q_{\text{DHW}} \) = heating consumption [kWh];  
\( t \) = time in hours.

The cost of the energy produced by the CHP is calculated by equation 4:

\[ C_{\text{fuel,tot}} = \frac{P_{\text{fuel}}}{U_{\text{fuel}} \times \eta_{\text{CHP}}} \]  

Where:  
\( C_{\text{fuel,tot}} \) = energy cost in [€/kWh];  
\( P_{\text{fuel}} \) = fuel price in [€/ton];  
\( U_{\text{fuel}} \) = energy content fuel in [kWh/ton];  
\( \eta_{\text{CHP}} \) = total efficiency CHP.

The CHP has an secondary output of electricity. The amount of electricity production by the CHP is calculated using the ratio heat – electricity (r) which is calculated by equation 5:

\[ r = \frac{\eta_h}{\eta_e} \]  

Where:  
\( r \) = heating to power ratio;  
\( \eta_e \) = electrical efficiency CHP;  
\( \eta_h \) = heat efficiency CHP.

2.2.3 Electricity (Plug-load & Lighting) Estimation
The daily electricity consumption is estimated based on statistics of Korean hotels [6]. The daily electricity consumption of Korean hotels shows the same characteristics as addressed in a European research [17] and another Korean research [18]. The daily pattern of electricity consumption is used, and scaled up to reach the annual electricity consumption as predicted by Wolter & Dros.
2.2.4 GRID DEMAND PREDICTION
The resulting energy needed from the grid is calculated by extracting the electricity from renewable sources from the electricity consumption, according do equation 6:

\[ E_{\text{grid}}^h = E_{\text{Consumption}}^h - E_{\text{CHP}}^h - E_{\text{PV}}^h - E_{\text{Wind\,turbine}}^h \quad (6) \]

Where:
- \( E_{\text{grid}}^h \) = predicted hourly electricity demand from the grid;
- \( E_{\text{electrical}}^h \) = predicted hourly electricity consumption by the hotel;
- \( E_{\text{CHP}}^h \) = estimated hourly electricity production by the CHP;
- \( E_{\text{PV}}^h \) = predicted hourly electricity production by PV;
- \( E_{\text{Wind\,turbine}}^h \) = predicted hourly electricity production by the wind turbine.

2.3 PHASE (3) DEFINE IMPROVEMENT OPTIONS AND OFFERS
The objective of phase 3 is to define the improvement options and offers which will be further evaluated in HOMER.

An inventory is made of the current situation of the energy supply system, the available space for RET and the available renewable energy sources at the location of hotel Amstelkwartier, after which a selection of RET used for further evaluation in HOMER is defined.

HOMER is an optimization software package which simulates many system configurations and scales them on the basis of LCC and technical feasibility. HOMER uses a 1-h time step to capture most of the variability of the load and the fluctuating renewable resources. HOMER requires hourly load and environmental inputs to assess the technical potential of RET via RF and economic viability via LCC. The methodology of the HOMER simulations is shown in section 2.3.1 concerning the energy performance assessment and in section 2.3.2 describing the life cycle cost analysis.

2.3.1 ENERGY PERFORMANCE ASSESSMENT

**Renewable fraction**
The renewable fraction (RF) is the portion of the total annual renewable power production by the hotel’s renewable energy supply system with respect to the total annual electrical consumption. The renewable energy content of the grid is not included in the RF calculations in the current study. The RF is used to indicate the environmental influence of the improvement options and offers in HOMER. The current requirement of the platinum LEED certificate is 13% RF achieved by biomass. The expectation is that the requirements of the RF significantly will increase in the near future.

**Wind**
The wind speed at the height of the wind-turbine with respect to the wind speed of the anemometer is determined by the ‘Logarithmic’ law as shown in equation 7:
\[
\frac{U_{\text{hub}}}{U_{\text{anem}}} = \frac{\ln \left( \frac{Z_{\text{hub}}}{Z_0} \right)}{\ln \left( \frac{Z_{\text{anem}}}{Z_0} \right)} \quad (7) \quad [11]
\]

Where:
- \(U_{\text{hub}}\) = the wind speed at the hub height of the wind turbine [m/s];
- \(U_{\text{anem}}\) = the wind speed at anemometer height [m/s];
- \(Z_{\text{hub}}\) = the hub height of the wind turbine [m];
- \(Z_{\text{anem}}\) = the anemometer height [m];
- \(Z_0\) = the surface roughness length [m] (= 1.5 for a suburban area).

The output of the wind turbine is calculated according to equation 8:

\[
P_{\text{WTG}} = \frac{\rho}{\rho_0} \times P_{\text{WTG,STP}} \quad (8) \quad [11]
\]

Where:
- \(P_{\text{WTG}}\) = the wind turbine power output [kW];
- \(P_{\text{WTG,STP}}\) = the wind turbine power output at standard temperature and pressure [kW];
- \(\rho\) = the actual air density [kg/m\(^3\)];
- \(\rho_0\) = the air density at standard temperature and pressure [=1.224 kg/m\(^3\)].

**Radiation**

The output of the PV arrays is calculated according to equation 9:

\[
P_{\text{PV}} = Y_{\text{PV}} \times f_{\text{PV}} \frac{G_T}{G_{T,\text{STC}}} \left[ 1 + \alpha_p (T_c - T_{c,\text{STC}}) \right] \quad (9) \quad [11]
\]

Where:
- \(Y_{\text{PV}}\) = the rated capacity of the PV array, meaning its power output under standard test conditions [kW];
- \(f_{\text{PV}}\) = the PV derating factor [%];
- \(G_T\) = the solar radiation incident on the PV array in the current time step [kW/m\(^2\)];
- \(G_{T,\text{STC}}\) = the incident radiation at standard test conditions [1 kW/m\(^2\)];
- \(\alpha_p\) = the temperature coefficient of power [%/°C];
- \(T_c\) = the PV cell temperature in the current time step [°C];
- \(T_{c,\text{STC}}\) = the PV cell temperature under standard test conditions [=25 °C]

### 2.3.2 Life Cycle Cost Analysis

The LCC represents the total amount of costs of the system and includes all costs and revenues that occur within the project lifetime, with future cash flows discounted to the present. The LCC includes the initial cost of the system components, the cost of any component replacements that occur within the project lifetime and the cost of maintenance and fuel. The project boundaries in the LCC calculations in HOMER reaches includes only the electricity supply from the grid and renewable energy technology. Operation of the CHP will remain the same after applying RET. The LCC is calculated according to equation 10:
\[
\text{LCC}[\text{€}] = \frac{TAC}{CRF} \quad (10) \quad [11]
\]

Where TAC is the total annualized cost which is the sum of the annualized cost of each system component and CRF is the capital recovery factor given by equation 11:

\[
\text{CRF} = \frac{i(1+i)^n}{(1+i)^n-1} \quad (11) \quad [11]
\]

Where: 
- \( n \) = the number of years;
- \( i \) = the annual real interest rate [%];

HOMER uses the real interest rate rather than the nominal interest rate. This method allows inflation to be factored out of the analysis. The project lifetime for this case study was taken as 25 years.

**Real discount rate**

The real discount rate is used to convert between one-time costs and annualized costs. The real discount rate is calculated out of the nominal discount rate and the expected inflation rate:

\[
i = \frac{i' - f}{1 + f} \quad (12) \quad [11]
\]

Where:
- \( i \) = real discount rate;
- \( i' = \) nominal discount rate (=5.5%);
- \( f = \) expected inflation rate (=2%).

The real discount rate taken into account in this research is 5.5%, while the expected inflation rate amounts 2% [28]. The corresponding real discount rate according to equation 12 is 3.43%.

**Salvage cost**

Salvage value is the remaining value of a component of in the power system at the end of the project lifetime. A linear depreciation of components is assumed, leading to a salvage value of a component which is directly proportional to its remaining life:

\[
S[\text{€}] = C_{\text{rep}} \frac{R_{\text{rem}}}{R_{\text{comp}}} \quad (13) \quad [11]
\]

Where:
- \( R_{\text{rem}} = R_{\text{comp}} - (R_{\text{proj}} - R_{\text{rep}}) \quad (14) \quad [11]

and

\[
R_{\text{rep}} = R_{\text{comp}} \text{INT} \left( \frac{R_{\text{proj}}}{R_{\text{comp}}} \right) \quad (15) \quad [11]
\]

Other definitions:
- \( C_{\text{rep}} = \) replacement cost [€];
- \( R_{\text{comp}} = \) component lifetime [yr];
- \( R_{\text{proj}} = \) project lifetime [yr].
Incentives
In the Netherlands, no incentives are available for wind-turbines. There do exist incentives for installing PV panels. Companies in Amsterdam get 20% of the investment cost in return, with a minimum of € 5.000 and a maximum of € 25.000 [19]. Thereby, the government allows companies to extract 41.5% of the investment cost from the taxable profit on top of the usual depreciations. In the current study, the incentives are discounted in the LCC calculations.

2.4 Phase (4) Cost optimality analysis and sensitivity analysis
The objective of phase 4 is to choose the cost optimal packages and analyze their sensitivity of different scenarios in electricity demand climate and economy.

2.4.1 Cost optimality analysis
In order to choose the cost optimal packages, the difference in LCC with respect to the base-case together with the RF of all RET options are shown in a scatter plot, where the performance of every renewable energy package is compared.

2.4.2 Sensitivity analysis
The RET evaluations contain some uncertainties. In order to estimate the risk of the decision making, several sensitivity analysis are made concerning electric demand scenarios, climate scenarios and economic scenarios. The sensitivity analysis are in compliance to the European Performance of Building Directives [32].

Electric demand scenarios
The electricity consumption of a building strongly depends to its occupancy. In hotel Amstelkwartier the occupancy is even more important, since the adaptable façade can be controlled in case a room is unoccupied. The calculations of Wolter & Dros assumed an occupancy of 80% throughout the year and didn’t take the adaptable façade into account. In the current study, 4 scenarios are created to obtain insight in the influence of the occupancy and adaptable façade on the expected electricity consumption. The difference in expected electricity consumption influences the expected performance of the RET configurations.

According to [20] the average occupancy of hotels in Amsterdam in 2014 was 80,5%, while a peak is observed in the months May, June, July and August. Low season (low expected occupancy) reaches from January until April.

Scenario 1, 2 3 and 4 consider the working of the adaptable façade and deviate in expected occupancy percentage, as shown in Table 1. Scenario 4 is a mixture of scenario 1, 2 and 3, according to the predictions in the seasonal occupancy of hotels in Amsterdam [20] and is shown in Table 2.

<table>
<thead>
<tr>
<th>Base-case (Scenario Wolter &amp; Dros)</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
<th>Scenario 4</th>
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<tr>
<td>Occupancy</td>
<td>80</td>
<td>80</td>
<td>60</td>
<td>100</td>
</tr>
<tr>
<td>Adaptable façade</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
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</table>

Table 1: Electricity demand scenarios due to occupancy and adaptable façade control.
Table 2: Occupancy deviation of scenario 4.

<table>
<thead>
<tr>
<th>Months</th>
<th>Occupancy</th>
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<tbody>
<tr>
<td>January-April</td>
<td>60%</td>
</tr>
<tr>
<td>May-August</td>
<td>100%</td>
</tr>
<tr>
<td>September-December</td>
<td>80%</td>
</tr>
</tbody>
</table>

Climate scenarios
According to the Dutch institute of meteorology KNMI, the Netherlands can expect higher temperatures, less precipitation and more irradiation [21]. This will inevitably affect the future revenues of PV panels. In order to see how sensitive the LCC is with respect to the annual average radiation, the influence of the expected value is shown for -10%, 0%, +10% and +20%. The prediction of the wind speed above a building is complex and can’t be established with confidence only by calculating the wind speed on the height above the building with the Logarithmic law (equation 5) [19]. HOMER doesn’t include the influence of the building on the wind speed in its vicinity, while according to [22] the building can cause an increased wind speed of a factor 1.32 in some areas above the building. The analysis of the sensitivity of the wind speed on the power production of the wind turbine above the building shows whether further research towards the real expected wind speed above the hotel Amstelkwartier is required.

Economic scenarios
This research includes the evaluation of installing PV panels on a roof of a neighbor building. The evaluations are made before obtaining an agreement with a neighbor building about options and price of renting a roof. The analysis of the sensitivity of several considered roof rental cost shows gives insight into the potential roof renting prices in a profitable PV configuration.

The real discount rate as well as the energy price escalation rate influences the annual cash flows which affect the calculated LCC of every RET configuration. The real discount rate is expected to be 3.43% (equation 10, where expected inflation=2% and nominal discount rate=5.5%) and its sensitivity is analyzed by changing the real discount rate with -1% and +1%. The annual energy price escalation rate is expected to be 2% [23,24]. The sensitivity of the energy price escalation rate is analyzed by changing this value with -2% and +2%.

3 Case Study (Hotel Amstelkwartier)
Section 3 describes the current situation of the hotel Amstelkwartier (phase 1), makes a prediction of the hourly energy load (phase 2) and defines the RET systems to be evaluated with the simulation tool HOMER (phase 3). Section 3.1 describes the collected building and energy system design (phase 1) and section 3.2 shows the prediction of the hourly load of the energy demand (phase 2). Section 3.3 describes the estimation of the improvement options and offer, which will be further evaluated in with HOMER in section 4.

3.1 Data Collection Building and Energy System
The objective of section 3.1 is to collect data about the building and its energy system, relevant for an RET assessment. The building design is described in section 3.1.1 and the energy system and the predicted annual energy performance is explained in section 3.1.2.
3.1.1 BUILDING DESIGN
By the end of 2015, the construction of hotel Amstelkwartier will be completed. The hotel will be the first LEED platinum certificated hotel of Europe, containing 308 guestrooms, a parking lot, restaurants, bars, a wellness and covers a total surface area of 16,890 m². All logistic facilities are located in the core of the building while the guestrooms are located around at the building envelope.

Adaptable façade
The building is provided of an adaptable façade, adapting under the influence of the occupancy of guests and outdoor weather variables. In case a room is unoccupied, the control system of the adaptable façade determines when to close the external shutters to avoid energy loss in the winter or overheating in the summer by increasing the overall U-value of the facade or by blocking the incoming irradiation. The U-value of an opened façade amounts 1.8 W/m²*K and in closed condition 0.5 W/m²*K. As a result, the façade is dynamic and changes continuously during the day under the influence of the weather conditions and occupancy. Figure 2 shows an impression of the hotel Amstelkwartier and its adaptable façade. Appendix 2 shows a typical layout of the floors with guest rooms for the lower wider part of the building (floor 2-7) and upper part of the building (floor 8-19).

Figure 2: hotel Amstelkwartier and its adaptable façade [31].
3.1.2 Energy System

In this section the most important parts of the energy system and its predicted annual energy flows is described.

The current energy supply system of hotel Amstelkwartier is provided with its own heat and electrical power generator. A combined heat and power (CHP) produces both heat to supply the DWH demand as electricity to supply the total electricity need of the hotel. The CHP runs on BIO-oil (waste oil from fryers) and is considered as a renewable energy system, contributing to the RF.

The main system to supply the space heating and cooling demand is the ground source heat pump. This heat pump is provided of an underground storage which stores waste heat in the summer, and stores cold during the winter. The heat pump uses the stored heat or cold in the following season, which increases the COP significantly. During peak-demands and as back-up for the heating supply system, the CHP and district heating is used. Room cooling units run non-stop for cooling the communication rooms.

Figure 3 is a simplified scheme of the energy flows in the hotel and addresses the priority in energy supply of the different systems by numbers. The upper row contains the energy sources, the middle row the supply systems and the lowest row the 4 energy demand sides.

Figure 3: Simplified energy flow scheme of hotel Amstelkwartier.

Wolter & Dros predicted the energy flows as shown in Figure 3 by calculations and simulations with the program VABI 114. Figure 4 shows the predicted annual energy consumption and supply of the system for the base-case scenario, as shown in Table 1. A more detailed scheme of the energy flows is shown in Appendix 5.
3.2 ENERGY PERFORMANCE PREDICTION

A prediction of the annual electricity consumption of the hotel is made by Wolter & Dros. For a reliable evaluation of RET, however, a more detailed prediction of the seasonal and daily profile of the energy consumption is required. The objective of section 3.2 is hourly electrical load data which is used as input in the HOMER simulations.

As shown in Figure 3, all energy flows influence the resulting electricity need from the grid. Therefore a prediction of the hourly demand of all 4 primary energy demands as shown in Figure 3 and 4 is required. Section 3.2.1 describes the prediction of the heating and cooling demand by IES VE while Section 3.2.2 shows the estimation of the DHW demand based on statistics. Section 3.2.3 shows the estimation of the plug-load and lighting demand. Section 3.2.4 describes the resulting electricity load from the grid.

3.2.1 HEATING AND COOLING BY IES VE

The heating and cooling demand of the hotel building is mainly provided by a heat pump which is a large consumer of electrical energy. The heating and cooling demand influences the resulting electricity need from the grid, and is simulated with the program IES VE.

IES VE is an energy simulation software based on networks which solve equations as the conservation of mass, energy and species concentration. The option ‘Apache’ in IES VE is used for the thermal calculations of the hotel building.
Model

In IES VE the same input data is used as the VABI114 simulations performed by Wolter & Dros. In contrary to VABI114, the simulation program IES VE has an output option of hourly data of the heating and cooling demand. In order to decrease the simulation time, only few typical rooms on several floors in the building are chosen to serve as reference rooms for estimating the total building’s heating and cooling demand. Appendix 3 shows the input data of the model as a lay-out including the reference rooms used for simulation, internal loads, U-values and heating and cooling set points. The simulations are performed for the scenarios as defined in Table 1. The adaptable façade is simulated as external blinds which have the increased U-value in lowered position and radiation blocking effect as the adaptable façade.

The capacity of the heat pump for heating is 335 kW and for cooling 251 kW. The capacity of the additional cooling units for the computer rooms is 61 kW, making the total cooling capacity 312 kW. In case the heating demand exceeds the capacity of the heat pump, the CHP or district heating supplies additional heat.

Wolter & Dros distinguished the prediction of the annual heating and cooling demand for the guestrooms and public parts of the hotel building. The cooling demand of the communication rooms is addressed separately and is considered to be constant in time. A detailed overview of the energy demand of the building is shown in Appendix 5.
**Results**

The heating and cooling demand is converted into an electricity consumption using a COP$_{\text{system}}$ depending on the partial load of the heat pump and additional cooling units. Figure 5 shows the influence of the adaptable façade on the predicted heating and cooling demand of the hotel Amstelkwartier considering an occupancy of 80%. Also the resulting electricity demand of the heat pump and cooling units is shown.

![Graph](image)

**Figure 5**: Predicted heating and cooling demand hotel Amstelkwartier by IES VE with and without adaptable façade, including the resulting predicted electrical consumption of the heat pump.

The effect of the adaptable façade is directly visible by comparing the heating and cooling demand of scenario 1 and scenario 2. The simulations predict a saving of 16% in space-heating demand and 41% in space-cooling demand due to the adaptable façade.
The saving of 41% in cooling demand can be explained by the low occupancy of a hotel during the day, which makes it possible to close the adaptable façade in a large part of the building, blocking the incoming irradiation to avoid overheating.

The 16% saving in space-heating demand as predicted by the IES VE simulations is caused by the decreasing energy losses due to transmission during nighttime. The adaptable façade closes when the guests are asleep, increasing the U-value of the façade.

The adaptable façade results in electrical energy saving of the heat pump consumption of 23% (from 149 MWh instead of 195 MWh). The same graph for the heating and cooling demand for comparing scenario 1, 2, 3 and 4 is shown in Appendix 4.

Note that the real saving in heating energy could be higher than concluded in the IES VE simulations. In a cold period during the day, the control system of the adaptable façade determines whether to open or close the adaptable façade, depending to the estimated heat gain from the irradiation and heat loss due to transmission. This option is not available in IES VE. Therefore the possible saving of heating demand during the day by closing the adaptable façade is not taken into account.
Figure 6 shows the duration curves of the heating and cooling demand for the occupancy scenarios 1, 2, 3 and 4, as defined in Table 1.

The scenarios show only small influence of the occupancy scenarios on the heating demand, while the cooling demand is strongly influenced by the different scenarios of occupancy.

The cooling demand is seems sensitive to the occupancy scenario regarding the large differences in cooling demand. It can be explained by the increasing of the internal gains while the occupancy increases, leading to an increase of cooling demand. An increasing occupancy also disables the opportunity of an extensive use of the adaptable façade during the day. Less irradiation is blocked by the shutters, increasing the cooling demand of the hotel.
The influence of the occupancy on the heating demand is lower. An increased occupancy leads to increased internal gains in the hotel. However, an increasing occupancy profile also leads to an increased number of rooms which need to be heated and less energy saving by using the adaptable façade. The second factor seems more important than the first one, considering a slightly increasing heating demand with an increased occupancy.

The demand for space heating is during a few hours in the year expected to be higher than the capacity of the heat pump. The CHP if possible or the district heating delivers the remaining heat necessary for space heating.

3.2.2 DHW ESTIMATION BY EXCEL MODEL

The CHP plays an important role in the electrical energy scheme of the hotel Amstelkwartier, since the secondary output is electrical energy and has an expected contribution to the total electricity supply of 52%. The CHP is heating tracked, which means that the electricity production of the CHP depends to the DHW demand of the hotel. In some situations, the CHP supplies heat for space heating in case the heating capacity of the heat pump is insufficient. The CHP has a heating capacity of 98 kW and a storage of 300 kWh.

The CHP runs on BIO-oil, and therefore can be considered as a renewable energy source in the consisting design of the hotel Amstelkwartier. The properties of the CHP and the fuel (BIO-oil) are shown in Table 2:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating capacity</td>
<td>98 kW</td>
</tr>
<tr>
<td>Electrical capacity</td>
<td>75 kW</td>
</tr>
<tr>
<td>Storage (heating)</td>
<td>300 kWh</td>
</tr>
<tr>
<td>BIO-oil (fuel)</td>
<td>950 [€/ton]</td>
</tr>
<tr>
<td></td>
<td>11.9x10^3 [kWh/ton]</td>
</tr>
<tr>
<td>Heating efficiency</td>
<td>65 %</td>
</tr>
<tr>
<td>Electrical efficiency</td>
<td>35 %</td>
</tr>
<tr>
<td>Distribution heat loss</td>
<td>5 %</td>
</tr>
</tbody>
</table>

Table 2: CHP system and fuel characteristics.

There is no data available for DHW demand in Dutch hotels. For a prediction of the hourly DHW load, measured data of Korean hotels [6] is used. The daily pattern of the DHW consumption of Korean hotels is shown in appendix 1 and is used for the prediction of the hourly DHW demand in the current research. The hourly demand for an occupancy of 80% is scaled up to reach the annual predicted values of Wolter & Dros as shown in Figure 4. The DHW demand for the other scenarios it is considered to increase or decrease directly proportional to the occupancy. Wolter & Dros assumes an increased DHW consumption in the weekends (+22%), and is considered in this study.

The CHP requires maintenance every 3000 running hours. The time the CHP is not running due to maintenance is not taken into account in this research.
**Figure 6A** shows the predicted DHW demand, CHP heat supply, CHP electricity supply and the heat content of the storage for two regular weekdays of scenario 1 (60% occupancy). The CHP in this case never runs on full capacity, and the storage remains full. As a result there is only small electricity production by the CHP.

**Figure 6B** shows the energy flows of the CHP for scenario 2 (80% occupancy). The CHP is unable to supply the full DHW demand during the peak load in the morning and in the evening. Therefore the stored heat in the storage supplies additional heat during the peak demand. The storage is large enough to supply the unmet heat demand during the peak. After 20:00h, as the demand decreases, the CHP refills the storage tank. The CHP heat supply drops around 00:00h, to serve the DHW only. Approximately until 8:00h the CHP runs in part load.

**Figure 6C** shows the energy flows of the CHP for scenario 3 (100% occupancy). The increasing DHW demand makes the CHP run to its full capacity. The CHP and storage can’t supply enough heat, thus additional heat needs to be supplied by district heating. The CHP runs to its full capacity, resulting in a maximum (renewable) electricity production, and increased RF.

Scenario 4 is a mix of scenario 1, 2 and 3 and has the characteristics of the three occupancy scenarios according to Table 2.
Figure 6: Hourly expected CHP supply, DHW demand, electricity production [kW] and storage heat content [kWh] on a day in the weekend. A) Scenario 1 (60% occupancy) B) Scenario 2 (80% occupancy) and C) Scenario 3 (100% occupancy).

Figure 6: hourly expected CHP supply, DHW demand, electricity production [kW] and storage heat content [kWh] on a day in the weekend. A) Scenario 1 (60% occupancy) B) Scenario 2 (80% occupancy) and C) Scenario 3 (100% occupancy).
3.2.3 **Electricity estimation based on statistics**

The prediction of electricity demand of the hotel is based on statistics. [6] Shows a detailed daily pattern of the electricity consumption of Korean hotels. The electricity consumption pattern of [6] has the same characteristics as is found for a large (378 bedrooms) Australian hotel [25] and a medium-sized (125 bedrooms) in Iran [26]. Moreover the daily electricity profile shows the typical hotel characteristics as 24 h base demand and two peaks during the day [5]. The daily pattern is used for estimation of the hourly electricity load by plug-load and lighting and scaled up to reach the predicted values by Wolter & Dros.

The total electricity demand predicted by Wolter & Dros amounts 799250 kWh, assuming an occupancy of 80%. The emergency lighting and lighting in the hallways, together with the electricity consumption of the public rooms is considered to be constant while changing the occupancy of the hotel. The remaining electricity for lighting, pumps, ventilators, elevators and plug load is considered to be proportional dependent by the occupancy.

Figure 7 shows the difference in total electricity consumption for a day in the winter for scenario 1, 2 and 3. The typical electrical consumption characteristics [5] of a hotel as 24h operation and two peak demands every day are visible.

![Graph](image)

**Figure 7**: Predicted total electricity consumption for occupancy scenario 1, 2 and 3.

A detailed overview of the predicted annual consumption of the different components in the hotel building is shown in Appendix 5.
3.2.4 **RESULTING GRID DEMAND**

The influence of the scenarios on the energy flows in the hotel is shown in Table 3. The predicted electricity need from the grid is calculated according to equation 5. The difference in % is calculated with respect to base-case (scenario Wolter & Dros).

<table>
<thead>
<tr>
<th></th>
<th>Base-case</th>
<th>Scenario 1 (60% occupancy)</th>
<th>Scenario 2 (80% occupancy)</th>
<th>Scenario 3 (100% occupancy)</th>
<th>Scenario 4 (mixed occupancy)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary heating demand [MWh/yr]</strong></td>
<td>531</td>
<td>461 (-13%)</td>
<td>448 (-16%)</td>
<td>440 (-17%)</td>
<td>457 (-14%)</td>
</tr>
<tr>
<td><strong>Primary cooling demand [MWh/yr]</strong></td>
<td>539</td>
<td>241 (-55%)</td>
<td>319 (-41%)</td>
<td>388 (-28%)</td>
<td>368 (-32%)</td>
</tr>
<tr>
<td><strong>Primary DHW demand [MWh/yr]</strong></td>
<td>712</td>
<td>534 (-25%)</td>
<td>712 (-0%)</td>
<td>890 (+25%)</td>
<td>742 (+4%)</td>
</tr>
<tr>
<td><strong>Electricity-production CHP [MWh/yr]</strong></td>
<td>547</td>
<td>417 (-24%)</td>
<td>547 (-0%)</td>
<td>645 (+18%)</td>
<td>538 (-2%)</td>
</tr>
<tr>
<td><strong>Total electricity consumption [MWh/yr]</strong></td>
<td>994</td>
<td>771 (-22%)</td>
<td>948 (-5%)</td>
<td>1062 (+7%)</td>
<td>930 (-6%)</td>
</tr>
<tr>
<td><strong>Predicted grid electricity need [MWh/yr]</strong></td>
<td>447</td>
<td>354 (-21%)</td>
<td>401 (-10%)</td>
<td>417 (-7%)</td>
<td>392 (-12%)</td>
</tr>
<tr>
<td><strong>RF</strong></td>
<td>55%</td>
<td>54%</td>
<td>58%</td>
<td>61%</td>
<td>58%</td>
</tr>
</tbody>
</table>

*Table 3: Influence of the scenarios on the energy flows.*

Scenario 4 is considered to be the most reliable since it has the most factors taken into account, and will be used in the HOMER simulations.

Figure 8 shows how the total electricity consumption of the hotel and the electricity production of the CHP form the resulting electricity need from the grid. The electricity produced by the CHP never exceeds the demand and is used by the hotel itself.

![Figure 8: Electricity flows in case of scenario 2 (80% occupancy).](image)
3.3 Define Improvement Options and Offer
The current study investigates how RET can improve the current energy supply system of hotel Amstelkwartier. This section defines a group of improvement options and offers which will be further evaluated in this study. The improvement options embodies the possible packages of RET installed in the hotel. The improvement offers are the possible improvements in the current energy system of the hotel, without installing additional RET. There are numerous types of RET systems available. Out of all possible RET, a selection is made which is used for further evaluation with the simulation program HOMER.

To come to a selection of improvement options and offers, firstly the possible RET for micro-generation is explained in section 3.3.1. In section 3.3.2 the available area for installing RET in and near hotel Amstelkwartier is described and in section 3.3.3 the available renewable energy sources are given. Section 3.3.4 finally shows the RET improvement options, chosen for further evaluation in this research and section 3.3.5 describes the improvement offer.

3.3.1 Renewable Energy Technology for Micro-generation
Micro-generation RET are energy generation technologies that are installed in individual buildings. These micro-generation RET components pertain to supply a particular source demand rather than a broad network. As mentioned before, this research focuses only on RET for electricity. RET for heating is not taken into account.

RET available for micro-generation is in general limited to PV, micro-wind and CHP (biomass). Other RET types such wave, tidal and geothermal are still at the research stage while micro-hydro is out of the scope of this research. These RET types are not evaluated in this paper.

The current energy system of the hotel is already provided of a CHP. Another CHP is not considered since a CHP is only feasible when both heating and electricity can be used [27]. The additional heat can in the current heating system only be used in extreme winter conditions, when additional heating of the heat pump is required.

Wind turbines for rooftop applications are available until 20 kW. Small wind-turbines generate renewable energy, without generating CO₂ or other greenhouse gasses. However, a wind-turbine can only be considered as sustainable in case the renewable energy production is larger than the energy needed to produce the wind turbine. Research [28] shows that the energy generation of a wind turbine strongly depends to the location it is installed. The same research shows that the ‘Montana’ wind-turbine is currently the most efficient wind-turbine. This wind turbine is used in the HOMER simulations.
3.3.2 **On-site available area for renewable energy technology**

In high-rise buildings, usually limited area available for installing RET. Especially PV panels and wind turbines require a large surface. In hotel Amstelkwartier, the rooftop of the glasshouse is a potential horizontal area of ±240 m² for installing PV panels, as shown in Figure 9A. The south façade of the hotel building forms a large potential surface for installing vertical PV panels. At the 65 cm width steady panels of the adaptable façade (the black panels in Figure 9C), vertical PV panels could be installed. Considering the shading effect of neighbor buildings on the south-side of the hotel, the façade PV panels can be installed from the 7th floor, creating a potential PV area on the southern façade of 530 m².

![Figure 9: A: Lay-out of the rooftop hotel Amstelkwartier, B: Environment of hotel Amstelkwartier and C: South façade of hotel Amstelkwartier.](image)

The roof of the hotel, the southern orientated façade of the hotel and the roofs of buildings in the hotel’s vicinity provide 3 types of PV panels to take into consideration:

- **Roof PV**, on hotel’s roof glass house;
- **Façade PV**, on the steady panels of the hotel’s southern façade;
- **Nearby PV**, on a roof of (one) of the neighbor buildings.

Installing PV panels on one of the neighbor buildings increases the amount of square meters of PV panels significantly. The new building on the south side of the hotel contains a large potential surface for PV panels. The PV-panels on this neighbor building will be visible in the hotel Amstelkwartier from at least the 7th floor and would increase the awareness of guests of the hotel’s sustainability. The potential profit by installing PV panels on an external roof is evaluated in this report before the possible availability of an external roof is guaranteed. In order to predict the
potential rooftop area to evaluate in the HOMER simulations, the environment of hotel Amstelkwartier is shown in Figure 9 B. Several buildings provide a potential roof for installing PV panels for hotel Amstelkwartier. Roof-rental for PV installation already exists within professional companies as ‘Sun-United’ where an annual compensation is granted for the rooftop owner.

Installation of a wind turbine on the roof of the 7th Floor is no option, regarding the wind-blocking effect on both the windward as the leeward side of the building [19]. A wind-turbine on the roof of the 7th floor would also hinder the guests their view on the environment. The only remaining option for installation of a wind turbine is the roof top on the 22nd floor. A permission of the government should be requested before installing a wind turbine on this roof top.

3.3.3 ON-SITE AVAILABLE RENEWABLE ENERGY SOURCES

The solar radiation profile, clearness index and wind speed profile of Amsterdam (52°22.2’N, 4°53.7’E) is considered for this work, obtained from the NASA Surface Meteorology and Solar Energy website [29]. The annual average solar radiation for this region is 3.02 kWh/m²/day and the annual average wind speed for this area is 7.07 m/s, measured on a height of 50 m. Figure 10A shows the average wind speed over a one year period. Figure 10B shows the solar radiation profile and clearness index over a one year period.

Figure 10 A) Monthly wind speed [m/s] and B) Monthly radiation and clearness index [kWh/m²/day] in Amsterdam [29].
In the prediction of the hourly values of the wind speed, HOMER takes several parameters into account, as shown in Table 4:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weibull K</td>
<td>1.5</td>
<td>A measure of the long-term distribution of wind speeds</td>
</tr>
<tr>
<td>Height of the wind-turbine</td>
<td>78 – 90 m</td>
<td>66 m building height and a height between 12-24 m for the wind-turbine</td>
</tr>
<tr>
<td>Surface roughness length</td>
<td>1.5</td>
<td>characterizes the roughness of the surrounding terrain</td>
</tr>
</tbody>
</table>

Table 4: Parameters concerning wind turbine calculations taken into consideration by HOMER.

a Surface roughness length = 1.5 for suburban area.

The wind speed profile in height is determined by the logarithmic law, as shown in equation 7. However, the influence of the building on the wind speed ratio in its vicinity is not taken into account by HOMER. In [19,22] the large influence of a building on the wind speed in its vicinity is shown.

The referential speed is the wind speed at 148 m, undisturbed by the building, is 9.7 m/s. In this case study the increased wind speed ratio in certain areas above the building can reach to more than 1.32, which depends among others on the wind direction. Its magnitude and area is different for every building, and remains an uncertain factor for the evaluation of wind turbines in the hotel Amstelkwartier.

The hub height of wind turbine can be delivered between 12 and 24 meter. In Figure 11A height of 20 m of the wind-turbine is shown. The wind-turbine would in this the case of the WTC building be located in the area with increased wind speed of factor 1.32.
3.3.4 IMPROVEMENT OPTIONS

Taken the current design of the energy system of the hotel Amstelkwartier in consideration, together with the available space on the own building site, only a few improvement options remain to be potentially feasible. The improvement options together with the considered sizes or unit numbers evaluated in HOMER are shown in Table 5. HOMER automatically sizes the amount of batteries and size of the converter, which limits the total amount of possible RET combinations to 2x3x3x4=72.

<table>
<thead>
<tr>
<th>Renovation measures</th>
<th>Options on size and unit numbers</th>
<th>Description installation</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind-turbine</td>
<td>0 or 1 wind-turbines</td>
<td>Montana wind turbine</td>
<td>28,500€ incl. 7,500€ installation cost</td>
</tr>
<tr>
<td>Roof PV</td>
<td>0, 120, 240 m²</td>
<td>BIPV</td>
<td>311 €/m²</td>
</tr>
<tr>
<td>Façade PV</td>
<td>0, 265, 530 m²</td>
<td>Vertical BIPV</td>
<td>334 €/m²</td>
</tr>
<tr>
<td>Nearby PV</td>
<td>0, 500, 1000, 2000 m²</td>
<td></td>
<td>236 €/m²</td>
</tr>
<tr>
<td>Battery</td>
<td>50,000 kWh</td>
<td>Numbers of batteries automatically chosen by HOMER</td>
<td>1,000 €/unit number</td>
</tr>
<tr>
<td>Converter</td>
<td>Automatically sized by HOMER</td>
<td></td>
<td>900 €/kW</td>
</tr>
<tr>
<td>Grid</td>
<td></td>
<td></td>
<td>€0,112 with energy escalation rate = 2% and sellback price is €0,056</td>
</tr>
</tbody>
</table>

Table 5: Improvement options considered in HOMER.

\(^{a}\)Considered is €100/MWh according to the commodity prices, adding a price of €11,80 of taxes/MWh.

More details about the HOMER simulations and input values can be found in Appendix 6.
Figure 12 shows the existing simplified energy flow scheme of hotel Amstelkwartier (Figure 3) and included the improvement options as defined in this section. The converter connects the AC bus with the DC bus. The grid changed in priority from 2 to 3 in electricity supply, since the renewable energy supply has priority above grid supply.

Figure 12: Simplified scheme of energy flows hotel Amstelkwartier including the evaluated improvement options (improvement of Figure 3).
3.3.5 IMPROVEMENT OFFER

CHP control
The current design of the hotel Amstelkwartier already knows one renewable energy system. A CHP, running on BIO-oil, provides the hotel of heat for DHW and electricity. The CHP is in the current situation heating tracked, which means that the CHP supplies heat according to the DHW demand, and sees the production of electricity as a secondary output. Another control option is to make the CHP electricity tracked which means that the CHP produces electricity whenever there is a demand for electricity. In the evaluation of the different control options, occupancy scenario 4 is considered, which contains a seasonal depending occupancy. The heating and electrical supply of the CHP in scenario 4 is a mixture of Figure 6 A, B and C occurring according to the scheme in Table 2. Especially during low-season months January, February, March and April the CHP is expected not to run to its full capacity. Also during mid-season months September, October, November and December more heat and electricity could be supplied by the CHP.

The electrical flows, as shown in Figure 8, show that the electrical production of the CHP never exceeds the electrical demand of the building. Changing the control of the CHP from heating tracked to electricity tracked therefore makes the CHP ‘always running’. The extra produced renewable electricity can directly be used by the hotel itself. This would lead to an increasing RF and reduction of the grid electricity need.

4 RESULTS AND DISCUSSION
Section 4 consists of an cost optimality analysis and a sensitivity analysis. The improvement options as shown in Table 5 are evaluated in HOMER. Section 4.1 shows the cost optimality analysis with an overview of the results of all combinations of PV and wind turbine, resulting in 5 optimal packages. Section 4.2 describes the results of the improvement offer and in section 4.3 a sensitivity analysis is performed for the 5 optimal packages as defined in section 4.1.
4.1 COST OPTIMALITY ANALYSIS

4.1.1 IMPROVEMENT OPTIONS

All possible combinations of PV and wind turbine as defined in Table 5 are shown in scatter plots, where they are examined on difference in LCC (dLCC) with reference to the base-case and the RF. HOMER automatically selects the most suitable capacity of the inverter and number of batteries. The RF of the base-case is 57% due to the renewable electricity production of the CHP in the current design of the hotel. All results are based on scenario 4 with seasonal dependent occupancy while taking the incentives for PV as described in section 2.3.2 taking into account.

Figure 13 shows all PV-packages in case no roof rental cost. Groups of same sized nearby PV surface area are circled. The groups of same sized façade PV packages can be identified by their color: black refers to 0 m² façade PV, orange refers to 265 m² façade PV and blue refers to 530 m² façade PV. Groups of same sized roof PV can be identified by the shape of the figure: a circle refers to 0 m² roof PV, a triangle refers to 120 m² roof PV and a cross refers to 240 m² roof PV. Preferable is a low dLCC and a high RF. The package with the lowest dLCC is the cost optimal.

The façade PV (comparing colors) leads to an increase of both the dLCC and RF. From economical point of view façade PV is not interesting. The roof PV (comparing shape), however, results especially in the lower RF areas in a decreasing dLCC and an increasing RF, which makes these packages both economically and environmentally interesting. The nearby PV packages should be evaluated while taking roof rental cost into consideration.

![Figure 13: Scatter plot for all PV-packages for scenario 4 (mixed occupancy) without roof rental cost.](image-url)
In Appendix 7 the importance of the matching of energy production by the PV panels and the electricity consumption of the hotel is explained by showing a graph with electricity production for the 4 sizes of nearby PV in comparison to the electricity consumption of the hotel.

Figure 14 shows all PV packages with and without wind turbine. Comparing the base-case same configuration with wind turbine, shows the contribution of the wind-turbine of € 10.435 in LCC and 2.7% in renewable fraction. The contribution of the wind turbine to the LCC has in every PV package approximately the same magnitude, which makes it economically unfeasible to add a wind turbine in hotel Amstelkwartier.

![Figure 14: Scatter plot of all PV packages with and without wind turbine for scenario 4 (mixed occupancy) without roof rental cost.](image-url)
Figure 15 includes all PV packages, where a roof rental cost of 5 €/m² is included for the nearby PV packages. The groups of packages with nearby PV increased in dLCC and significantly changed the expected economical performance. Achieving a RF above 75% with PV panels appears to be very hard to achieve considering the quickly growing dLCC.

5 optimal packages are chosen for further evaluation:

- Optimal package 1: Cost optimal in case of no nearby PV;
- Optimal package 2: Cost optimal in case of nearby PV only;
- Optimal package 3: Cost optimal solution out of all combinations;
- Optimal package 4: Preferable solutions out of all combinations;
- Optimal package 5: Preferable solution out of all combinations: negligible profit and large contribution in RF.

![Figure 15: Scatter plot of all PV packages including 5 €/m² roof rental cost for nearby PV and the 5 optimal PV packages for scenario 4 (mixed occupancy).]
In Table 6 the properties of the 5 optimal solutions are shown:

<table>
<thead>
<tr>
<th></th>
<th>1: Cost optimal package for on-site PV only</th>
<th>2: Cost optimal package for nearby PV only</th>
<th>3: Cost optimal package</th>
<th>4: Optimal package</th>
<th>5: Optimal package</th>
</tr>
</thead>
<tbody>
<tr>
<td>dLCC</td>
<td>€25,589</td>
<td>€19,531</td>
<td>€41,452</td>
<td>€24,339</td>
<td>€2,268</td>
</tr>
<tr>
<td>RF</td>
<td>61.3%</td>
<td>64.6%</td>
<td>67.6%</td>
<td>69.9%</td>
<td>72.0%</td>
</tr>
<tr>
<td>Roof PV [m²]</td>
<td>240 m²</td>
<td>-</td>
<td>240 m²</td>
<td>240 m²</td>
<td>240 m²</td>
</tr>
<tr>
<td>Façade PV [m²]</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>265</td>
<td>-</td>
</tr>
<tr>
<td>Nearby PV [m²]</td>
<td>-</td>
<td>500 m²</td>
<td>500 m²</td>
<td>500 m²</td>
<td>1000 m²</td>
</tr>
<tr>
<td>Wind-turbine</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Amount of Batteries of 50 kWh</td>
<td>2</td>
<td>4</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Converter</td>
<td>10 kW</td>
<td>20 kW</td>
<td>20 kW</td>
<td>30 kW</td>
<td>30 kW</td>
</tr>
</tbody>
</table>

Table 6: Overview of the 5 optimal packages: properties and performance.

4.1.2 IMPROVEMENT OFFER

In this section the results of the improvement offer of changing the CHP control from heating tracked to electricity tracked. Since the expected electricity consumption of the hotel at any time can directly be used by the hotel, the electricity tracked control option leads to running of the CHP on full capacity, and an excess of heat production. In the calculations an average price escalation factor of 2% and inflation of 2% every year is considered, resulting in a constant real fuel cost. The energy flow scheme of scenario 4 (mixed occupancy) is considered in the calculations.

Table 7 gives an overview of the electricity production, excess heat production, RF and fuel cost for the change in CHP control in the current design of the hotel, based on the CHP energy flow scheme in case of heating tracked shown in Figure 6.

<table>
<thead>
<tr>
<th></th>
<th>Heating tracked</th>
<th>Electricity tracked</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity production</td>
<td>538 MWh</td>
<td>660 MWh</td>
</tr>
<tr>
<td>Excess heat production</td>
<td>0</td>
<td>226.6 MWh</td>
</tr>
<tr>
<td>RF</td>
<td>57.5 %</td>
<td>70.5 %</td>
</tr>
<tr>
<td>Fuel cost</td>
<td>102,885 €/yr</td>
<td>125,950 €/yr</td>
</tr>
</tbody>
</table>

Table 7: Annual production and fuel cost CHP in case of scenario 4 (mixed occupancy) for the two control options.
Figure 16 shows the electricity production of the CHP for the two control options, and the difference in electricity production. The profile of the excess of heat production is directly proportional to the difference in electricity production between the two control options, according to the heat to power ratio described in equation 5.

![Figure 16: CHP electricity flows in case of scenario 4 (mixed occupancy) comparison between heating tracked and electricity tracked.](image)

Due to the high considered occupancy (100%) in the summer months, a negligible amount of excess heat from the CHP is expected. The excess of heat production takes places mainly during the heating degree days, when heating for buildings is needed. The pattern of a lower DHW demand during the weekdays and increased DHW demand in the weekends is clearly visible. The irregularities in January, February and December are to be allocated to the additional heat required for space heating, when the capacity of the heat pump is insufficient to serve the heating demand.

Note that the predicted seasonal energy flows of the CHP is an approximation of the real future CHP energy flows, and will never change as abruptly as shown in Figure 16.

There are several options to use the surplus of heat due to the change in CHP control:

- Use the heat for own space heating and save on electricity cost of the heat pump;
- Use for water heating in the wellness on the top floors of the hotel;
- Sell back heat to the district heating;
- Sell heat to neighbor buildings.

Selling back the heat to the district heating doesn't exist in any other case yet. Government rejects the request of building owners to sell back heat to the district heating, since in most cases the surplus of heat of a building only occurs in the summer months, when renewable heat suppliers as solar thermal produce more heat than the building consumes. The district heating
can't use this heat during the summer months since the demand is low. The expected excess heat of hotel Amstelkwartier however mainly occurs during the heating degree days.

The price of the surplus of heat to reach the economical break-even point for both control options is calculated with equation 4 and 5. The average kWh price from the grid over 25 years is considered to be 0.148 €/kWh, and the heat loss due to distribution is considered to be 15% and is discounted from the total heat production. The break-even point is reached in case the excess of heat production brings in 0.05 €/kWh by selling or by saving on own cost. The current price for district heating is 0.076 €/kWh [18], which means that neighbor buildings could save 34% on a part of their heat purchases, additional installation cost for the distribution of the heat not included.

Additional maintenance time and cost due to change in control are expected to be negligible and are not taken into account.

The expected excess of heat is very sensitive to the actual occupancy in the hotel, since the occupancy directly influences both the DHW and electricity consumption. The current calculations assume a seasonal dependent occupancy of 60, 80 and 100%.

4.2 Sensitivity analysis
The sensitivity of the assumptions made in the simulation process is important to consider in any decision making, and is in compliance to the European Performance of Building Directives [32]. An overview of the parameters examined on the sensitivity on the results as LCC and RF is shown in Figure 17:

![Sensitivity analysis](image)

**Figure 17:** Overview of the examined parameters in the sensitivity analysis.

In section 4.2.1 the sensitivity of the energy demand due to different occupancy scenarios is analyzed. Section 4.2.2 analyzes the economical sensitivity and section 4.2.3 the climatic sensitivity.
4.2.1 Energy Demand Scenarios

The sensitivity of the different scenarios as defined in Table 1 is shown in Figure 18. The LCC (A) and RF (B) are compared for the different occupancy scenarios.

In the base-case, the LCC and RF of the occupancy scenarios without any improvement packages are shown. From this starting point can be evaluated how the LCC and RF changes for every optimal package. The large difference between the LCC of 60% and 80% occupancy in comparison with the difference between the LCC of 80% and 100% occupancy, is caused by the difference in total electricity consumption between the occupancy scenarios, as shown in Table 3. The total difference in predicted electricity need from the grid between 60% and 80% occupancy is 13%, while the difference between 80% and 100% occupancy is only 4%. The reason the base-case in the RF evaluation (Figure 18B) has a different profile is due to the
influence of the CHP, which generates less (renewable) electricity in scenario 2 with respect to scenario 3.

With increasing number of optimal package, also the total amount of PV surface inside of the package increases, resulting in a higher RF. Under influence of increasing PV surface, the RF of scenario 1 increases faster than the RF of the other scenarios. This is caused by the larger percentage of non-renewable electricity in the base-case, or higher growing potential of the RF.

In every scenario, optimal package 3 is the cost optimal package which makes it a robust package.

4.2.2 Economical Scenarios

**Roof rental cost**

The influence of the roof rental cost magnitude of the nearby PV packages is shown in Figure 18, where the expected dLCC and RF of all packages is shown for roof rental prices of 0, 2.50, 5 and 10 [€/m²].

![Figure 18: Influence of roof rental cost on dLCC for all PV packages, in case of scenario 4 (mixed occupancy profile).](image)

Roof rental cost above 5 €/m² make it economically unfeasible to rent a roof for the purpose of installing PV panels. The maximum economically feasible PV surface on nearby roofs considering a roof rental price of 5 €/m² is 500 m², as shown in Figure 13 (optimal package 3).
**Real discount rate**

The real discount rate is in this research expected to be 3.43% [23]. The sensitivity of the expected real discount rate is evaluated by taking a real discount rate of 2.43% and 4.43% into consideration. Figure 19 shows the influence of the real discount rate on the LCC for the base-case and optimal packages. The RF is not influenced by the real discount rate.

A lower real discount rate makes it more interesting to invest capital in RET because the 'discount' on the future cash-flows is lower and the expected profit by applying RET increases. In case of a real discount rate of 4.43%, the expected profit decreases, resulting in an economically unfeasible situation for optimal package 5. Since the real discount rate directly influences the future cost, the influence get minimized by applying RET. An increasing package number corresponds to a higher total amount of PV area. The higher the PV area, the lower the future cost and the lower the influence of the real discount rate. The influence of the real discount rate on the LCC is shown in Table 8, where the difference in % between the lowest LCC and highest LCC is given for every optimal package and the base-case is given.

<table>
<thead>
<tr>
<th>Real Discount Rate</th>
<th>Base-case</th>
<th>Optimal package 1</th>
<th>Optimal package 2</th>
<th>Optimal package 3</th>
<th>Optimal package 4</th>
<th>Optimal package 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>19.6%</td>
<td>18.7%</td>
<td>18.1%</td>
<td>17.2%</td>
<td>15.9%</td>
<td>15.5%</td>
</tr>
</tbody>
</table>

Table 8: difference in LCC for a real discount rate of 2.43% and 4.43%, in [%].

The cost optimal solution (Optimal package 3) is for all three considered real discount rates the optimal package, and can be considered as robust.

Overall the LCC is sensitive to the real discount rate. A carefully chosen real discount rate is required for a reliable LCC based decision making.
Energy price escalation factor

An energy price escalation factor of 2% is assumed in this research [24]. The sensitivity of the energy price escalation rate is analyzed by evaluating the effect of an energy escalation factor of 0% and 4%. Figure 20 shows the influence of the energy escalation factor on the LCC of the base-case and the 5 optimal packages. The RF is not influenced by the energy escalation factor.

Figure 20: Influence of the energy escalation factor on the LCC of the base-case and optimal packages for scenario 4 (mixed occupancy profile).

RET saves on future energy cost by generating energy out of natural sources. The higher the future energy price, the more interesting an investment in RET becomes. In case the energy escalation factor is expected to be 0%, the expected saving on future electricity cost decreases which increases the LCC increases in comparison to a higher energy escalation factor. In case of an energy escalation factor of 0%, only optimal package 1 remains profitable since it contains the least amount of PV panels. In case the energy escalation factor increases with 4%, the expected LCC for all optimal packages decrease significantly comparing to an energy escalation factor of 2%. This faster growing grid-electricity price leads to an advice of installing more PV panels, turning optimal package 5 into the cost optimal package. Optimal package 3 appears to be less robust under influence of the energy price escalation factor.

Table 9 shows the difference in minimum and maximum LCC for every optimal package within the range of energy price escalation rate from 0% to 4%. The energy price escalation factor has less influence on the LCC when the PV surface area increases.

<table>
<thead>
<tr>
<th>Energy price escalation factor</th>
<th>Base-case</th>
<th>Optimal package 1</th>
<th>Optimal package 2</th>
<th>Optimal package 3</th>
<th>Optimal package 4</th>
<th>Optimal package 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>45.4%</td>
<td>43.5%</td>
<td>40.5%</td>
<td>38.7%</td>
<td>36.0%</td>
<td>33.1%</td>
</tr>
<tr>
<td>2%</td>
<td>43.5%</td>
<td>40.5%</td>
<td>38.7%</td>
<td>36.0%</td>
<td>33.1%</td>
<td></td>
</tr>
<tr>
<td>4%</td>
<td>40.5%</td>
<td>38.7%</td>
<td>36.0%</td>
<td>33.1%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 9: difference in LCC for an energy price escalation factor of 0% and 4%, in [%].

Overall the LCC is sensitive to the real discount rate. A carefully chosen energy escalation factor is required for a reliable LCC based decision making.
4.2.3 CLIMATE SCENARIOS

Wind speed

The prediction of the wind speed above a building is complex and can’t be established with confidence only by calculating the wind speed on the height above the building with the Logarithmic law (equation 5) [19]. According to [22] the building can cause an increased wind speed of a factor 1.32 in some areas above a high-rise building, as shown in Figure 11. Figure 21 shows the influence of the wind speed ratio above the building on the RF (A) and dLCC (B) for the optimal packages in case they are provided of a wind turbine for a wind speed ratio of 1 and 1.32 in comparison with the PV packages without wind turbine.

![Figure 21: Influence of the wind speed ratio above the building on the A) RF and B) dLCC with and without wind turbine for scenario 4 (mixed occupancy).](image)

Increasing the wind speed ratio from 1 (default setting in HOMER) to 1.32 increases the expected power output of a wind turbine and makes the installation of a wind-turbine expected to be profitable. The decision making for installing a wind turbine depends on the actual wind behavior above the building, and requires additional research by computational fluid dynamics [19,22] or on-site measurements [30] towards the wind speed above hotel Amstelkwartier.
Radiation

According to the Dutch institute of meteorology KNMI, the Netherlands can expect higher temperatures, less precipitation and more radiation per year [21]. To analyze the sensitivity of the future radiation on the optimal packages, several values for the annual average expected radiation are considered. The annual average expected radiation is 3.02 kWh/m²/yr. Two higher values (+10% and +20) and one lower value (-10%) are analyzed. The influence of the annual average expected radiation (Ē) on the dLCC and RF is shown in Figure 22.

![Figure 22: Influence of the annual average expected radiation on A) RF and B) dLCC for scenario 4 (mixed occupancy).](image)

The optimal packages are sensitive to the expected average radiation regarding the change in RF and the difference in dLCC. Since the radiation is expected to increase [21] the expected RF and dLCC could be better than predicted in section 4.1. The optimal package 3 remains the cost optimal package in the 4 radiation scenarios.
5 CONCLUSIONS

This study was motivated by the expected increasing requirements for a platinum LEED certificate of building operation in the near future. Remaining the current platinum certificate will require an improvement of the current design of hotel Amstelkwartier. Applying RET is considered to be a potential opportunity to improve the hotel's energy supply system. The design question below is answered, based on the results obtained in this study.

- Is it economically and environmentally feasible to apply renewable energy technology in the current energy supply system of hotel Amstelkwartier?

In the current energy system of the hotel Amstelkwartier, heating, cooling, DHW and plug-load and lighting demands all influence the resulting energy need from the grid. A prediction of all energy demands is made, resulting in a predicted hourly energy need from the grid for 4 different occupancy scenarios, shown in Table 3. The influence of the occupancy on the electricity need from the grid is small, since the additional electricity consumption due to increasing occupancy gets reduced by the increased electricity production of the CHP. Occupancy scenario 4, with the seasonal dependent occupancy, is considered in the assessment of the improvement options and offer.

The cost optimality analysis results in five optimal packages and are shown in Figure 15. Optimal package 3 with 500 m² nearby PV and 240 m² roof PV is the cost optimal solution, leading to a difference in LCC of -€ 41,452 and contributes for 10.5% to the RF.

The visibility of the façade PV leads to a ‘green’ image of the hotel, however appears not to be feasible. The cost optimal surface area of nearby PV on neighbor buildings strongly depends on the roof rental cost. When roof rental cost is 5 €/m², the cost optimal area of nearby PV is 500 m².

A change of CHP control from heating tracked to electricity tracked increases the RF from 57.5% to 70.5%. A break-even point in cost point of view is reached when the excess heat can be sold for 0.05 €/kWh, or when the use of the excess heat for own purpose leads to the saving of 0.05 €/kWh.

The installation of a wind turbine is not profitable, as shown in Figure 14. However, one can wonder whether this prediction is reliable, since HOMER doesn’t include the influence of the building on the wind speed in its vicinity, which would make the installation of a wind turbine potentially profitable as shown in Figure 21. The wind speed above the building however remains an uncertain factor, critical in the decision making for installing a wind turbine. Therefore further research is required in the wind behavior above the building.

Economical parameters as real discount rate and energy escalation rate have a large influence on the expected LCC. A negative development in these economic parameters can lead to a loss due to investment in RET. Optimal package 3 is, except for different assumptions in energy escalation rate, the cost optimal and robust package.
6 RECOMMENDATIONS

This section shows the opportunities for more extensive research in addition to this study and recommendations regarding future research procedures.

- The prediction of the hourly energy load of the hotel was a time consuming process. Generating all type of data out of the same simulation tool by Wolter & Dros would decrease the effort made in future research in building performance.

- Wolter & Dros is responsible for the commissioning of the hotel Amstelkwartier. Data of all energy flows will be logged. An analysis in energy performance gap between predicted energy flows and actual measured energy flows could be conducted to increase the prediction accuracy in future projects.

- In this research only the amount of excess heat and the break-even price is analyzed. Further research could aim at a fully worked out plan for using the excess heat.

- In the current research only batteries are considered for electricity storage. Other less well known storage systems as flywheel and hydrogen tank in combination with an electrolyzer could be objectives in a following research.

- As shown in section 4.2.3, a wind turbine can potentially be profitable and contributing to the RF of the energy supply system of the hotel, depending to the actual wind speed and its fluctuations above the building. On-site measurement of the wind speed and its fluctuations can tell whether a wind turbine at this location can be profitable.
ACKNOWLEDGEMENTS

I would like especially to give thanks to Mohamed Hamdy and Benedetto Nastasi for their assistance and help during the graduation process. Also I would like to thanks Charlotte Philips and Pieter Veenendaal for their assistance and providing me the opportunity to conduct research in collaboration with the company Wolter & Dros.

REFERENCES


APPENDIX 1

Energy flows Korean hotel [6]
Electricity demand daily pattern: measurements
DHW demand daily pattern: measurements
Electricity demand daily pattern a) [6] and b) [17].

DHW demand daily pattern [6].
APPENDIX 2
Representative floors and floor description
Lay-out of the lower part of the building, representative for the floors 2-6 [Floor plan from 'JP van Eesteren'].
Lay-out of the upper part of the building, representative for the floors 7-19 [Floor plan from 'JP van Eesteren'].


### Description of the floors.

<table>
<thead>
<tr>
<th>Floor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>-2</td>
<td>Technical rooms, parking, dressing rooms</td>
</tr>
<tr>
<td>-1</td>
<td>Parking, toilets, kitchen, facility rooms</td>
</tr>
<tr>
<td>0</td>
<td>Reception, restaurants, kitchen, bicycle storage</td>
</tr>
<tr>
<td>Mezzanine</td>
<td>Diner rooms, toilets</td>
</tr>
<tr>
<td>1</td>
<td>Restaurant, meeting rooms</td>
</tr>
<tr>
<td>2-6</td>
<td>Guestrooms</td>
</tr>
<tr>
<td>7</td>
<td>Guestrooms, green roof, technical installations on roof</td>
</tr>
<tr>
<td>8-19</td>
<td>Guestrooms</td>
</tr>
<tr>
<td>20</td>
<td>Wellness</td>
</tr>
<tr>
<td>21</td>
<td>Bar/lounge, roof terrace, multi functional room</td>
</tr>
<tr>
<td>22</td>
<td>Roof terrace, green roof, green house. Possibility of 234m2 of pv panels</td>
</tr>
</tbody>
</table>
APPENDIX 3
Input data IES VE model
Lower part building in IES VE, representative for the floors 2-6.

Upper part building in IES VE, representative for the floors 7-19.

<table>
<thead>
<tr>
<th>Room number</th>
<th>Number of occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>35</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>45</td>
</tr>
<tr>
<td>6</td>
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</tr>
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<td>7</td>
<td>5</td>
</tr>
<tr>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>9</td>
<td>84</td>
</tr>
<tr>
<td>10</td>
<td>60</td>
</tr>
<tr>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>14</td>
<td>12</td>
</tr>
</tbody>
</table>
A: Adaptable façade control summer

Control adaptable façade summer: Lowers according to blind control profile A (when unoccupied), or in case incident irradiation > 500 W/m².

B: Adaptable façade control winter

Control adaptable façade Winter: Lowers according to blind control profile B (when unoccupied or sleeping of guests). a

a modulating value of 0.2 corresponds to an expected occupancy of 80%, then 20% of the adaptable façade can be closed.

b additional control of adaptable façade during the day when incoming irradiation is higher than heat loss through transmission is not possible to simulate in IES VE.

Temperature set points in IES VE:

<table>
<thead>
<tr>
<th>Temperature set points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating set point</td>
</tr>
<tr>
<td>Cooling set point</td>
</tr>
</tbody>
</table>

U-value construction parts:

<table>
<thead>
<tr>
<th>Construction part</th>
<th>U-value [W/m²K]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Window</td>
<td>1.4</td>
</tr>
<tr>
<td>External wall</td>
<td>0.47</td>
</tr>
<tr>
<td>Closed adaptable façade</td>
<td>0.5</td>
</tr>
<tr>
<td>Internal partition</td>
<td>2.05</td>
</tr>
<tr>
<td>External roof</td>
<td>0.18</td>
</tr>
<tr>
<td>External floor</td>
<td>0.36</td>
</tr>
</tbody>
</table>

Internal loads in IES VE:

<table>
<thead>
<tr>
<th>Internal loads</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>10 W/piece</td>
</tr>
<tr>
<td>People</td>
<td>130 W/person</td>
</tr>
<tr>
<td>Appliances</td>
<td>170 W/room</td>
</tr>
</tbody>
</table>
APPENDIX 4
Prediction heating and cooling demand by IES VE
Comparison heating and cooling demand for occupancy scenarios 1, 2 and 3.
APPENDIX 5

Annual energy flows  [Wolter & Dros]
APPENDIX 6
Homer simulations
Hybrid energy scheme in HOMER:

Daily and seasonal profile of scenario 4 (mixed occupancy) generated by HOMER of the expected grid demand:
APPENDIX 7
Electricity match nearby PV
As shown in Figure 13 of the report, the LCC decreases when the nearby PV increases from 0 to 500 m². The increasing from 500 to 1000 m² leads to only a slightly decreasing dLCC while the dLCC increases significantly when the nearby PV increases to more than 1000 m². The reason for this is the occurring energy mismatch when the nearby PV area increases above 1000 m². All electricity produced by the 500 m² nearby PV panels can directly be used by the hotel. The main part of the electricity production of the 1000 m² nearby PV is used directly, while a small part firstly needs to be stored in the battery, and is delivered to the hotel later. This leads to small energy losses. Increasing the nearby PV to more than 1000 m² leads to a large part of electricity which needs to be stored in the batteries for a longer time; the electricity production of the nearby PV way higher than the electricity consumption. This leads to large energy losses and quickly increasing dLCC.

![PV power production of the three nearby PV packages versus the net grid demand](image-url)

**PV power production of the three nearby PV packages versus the net grid demand**