Sustainable Roofs: An insight into the optimal utilization of the University of Groningen's buildings

Bachelor Integration Project Report

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Preface

The following report serves as a Bachelor Integration Project for the University of Groningen. It seeks to provide insight into the chosen topic of rooftop sustainability practices, and in doing so hopes to bolster the RUGs effort against climate change. Firstly, it will provide background on the topic, then outline what the report seeks to achieve. Following this, it will delve into the state of the art, then provide an analysis and recommendation based on the findings.

Acknowledgements

The following report serves as the summation of my study in the field of BSc Industrial Engineering, and represents three years of growth, knowledge, and perseverance.

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Abstract

Global warming is a prevalent issue across the surface of the Earth. One such issue that exacerbates global warming is the Urban Heat Island Effect, which is the increased temperature of cities relative to their surrounding areas. In order to combat these issues, the RUG seeks to utilize its assets and provide mitigation practices. Among these practices are vegetated rooftops, and applying PV-panels to roofs. The RUG thus seeks insight into the effects of these methods in order to most effectively implement them. This report thus garnered data on each practice, then went a step further to provide insight into the effects of combining both methods. The results yielded the facts that although each method presents strong positive effects on their own, the ideal pathway for the RUG is to combine both methods and reap the benefits of both simultaneously, while benefitting from the emergent effects displayed in the integration.

1. Introduction

1.1 Background

Global warming is a term that pertains to the increasing surface and atmospheric temperature of the planet, primarily due to human activity (Hougton, 2017). Already a significant issue, the effects of global warming in urban areas are exacerbated by the Urban Heat Island (UHI) phenomenon (EPA, 2019): which is the increased temperature of metropolitan areas, due to human activity, as compared to surrounding sub-urban and rural areas (Santamouris, 2014). These UHI's present a myriad of negative effects on surrounding ecosystems, organism health, and energy consumption (Hassid et al 2000; Stathopoulou et al, 2008). A warming city is a threat to its population, as increased temperatures lead to higher mortality rates, greater hospital admission, and accelerated degradation of infrastructure (Chhetri et al, 2012; Fouillet et al 2006; Ma et al, 2017). UHI's also increase the peak summer time energy demand specifically due to increased cooling costs. Furthermore, even though global warming in itself is predominantly compounded by the dependency and use of fossil fuels, UHI's exacerbate this effect due to the acceleration of pollutant creation, and increased emissions from cooling processes. (Fouillet et al 2006; EPA, 2016).

In order to combat global warming and its effects, world governments are issuing directives and deadlines in order to successfully tackle the growing problem. One such directive is the European Union Strategic Agenda, which aims at a sustainable Europe by the year 2030 (EU Commission, 2019). As the most documented phenomenon under climate change (Santamouris, 2014), heat island mitigation is thus a priority in the effort against global warming. Furthermore, renewable and non-polluting energy sources are being sought after as countries recognize the ever-present threat caused by climate change (UN, 2020). Among the institutions that seek to combat climate change lies the University of Groningen (RUG), which has its own 5-year plan to execute its vision of complete sustainability (University of Groningen, 2019). A plan which would result in a carbon neutral University powered by sustainable processes and environmentally conscious employees. Two promising solutions to the aforementioned issues that the RUG is considering are: vegetated roofing, and photovoltaic (PV) modules, more commonly referred to as green roofs and solar panels respectively.

Vegetated roofs refer to when the roof of a building is either completely or partially covered with vegetation and a growing medium, over a waterproof membrane. Other features include a root barrier, drainage board, and irrigation system. They can be classified into two main groups: intensive, and extensive; characterized by >15cm and <15cm of depth respectively ((Berndtsson, Bengtsson and Jinno, 2009; El Halow, 2018). Green roofs can be utilized on buildings in order to reduce storm-water runoff, create cooling effects in hot climates, create insulating effects in colder climates, improve air quality and stimulate evapotranspiration. (Santamouris, 2014; El Halow, 2018). In addition to this, there is research that suggests a positive effect of green roofs and the mental health as well as perceived aesthetic value by observers (Loder, 2014). A number of the aforementioned benefits serve as effective components in the efforts to mitigate UHI effects, and climate change by extension.

Energy from the sun can be harvested and transformed into electrical energy through the use of PV-panels, which utilize semi-conductors for this process (n.d. 2020). In

doing so, a sustainable and clean method of energy generation is created. By generating energy, PV-panels lower the energy costs of the system they operate in, as well as yield other effects such as reduce cooling costs, and bolster the longevity of roofing material when placed above it (Masson, 2014).
Low albedo, impermeability, and internal energetic processes cause buildings and their respective rooftops to be several degrees hotter than surrounding air temperatures, thus contributing to UHI (Gagliano et al 2017). In addition to this, rooftops represent 20 – 30% of impermeable space within cities, making them a highly under-utilized and underexploited resource (MacIvor et al, 2017). These factors have made utilizing rooftops as a tool in sustainable practices the subject of study in the efforts against climate change. Even though the costs and maintenance associated with green roofs and PVs are high, they are offset by the environmental benefits created (Ma et al, 2017).

1.2 Problem Context

The University of Groningen is currently increasing the magnitude of its endeavors against climate change. Some of the RUGs key goals in its efforts involve Carbon Dioxide neutrality, using 25% renewable energy, increasing biodiversity, reduction of water use, healthy employees and saving up to 30% on energy use (University of Groningen, 2019). To bolster its efforts, the RUG seeks utilize its available assets to meet its goals. Among these assets include the rooftops of the University buildings, which can be utilized with vegetation, PV-panels, or a combination of the two. In order to most efficiently and effectively achieve its goals of climate change mitigation and sustainability, the RUG requires insight into the potential effects of each system within the University's geophysical area, as summarized in the following Problem Statement:
The University of Groningen is seeking to maximize its adoption of green practices among its assets in order to combat climate change; among these assets are its rooftops, whereby it wishes to install vegetated roofing or PV-panels. To do so, the RUG requires an overview on the systemic effects of each green method, and the most feasible means by which to implement the most effective method.

1.3 Research Objectives

The objective of the research is to collect information on the following practices: vegetated roofs, and PV-panels, and provide the RUG with insight as to how each practice will affect its surrounding area financially, socially, and environmentally. This information will allow for judgement on which practice most nearly aligns with the RUGs goals, and thus what the optimal pathway for the RUG is. Finally, the report will provide a recommendation on the theoretical ideal form of implementation of the chosen practice is for the RUG, with the information idealized for the fact that the RUG is in the Netherlands.

1.4 System Description

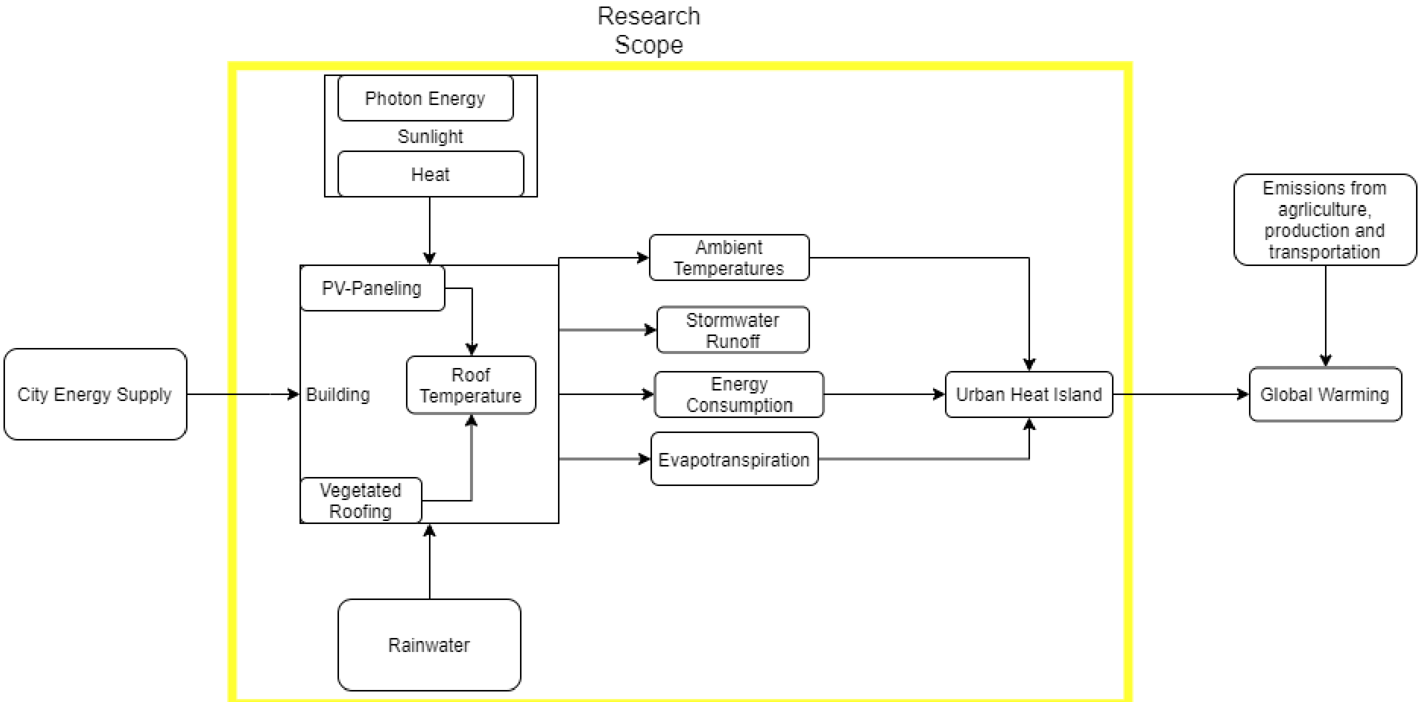

Figure 1: Simplified Physical System Description

As shown by the yellow border in Figure 1, the research will strictly be limited to studying the theoretical effects of PV-panels and green roofs on a single building within the University's context. The objects of study will be how each method affects the buildings energy balance, water retention balance, and social-aesthetic perception.

2. Methods

2.1 Outline

In order to provide the RUG with a highly comprehensive overview of each method, a thorough literature review will be combined with a simulation in order to display the distinct products of each system implementation.

Firstly, the literature review will be conducted in order to outline how each green practice interacts with its surrounding system, and yield the theoretical effects of each practice. The literature review will study the uses, costs, and benefits of PV-panels, vegetated roofs, as well as the theoretical combination of the two. Following this, a simulation using one of the RUGs buildings will be conducted, in order to supply results that are tailored for the RUG.

The building under study will be the RUGs Bernoulliborg building (Nijenborgh 9, 9747 AG Groningen), which was chosen due to its flat, even, and symmetrical roof layout. The first simulation will utilize TU-Delft's PV-panel simulator (pvportal-2.ewi.tudelft.nl, n.d.) in order to show how the Bernoulliborg buildings energy consumption, water balance, and aesthetic appeal would be affected by the PVs. The second simulation, will

come from the University of Arizona's Green Roof simulator (Urban Climate Research Center, n.d.) , in order to show the Green Roof's effects.
Finally, in order to provide an encompassing overview, the variables which were not available from simulation were derived from the literature review and placed in the results tables.

2.2 Input Parameters

Variable	Input Parameter
Panel Tilt	38°
Panel Azimuth	180°
Building Area	2770m²
Panel Area Coverage	2670m²
Module Technology	Medium Efficiency Monocrystalline Silicon
System Type	Rooftop PV System
Green Roof Coverage	90%
Non-Covered Roof Type	Dark (Low albedo) & White (High albedo)

Table 1: Simulation Input Parameters

Table 1 represents the input parameters to be used within the simulation, with the light blue shaded cells pertaining to the parameters that are strictly for the PVs, and the light green cells pertaining to the green roofs parameters.

2.2.1 PV-Panels

The orientation of the panels, namely tilt and azimuth, were chosen as they are deemed to be the optimal angles for maximal PV efficiency within the Netherlands, and thus an ideal to set as a baseline (Jacobson and Jadhav, 2018; pvportal-2.ewi.tudelft.nl, n.d.). The buildings area, was derived from three map area calculating tools, and then averaged to the amount given (Mapdevelopers.com, 2015; CalcMaps, n.d.; Daftlogic.com, 2010). Medium efficiency monocrystalline silicon was chosen as the technology for the PV-panels due to the fact that, monocrystalline silicon is currently the most accessible PV-technology, and accounts for over 90% of worldwide PV-panels (Photovoltaics Report, n.d.). Additionally, it was chosen to be medium efficiency in order to provide conservative output results for the report. Both the PVs and green roof significantly cover the rooftop in order to maximize the utilization, however a small area has been left to be dedicated to walkways in order to allow for ease of installation, observation, and maintenance.

2.2.2 Green Roofs

It is important to note that non-covered roof type is added as input variable in order to compare the green roofs performance against a dark roof, and a white roof, as each roof type yields different outputs. Such as the facts that dark roofs provide higher thermal insulation, and thus heat up the rooftops in the summertime, but assist with heating in the winter (Rosado et al, 2014). Additionally, lighter roofs reflect sunlight and thus assist with cooling in summertime, but detract from heating (as compared to dark roofs) in the winter (Akbari, Member and Konopacki, n.d.).

3. Literature Review

3.1 PV-Panels

Firstly, Photovoltaic (PV) panels allow for the utilization of energy provided by the sun by transforming photonic energy into electrical energy (Dominguez, 2011). In the process of doing so, PV panels do not create any carbon dioxide emissions or heat trapping gases, thus characterizing them as 'clean' as compared to other energy production methods such as burning natural gas and coal (Ma et al, 2017). In addition to this, PV-panels do not contaminate water in their use-as opposed to nuclear power-and have no negative effect on surrounding wildlife when placed on rooftops. (UCSUSA, 2020). The use of PV-panels within the Netherlands also presents financial benefits, such as the fact that excess electricity can be used to offset energy bills, and government subsidies for their installation and use (Zaken, 2017). Infact, if every usable roof in the Netherlands were to be outfitted with PV-panels, 50% of the entire Dutch energy demand would be fulfilled (Broerson, 2020).

The benefits of PV-panels go beyond financial effects. Cities in general import energy from respective power stations, thus contributing to the UHI effect via the addition of energy to the system. The widespread use of PV-panels mitigates the UHI effect by decreasing the amount of energy cities need to import, and utilizing the energy (sunlight) that is already entering the system, (Ma, 2017). However, even on a large scale, wherein over 50% of rooftops are utilized for PV-panels, the aggregate drop in city temperature is still less than 1°C. (Ma, 2017). However, this should not undermine the fact that PV-panels allow for the cooling of roofing and the buildings beneath them by absorbing the light and heat that would otherwise have fallen on the building. (staff, 2011; Dominguez, 2011). One such study showed that PV-panels reduce the amount of heat that reaches the building underneath by as much as 38%. Furthermore, by reducing the amount of heat that comes into contact with the roofing, the longevity of roofing is significantly increased up to a factor of 2, due to the reduced degradation from thermal stresses (Dominguez, 2011).

Even though PV-panels provide objective financial and environmental benefits, the importance of subjective factors such as aesthetics must not be overlooked, as non-aesthetically pleasing structures compromise the value of the surrounding landscape and become a burden for future generations to renovate (Roeser, 1970). One study in the Netherlands revealed that aesthetics was an important factor to as many as 40% of adopters, as well as the fact that there was a very mixed reaction to the aesthetics of PV-panels in general (Breuk, 2016).

3.2 Vegetated Roofs

Urbanized areas tend to evaporate very low amounts of water, thus necessitating the need for methods that stimulate evapotranspiration (EPA, 2017). Furthermore, typical bitumen roofs are generally several degrees warmer than nearby waterways within the Netherlands, significantly increasing cooling costs and underpinning the need for evapotranspirative methods of cooling (Corder, 2017). Additionally, the low permeability of urban areas allows for little to no absorption of storm-water, yielding a plethora of issues ranging from: erosion from storm-water runoff, increased sewage treatment fees from overflow, polluted waterways from sediment, and habitat destruction (Schroll, 2011; Bass, 2007)

Green roofs are layers of vegetation placed upon rooftops growing on a medium and waterproof membrane (LivingRoofs, 2019). As mentioned previously, they are characterized by their depth, the options lying between extensive green roofs (0 – 15/20cm) and intensive green roofs (+20cm), (El Halow, 2018).

The benefits of Green roofs tend to work in conjunction with one another. Firstly, green roofs can absorb up to 100 L/m² of rainwater (Marineterrein, 2019), which in turn reduces the magnitude and timing of storm water runoff (Schroll, 2011). Financially speaking, the reduced amount of stormwater runoff results in fewer sewage water purification costs, amounting to about €5/m2 of green roofs per 40 years for the Netherlands (Symbaal Zuivering, 2013). In addition to this, the large amount of absorbed water promotes evapotranspiration, which in turn cools the building by up to 4°C and surrounding area by up to 2°C (Groene Daken, 2019; Bass, 2007;). The cooling effects therefore apply to the city at large with increasing green roof application, thereby mitigating UHI effect (Razzaghmanesh, Beecham and Salemi, 2016). Green roofs also reduce noise pollution by reflecting up to 3db less of sound, and preventing over around 10db of sound entering the building with the average green roof (Renterghem et al, 2011). Finally, green roofs have direct beneficial effects on the well-being of humans in their vicinity; studies show that patients in buildings with green roofs use up to 30% fewer painkillers, and can reduce their time in care by an entire day (Gezondheidsraad, 2018). In addition, green roofs can potentially reduce dust particles in the air by up to 200g/m² per year (Trepanier, 2009). In fact, the Green roofs even prove the ability to increase productivity and attention span when beheld, partially due to the highly positive aesthetic and restorative perception embodied by them (Lee et al, 2015).

3.3 Integrated PV-panels and Vegetated Roofs

Although each technology provides distinct effects and benefits when utilized individually, research and practical application has yielded the fact that when implemented together, green roofs and PV-panels display emergent effects through a symbiotic relationship (Catalano et al, 2017). The combined employment of each method allows for each to function more efficiently and optimally than each would on its own respectively (Santamouris, 2014; El Halow, 2018; Catalano, 2017; Hui, 2009; Masson, 2014).

Firstly, by combining the two methods, one gains the benefits of each (Chow, 2019; Scherba, 2000; Pisello, 2015), however the two systems complement each other in a variety of ways. Firstly, the vegetation provides heightened efficiency for the panels in two pathways; by minimizing the particles that settle on the panel via absorption, and by lowering the peak temperature, as well as reducing thermal degradation, of the panels via evapotranspiration (Groene Daken, 2019). Lowering peak panel temperature is essential, as the efficiency of PV-panels reduces with increasing temperature (University of Kansas, 2018; El Halow, 2014). Additionally, green roofs outperform both black and white roofs in terms of increasing panel operating efficiency due to the fact that black roofs significantly increase ambient temperatures, and white roofs reflect light unto panels, thus increasing the temperature on the panels respectively (Bass, 2007;

University of Kansas, 2018). In fact, various sources have shown an increase in efficiency ranging from 0.5% to 8.3% higher output (Chow et al, 2019). With regards to flora and fauna, increased options for biodiversity are created as PV-panels create micro-climates around the vegetation (Living Roofs, 2017). Finally, their perceived effect as a combined sustainable resource helps to boost urban aesthetic values (Chow et al, 2019), the importance of which has been underpinned previously.

4. Results

4.1 Literature Results

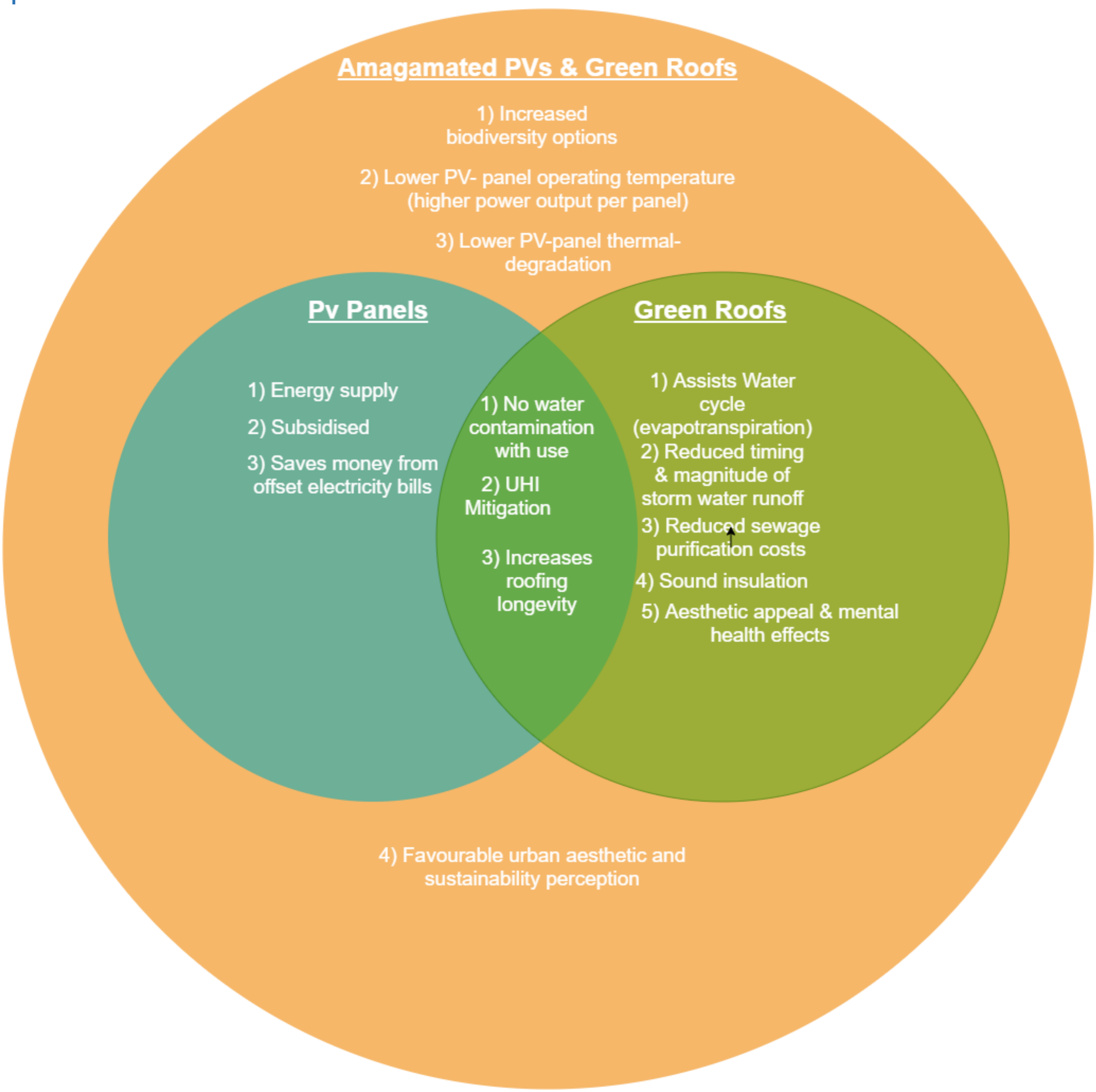

Figure 2: Venn Diagram of Literature Review Results

The first set of results depicts a summary of the literature review in order to provide a more visual representation of the effects of each green practice. The intersection of the blue and green shaded circles highlights the effects that both the PV-panels embody; whereas the listings within the orange circle but outside the blue and green circles describe the effects that are provided strictly by the integration of PV-panels and green roofs. It is important to note that, as stated in the literature review, the integration yields all the effects of both PV-panels, as well as emergent effects of its own.

4.2 Simulation & Literature Results

<table>
<tr><th></th><th>PV Panels</th><th colspan="2">Green Roof
Dark Roof/White Roof</th><th colspan="3">Amalgamated
PV Panels/Green Roof(Dark Roof-White Roof)</th></tr>
<tr><td>Area covered, m²</td><td>2760</td><td colspan="2">2493</td><td>1000</td><td colspan="2">1662</td></tr>
<tr><td>Electricity saved, kWh/year</td><td>453,020</td><td>10674.1</td><td>5279.1</td><td>160,000</td><td>4744</td><td>1147.4</td></tr>
<tr><td>Gas saved, kWh/year</td><td>n/a</td><td>-176.2</td><td>6746.1</td><td>n/a</td><td>-78.3</td><td>4536.6</td></tr>
<tr><td>Total Energy Saved, kWh/year</td><td>453,020</td><td>10497.9</td><td>12025.2</td><td>160,000</td><td>4665.7</td><td>5684</td></tr>
<tr><td>Profit from Energy Savings, EUR/year</td><td>35245</td><td>839.92</td><td>649.93</td><td>12256.28</td><td>373.48</td><td>273.57</td></tr>
<tr><td>Initial Investment, EUR</td><td>524,472</td><td colspan="2">173125*</td><td colspan="3">292985*</td></tr>
<tr><td>Roof longevity</td><td>40 – 50 years (doubles)</td><td colspan="2">40 – 50 years (doubles)</td><td colspan="3">40 – 50 years (doubles)</td></tr>
<tr><td>Roof Load Strengthening Requirements</td><td>None</td><td colspan="2">None</td><td colspan="3">None</td></tr>
</table>

Table 2: Financial Effects

**= (Living roofs, 2016; Green Deal Groene Daken, n.d.)*

	PV Panels	Green Roof	Amalgamated PV Panels/Green Roof
Precipitation, mm	376.6	376.6	376.6
Evapotranspiration, mm	0	330.6	246.1
Net Runoff, mm	376.6	49.5	130.8

Table 3: Water Balance

	PV Panels	Green Roof	Amalgamated PV Panels/Green Roof
Effect on UHI (Assuming large scale implementation, =>50%), °C	>1	0 – 2	0 - >2
Effect on roofing temperature, °C	-3	-4	-3 to -4
Relative Efficiency Per Panel	Lowest	-	Highest

Table 4: Temperature Balance

	PV-Panels	Green Roof	Amalgamated PV Panels/Green Roof
Aesthetic Appeal	Mixed	Strong	Very Strong
Biodiversity Applications	No	Yes	Yes
Mental Health Effects	Neutral/Slightly Positive	Positive	Positive

Table 5: Miscellaneous Effects

5 Discussion

5.1 Simulation-Literature Table Analysis

Firstly, as stated earlier, the simulations are not all encompassing, and were thus combined with the data provided in the literature review for a stronger system overview. Following this, in order to distinguish between simulation results and literature results, the cells in the table shaded rust-orange are to be interpreted as containing strictly simulative data; whereas the cells in the table shaded grey are to be taken as derivations from the literature review. Finally, the mustard-yellow cells depict data derived from both simulation and literature.

5.1.1 Financial Effects

In accordance with theory, PV-panels have been shown to provide the greatest possible financial benefit, due to the relative immense energy savings they provide. Infact, the table shows that fact that PV-panels yield energy savings over 42 times as large as compared to the optimal performance of green roofs. Additionally, within the green roof analysis, green roofs have been shown to provide electricity savings, due to reducing cooling costs, as compared to dark and white roofs. However, it is notable that green roofs have once more been shown to be less energy efficient than dark roofs with regards to saving gas. Although not stated in the simulation, one can draw the reason from this from a point mentioned prior, which is the fact that green roofs provide lower thermal insulation than dark roofs within the winter months due to the low albedo of dark roofs. Regardless, green roofs have proven to have greater net savings than both low and high albedo roofs on an annual scale. As stated in the literature, the amalgamated roofing underperformed against PV-panels in terms of energy savings, however, it outperformed the green roof in the same aspect, proving the point that the integration of the two methods can draw upon the effects of either, as will be further highlighted in the rest of the results.

5.1.2 Water Balance

The ability of vegetated roofing to mitigate storm water runoff is demonstrated in Table 3, as the vegetation absorbs and steadily releases an overwhelming proportion of the precipitation it encounters, as compared to PV-panels, which are completely impermeable and thus contribute further to storm water runoff. Once more, the integrated system allows for one of the characteristics of the two practices to be utilized; however, it should be noted that the numbers were generated with the assumption that the PV-panels were optimally placed in order to allow precipitation to drain from the PV surface unto the vegetation. Such figures would be erroneous in a situation where PV panels were placed beyond a point where precipitation could drain out unto the vegetation.

5.1.3 Temperature Balance & Miscellaneous Effects

The results of the temperature balance (specifically effect on UHI and roofing temperature) differ from other variables in the sense that it relied on the information provided in the literature review. Following this, it extrapolated the data into an educated assumption which is strictly the fact that in following the previous trend, and

by relying on the fact that the presence of vegetation is a cooling factor; the integration of the two systems would provide cooling benefits which are stronger than isolated PV-panels, but not as a vegetated roof on its own. Similarly, the simulation does not account for the emergent effects outlined in the literature, which are the facts that green roofs cool down PV-panels and thus increase their efficiency and power output. Thus, a numerical figure for increased efficiency would not be holistic and thus it is more beneficial to show the relative efficiency of the PV panels against the amalgamation. However as mentioned in the literature review, a 2019 study (Chow et al, 2019), coalesced various studies on percentage output increases when the integration occurs, with numbers varying from 0.5% to 8.3%. Thus, the possibility exists to calculate a theoretical increase in power output with a lower error margin.
Finally, the miscellaneous effects are reiterated from the literature as they are more qualitative and are beyond the scope of the simulation.

5.12 RUG Context

When viewed alongside the RUGs energy, environmental, and social goals, the amalgamation of both methods is the only means by which the RUGs efforts can be bolstered upon a single rooftop. The effects of both practices are needed in order to combat increasing temperatures while remaining energy efficient, particularly in summer periods, where Western Europe is currently experiencing a trend of rising heatwaves magnitudes (Della-Marta et al., 2007). Theoretically, by implementing both, the RUG would allow for less energy importation into the city by using the PV-panels for energy supply, and create a cooling microclimate within the city which directly combats the UHI by adding vegetation underneath the PV-panels.
By allowing access on the rooftops where the integrated systems are installed, the RUG will reap the benefit of increased employee wellness, as the benefits of such a system on mental and physical health were outlined in the literature review. The RUGs goal of water use efficiency will not be directly met with the initial system, as the basic integration does not bolster this, however, in mitigating storm water runoff, the RUG will provide the benefits highlighted in the literature to the city of Groningen. Namely, lower sewage treatment costs, and less sediment deposits into waterways. As a country characterized by high precipitation and numerous freshwater bodies (van Den Hurk et al, 2007; Mooij et al, 2005), the importance of mitigating storm water runoff within the Netherlands must not be understated. There exist green roof methods which would provide direct water use benefits for the Netherlands, however they go beyond the basic extensive roof discussed within this paper, and thus will be outlined in the section dedicated to future studies.

6. Parameter Setting

The following section will seek to provide the recommended parameters under which the University should implement its green and PV-roof program.
Firstly, it is important to note that there is an absence in the literature on the singular ideal way to install a green-PV roof system. However, there are certain variables which must be considered and optimized in the event of such an installation. These variables

have been tailored for the Netherlands, due to the RUG being located in said geophysical location, and are highlighted within table 5.
Additionally, with regards to a recommendation schematic, there is no single best ratio of PV-panels to vegetation to provide. Rather, as shown in the results, each ratio presents its own host of benefits to the system. Such as the fact that, a higher proportion of vegetation yields greater cooling effects, but a higher proportion of PV-panels yields greater energy and financial savings. The vegetation proportion is simply limited by the amount of space required for walking, whereas the PV-panel proportion is limited by both the needed space for walking, the amount of sun and shade required by the adjacent vegetation, as well as the drainage planning.

Figure 3: Amalgamated Green-PV Roof (Source: Renewable Energy HUB, 2020)

Variable	Recommendation	Reasoning	Source
Green Roof Type	Extensive	Best fit with PV-panels due to low lying vegetation, easiest to start off with	Living Roofs, 2017 El Halow, 2014
Extensive Roof Technology	Modular	Ease of installation, flexibility, self-containment	Hui, 2008
Dominant plant species	Sedum	hardiness, shallow roots, and strong water absorption capabilities	Durham et al, 2019 MacIvor et al, 2011
Other plant species	Grasses, Forbs	Best combination of water capture, evapotranspiration, and temperature reduction	Lundholm, 2010 RHS, 2020

Protection	Mesh shields	To protect against recurring strong winds	RHS, 2020
PV-Panel Tilt	34° - 38°	Prime tilt for optimal light absorbance Placing panels on stilts allows for tilt manipulation regardless of building orientation	Jacobson et al, 2018 TU Delft, 2020
PV-Panel Azimuth	180°	Prime direction (south) for optimal light absorbance	TU Delft, 2020
Panel Height	1 – 1.5m	Optimal space for air to pass underneath and vegetation to grow	El Halow, 2018
Construction Consultation	Vereniging Bouwwerk Begroeners	Member of the European Federation of Green Roof Associations, as well as involved in the creation of ISO level Green Roof installation standards	VBB Richtlijnen, 2017 EFB, 2020

Table 5: Parameters for Installation

7. Recommendations and Future Studies

In the analysis of the state of the art, a more efficient method of sunlight harvesting was discovered, known as Photovoltaic Thermal (PVT) panels (IJEEE, 2020). These panels have the ability to utilize both the light and heat generated by sunlight, and harvest both into electrical and heating purposes. As a more advanced method, it is recommended that once competent in the basic application of Green roof-PV application, the RUG should consider exploring the use of PVT panels in order to maximize its use of renewable sources. Furthermore, other avenues of exploration for the RUG are the use of storage containers within roofing, in order to use the collected storm water for purposes such as toilet flushing and vegetation cultivation. Finally, the RUG should consider utilizing the vegetated spaces for agriculture cultivation, as certain studies have yielded the facts that green roofs can produce up to 2kg/m^2 of agriculture (Green deal, 2020).

8. Conclusion

As the surface temperature of the Earth increases, institutions seek to combat the negative effects of these changes on a local and global scale. One such institution being the University of Groningen. In order to most effectively combat these changes, the RUG sought insight into the most effective way to utilize its assets, one such asset-type being its rooftops. Having chosen two methods in which its rooftops can be utilized, namely green roofs and the installation of photovoltaic panels, the RUG sought insight into the effects of the implementation of these methods, and how said effects aligned with the RUGs goals. The research yielded the facts that both methods provided both unique and shared effects, such as the large energy savings for PVs, a bolstered water cycle with green roofs, and the mitigation of Urban Heat Island in both. The research yielded that, in order to draw upon the positive benefits of both practices, an amalgamation was necessary, and this was indeed the only way to make progress with the RUGs goals with a single method. Throughout the study it was proven that although inferior to single methods in some aspects, the amalgamation proved the overall superior due to its ability to yield the benefits of both.

In order to further bolster the RUGs efforts, the study then provided the important variables for the RUG to consider once implementing the integrated system, whilst showing the reasoning behind each variable.

It should be duly noted that this is not the end of the RUGs efforts into the field, but rather the beginning, as the study has proven that it is a multi-layered system whereby there are many future pathways of exploration for the RUG to attempt and experiment with. By using the guidelines presented, the RUG can begin the decade with a stronger foundation upon which to continue its valiant efforts in the preservation of planet Earth.

9. References

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