Reflection

Milan Voorhorst - 4158342

Method

The chosen method (literature, analyses, design) worked out well. With this methodology, I have touched all scales of the research question; from theory to design. The results I got from the analyses part, give justified input for the design. Because of this process, I would describe the graduation 'design by research' since all decisions until now are based on the output from the parametric model.

Graduation is characterized as design by research

During the process, I learned software I had not a lot of experience with. I did not use the parametric software Grasshopper too much before and especially the plugins honeybee and ladybug took me quite some time to learn. Now, this effort payed off, and the research method worked in that sense. I got substantiated conclusions from the calculation models, and I made visual what the impact of geometry and context is on the local radiation level of a surface. What is new, is the link between the energy weather data, parametric design and climate calculations. However, I expected that it would take less time and wonder if this is the most effective method to make these calculations. The temperature calculations should be validated. Now, the results can only be used for reciprocal comparison. Also, the PV yield calculation should have an extra validation with another project, over a longer time.

The morphological design overview is a good way to give insight in the choices that you need to make, designing a large glazed space with PV cell. However, I think that there are more options to add in the overview. Also, numerical consequences of choices could be attached.

Social context and relation graduation lab theme

In general, the world needs 'clean' energy sources (without greenhouse gas emissions). Most people agree that humans emit too much greenhouse gasses, especially carbon dioxide, and that it leads to climate change. This climate change threatens the way people live today. Buildings use a significant portion of world's energy consumption. With new and cheaper becoming technologies like photovoltaic cells, decentralized energy production emerges as a promising option for energy production on buildings. The theme of this graduation lab is sustainability. The starting point of my thesis is focused on the energy part of sustainability; reduction and production. So, one specific theme in sustainability is considered. Reduction of use of energy from non-renewable resources is the aim throughout the thesis. However, sustainable aspect could be worked out further. For instance, what is the lifetime of an atrium or how does such a space influence human wellness?

Architectural value

Architects tend to make more transparent building nowadays. However, overheating is a problem for large glazed spaces. Often, the coating to filter as much of the near-infrared part away, is not enough to meet the requirements. With the new PV cell technologies you can meet these requirements and use the solar energy instead. With the parametric model and design overview a designer 'knows what to do', without the need of extensive knowledge on the subject. With this insight, you can give solar shading something 'extra' in a design, and design with it instead of adjust the STF at the end.

Reflection on sustainability

Large glazed spaces have several climate/comfort issues. Currently, the internal thermal comfort is one of the most important ones. On summer days, large glazed spaces tend to get overheated. Leading to low thermal comfort. Human wellbeing is an important aspect of sustainability. Also, if people do not feel comfortable in the space, it will be used less or demolished quicker (durability).

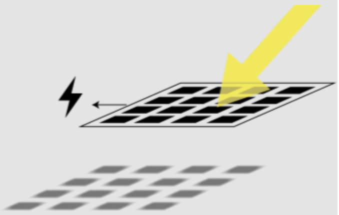

figure 1: solar cells provide shading and electricity

Operating buildings in general, is a large part of the global annual energy consumption. Adding to the thermal comfort reduces the probability that such a space is climatized actively. To affect the climate of large glazed spaces, much energy is needed. So, the probability that a space will be actively climatized should be brought to the minimum. The concept is to shade the space (adjust the STF) by applying solar cells. The focus of thesis considering sustainability is presented in figure 2.

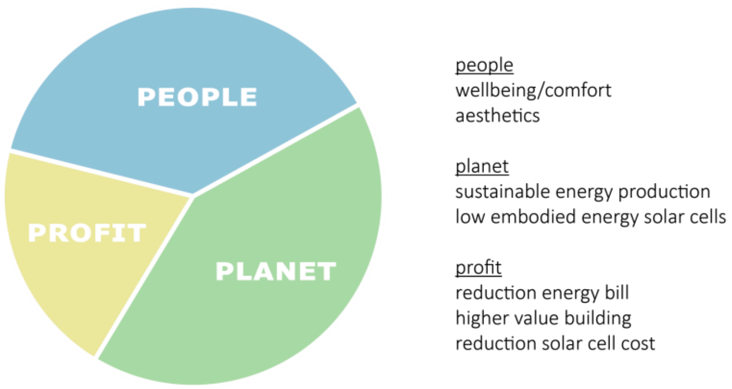

figure 2: focus of thesis regarding sustainability

Results

The focus of this thesis is on thermal comfort in summer of large glazed spaces. With solar cells a double effect is achieved; increase of thermal comfort and production of sustainable energy. The most significant parameters to bring down the temperature in summer are the solar transmittance factor, the (passive) ventilation rate and the thermal mass.

There are several solar cell technologies that all have their own specific properties to select on. Cost and efficiency are the most well-known criteria. Also embodied energy (from production) is a very important factor, regarding sustainability. When you compare the embodied energy of a solar system, it is important to take into account the total "balance of system" (BoS). The second generation of PV cells already have a significant lower embodied energy (Figure 3).

The new third (nano) generation of PV cells has some important advantages relative to first or second generation solar cells. For example, dye-sensitized solar cells, the embodied energy is much lower than regular crystalline and thin film solar cells. In production, you just need a maximum temperature of 500 oC instead of 1600 oC. Also, the light level threshold is low. So even with a little light, DSSC's produce energy. How much energy is saved per kWp relative to c-Si solar cells, is hard to say since there is no large scale, commercial production yet.

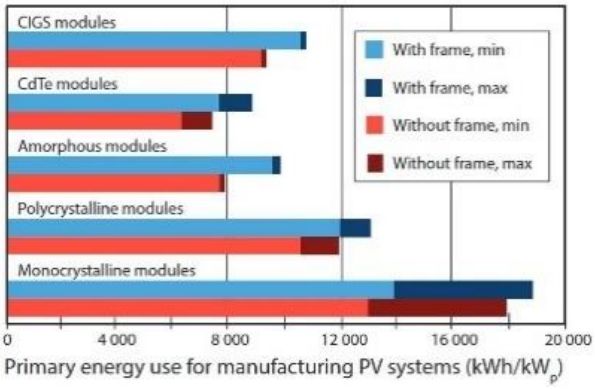

Figure 3: primary energy use for manufacturing different PV systems (kWh/kW$_p$); top to bottom: CIGS, CdTe, a-Si, poly c-Si, mono c-Si. The three thin films use about 30 to 50% less primary energy relative to crystalline silicon cells. (Smets et al., 2016, p. 346)

The efficiency of these solar cells is typically lower. However, if the embodied energy per kWp is lower than for instance c-Si cells. Maybe you need more square meters per kWp, when it is cheap and you have plenty of surface area, it does not matter.

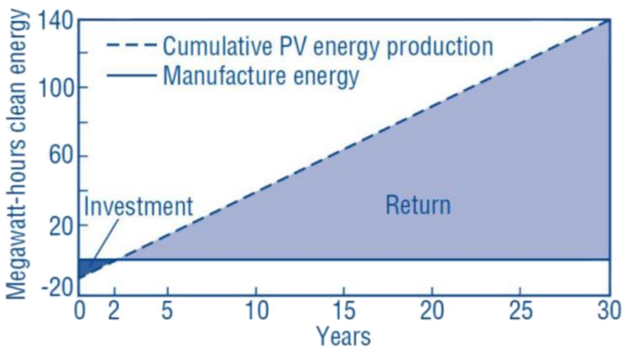

figure.4: PV module (c-Si) energy payback time of 2 years; during expected lifetime of nearly 30 years, the module produces multiple times the invested energy (U.S. Department of Energy, 2004, p. 2)

The application of solar cells to bring down the indoor temperature is studied before. James et al. (2009) concluded that "*with appropriate consideration of added value factors*" the use of semi-transparent solar cells in atria/large glazed spaces can be justified in terms of both cost and carbon footprint (figure.5). Factors that should be considered to make it

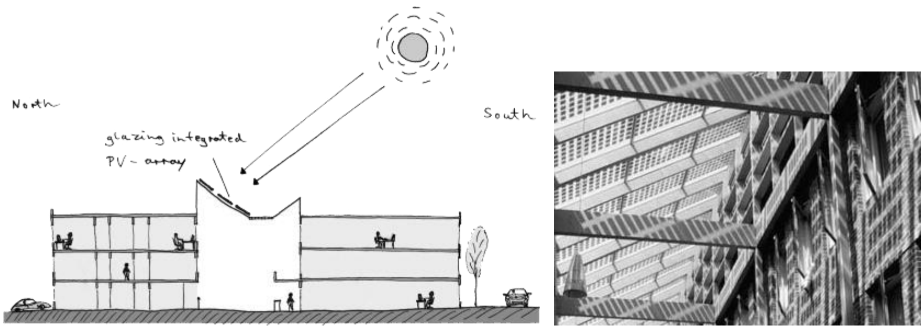

figure.5: PV cells as a replacement for shading, placed on the most intensely radiated part of the roof (James, Jentsch, & Bahaj, 2009, p. 222)

pay off are orientation, location, context, function of space and temperature demand, for example.

With the developed parametric model for this thesis you can calculate the added value of integrated PV cells (figure.6). Now, in an early design phase you can already test whether the concept ‘works’ like you have in mind. Based on results for the parametric model you can make design decisions. Before you had to experiment like the project in figure.5. Or in the best situation, the design is calculated by a consultancy company. But this would always be after the first temporary design decisions are made.

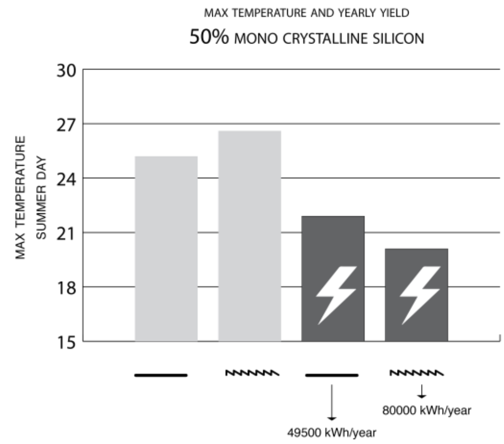

figure.6: solar radiation analysis result of a total year. Comparison between flush or sawtooth texture and with or without PV cells.

Mono crystalline silicon cells, spaced so it has 50% transparency and 21% conversion efficiency is used.

In the thesis, thermal comfort is only addressed as the maximum temperature in summer. However, it would be good if from the calculations the thermal comfort, per month e.g., would be rated. In that way, one would really see whether the double effect of integrated solar cells work or not.

Recommendations for further research

- Exact values on the solar transmittance factor/absorption facto of the ‘new’ types of PV (for instance thin films, DSSC’s, OPV);
- Only a moderate climate is considered in this thesis. What would a different climate mean for the parameters and design decisions?
- Solar cells on a curved surface will receive a different level of insolation. This will cause the cells to wear off uneven. What is the relevance per solar cell technology; which one is more suitable to apply on a curved surface than a the other? Maybe half of the cells should be replaced for example after fifteen years, and the other half already after eight years;
- A daylight level study can be added to the parametric analysis tool;
- The parametric model can be optimized to make it user friendly/fool proof;
- Development of parametric tool, to make it possible to let the computer search for the best options (computational optimization)