Note:

1. The content in green is newly updated from the last version (v1.0).

2. This template is the guidance for content to be included in the report (which means it is strictly defined), and it is the recommended structure to follow (which means you can tweak). It is fine to have your own format as long as it fits in the page limits (strict page limits; font size not smaller than 10).

**Report Title**

Group Number:

Name of members (in the format: ‘subsystem 1: xx xx; subsystem 2:xx xx; subsystem 3: xx xx’)

*Note: This is a formal report and should be well-written and organized. Part of the grade will be for professionalism and presentation. (This paragraph should be deleted in your report.)*

# Abstract

An abstract of approximately 200 words describing your problem and the results obtained. Do not write generalities and be specific about your work.

# Introduction

This section should introduce a qualitative statement of the system design optimisation project. Describe the system design problem, the anticipated trade-offs that motivate the optimisation study, and the previous work that has been done by others. Define the goal of your study.

Image of the property and areas of focus.

# System-level problem and Subsystem breakdown

Present a system-level optimisation formulation, with a single top-level objective, all relevant variables, and constraints. Remember, there should be at least 8 variables and 8 constraints at this level. Present it in negative null form with the below structure. You may want to rename your variables or functions so that it is easier to follow; e.g., if one variable is speed/velocity, you may want to call it or instead of .

where

subject to

...

...

(Note: feel free to move the formulation part to ‘Section 6.System-level optimisation’, if you think it works better with your structure)

State clearly in the text what each variable represents, what each function means, and where the equations came from. Justify why you have chosen your objective and your constraints (with references where relevant).

Identify the individual subsystems, rationalize selection of these subsystems, and explain qualitatively how they are linked. A diagram may help to show the interdependencies (e.g., linking variables, outputs from one subsystem that are inputs to another or to the system-level problem, etc.).

# Subsystem 1 – Window Integrated Photovoltaics

Subsystem 1 focuses on the use of Building Integrated Photovoltaics (BIPVs) which can be implemented in the pre-existing window frames of the domestic property. The BIPVs models come in a range of power ratings, with varying transparencies (SEE TABLE).

The main objective of subsystem 1 is to find the best combination of panels in the 5 windows that minimises the number of years it takes to achieve a return on investment (ROI) for the installation. In order to do this the upfront costs must be minimised and the yearly return and hence power output must be maximised. (REFERENCE EQUATION).

However, other design constraints must be considered. For instance, the windows in question all belong to one room in the property which is used as a study and will require a **certain** number of hours in the day for work. (REFERENCE OFFICE WORKING CONDITIONS LUX). In addition the overall cost of the installation must be capped to a reasonable amount, defined by **subjective design decision (OVERALL SYSTEM COST).**

BUT ALSO A multi objective Genetic algorithm makes a lot of sense here.

The model of BIPV used was PS-M-NX Series panels from Polysolar (1) . This model of BIPV was selected for its range of available transparency types and relatively high power values compared to other models. Having spoken to a representative from Polysolar it was gathered that the panels from a specific series came in a fixed size and price regardless of power rating. The panels could be cut down to size to fit window space required. It is also assumed that each window will be completely filled with one type of panel for consistency and aesthetic purposes. Another assumption made is that to a single series type of panel should be used so that a single inverter can be implemented for all BIPVs **(Source).**

**IS IT POSSIBLE TO TEST DIFFERENT TRANSPARENCY TYPES – tested and Panel 1 is better show in diagram**

Subjective design decision – minimise use of intrusive panels so subsystem 1 is required

Image of subsystem

# Optimisation formulation

In negative null form, present the subsystem optimisation formulation. This should stand alone and it should possible to optimise without knowledge of the other subsystems. If there are interdependencies, use parameters to represent assumptions needed to decouple the subsystems. (Remember to be consistent with variable names in the system-level formulation.)

|  |  |  |  |
| --- | --- | --- | --- |
| Variables | Definition | Units | Value |
|  | Power value of panel (1-5) | *kW/* | - |
|  | Area of window 1 |  | 1.44 |
|  | Area of window 2 |  | 1.44 |
|  | Area of window 3 |  | 0.5 |
|  | Area of window 4 |  | 0.5 |
|  | Area of window 5 |  | 1.8 |
|  | Area of working space |  | 9 |
|  | Yearly Irradiance value on window 1 |  |  |
|  | Yearly Irradiance value on window 2 |  |  |
|  | Yearly Irradiance value on window 3 |  |  |
|  | Yearly Irradiance value on window 4 |  |  |
|  | Yearly Irradiance value on window 5 |  |  |
| FIT | Feed in tariff | £/kWh | 0.386 |
|  | Irradiance values for wall for each hour of the day |  | - |
|  | Irradiance values for roof for each hour of the day |  | - |
|  | Quality of light | - | {0,1} |
| lx | Lux value | lx | - |
|  | Distance from window 1 to working space | *m* | 0.4 |
|  | Distance from window 2 to working space | *m* | 1.5 |
|  | Distance from window 3 to working space | *m* | 1.5 |
|  | Distance from window 4 to working space | *m* | 2 |
|  | Distance from window 5 to working space | *m* | 2 |

|  |  |  |  |
| --- | --- | --- | --- |
| Functions | Definition | Units | Value |
|  | Objective function, the number of years until ROI | *Years* | - |
|  | Function that calculates the cost of the array | £ | - |
|  | Function that calculates the energy output of the array | kWh | - |
|  | Function that calculates the financial payback of the array | £/Year | - |
|  | Function that calculates the number of hours of light that qualifies as sufficient to work during the day | Hours | - |
| t(x) | Function that calculates transparency (Coefficients from linear regression) | % | - |

**Describe all functions** and **variables**. Justify this structure using references and explain any assumptions.

Put parameter nomenclature in an appendix

# Modelling approach

The variables correspond to the power ratings of the panels installed in windows 1-5.

The objective function calculates the number of years that it takes for a return on investment of the configuration and is the ratio of upfront cost over the yearly payback **(REFERENCE?)**.

was calculated by the sum of the number of panels used for that configuration. Each panel cost £600 with an additional installation cost of £500 per window that had panels installed. An value of 0 implied that the window remained unchanged so incurred no costs.

was calculated by the product of energy of the array configuration, and the feed in tariff (FIT) rate (2). was calculated using the yearly solar irradiance values on both the wall façade and roof area as well as the power ratings of the panels taken from the product specification sheet (1) . These were acquired from a PV SOL simulation that took into account the geometry, shading and geographical location of the property.

states that the number of hours of ‘quality’ light must be greater than 6. The ‘quality’ of light was determined by being greater than standard office lighting conditions of *500 lux* (3). The irradiance values selected for this constraint was a dim day in January, obtained from PV SOL. The Light levels in Lux falling on the work area for each hour of the day was calculated. **Number of hours = 6 why?**

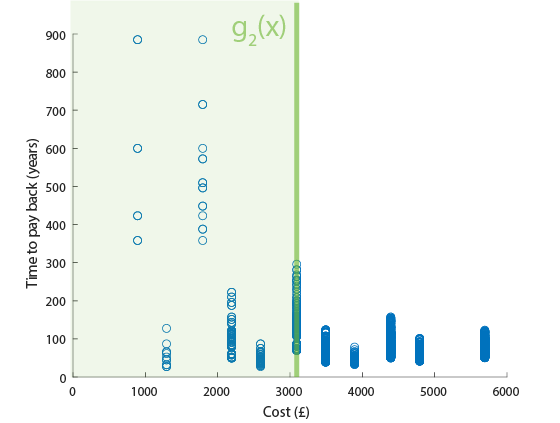
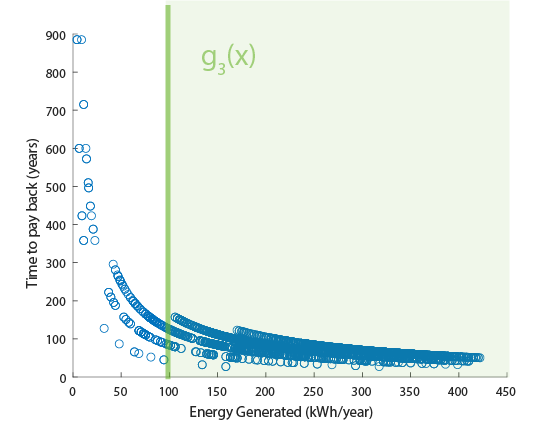
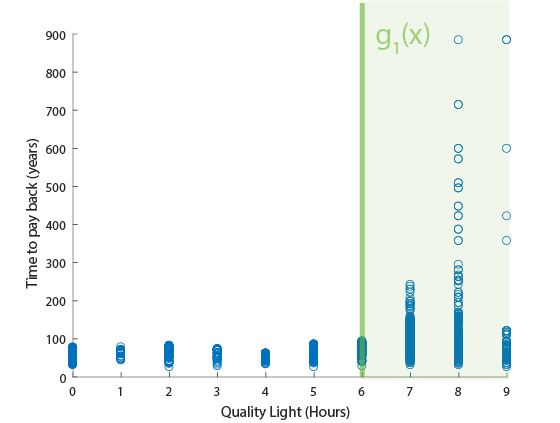
states that cost of this subsystem must be less than £4000 **why?.** This was calculated by the cost function described earlier.

states that the yearly energy generated by the subsystem must be greater than 100 kWh. **This is** **arbitrary .**

*Describe all models needed. This should make it entirely clear how the objective and each constraint are calculated. Justify each model/function with a* ***reference or an explanation of why the model is meaningful.******Explain any assumptions that you have made.***

# Explore the problem space

In order to understand the problem better a full factorial experiment was conducted. For every combination of the , and was plotted against the objective function (figure X).



Upon visual inspection of the range space it was noted that due to the complex and discrete nature of the problem space, the range space no clear gradients were found in light quality and cost. There did seem to be some exponential relationships with energy and the objective function, however the complexity and layers of values implied that it would be difficult to solve with gradient based solutions.

**When constraints were added (shown in green)…** However, using an optimiser would be needed to test this in more detail. Constraints and appeared active wrt cost and to light quality as it appeared to eliminate possible minima from the range space. Constraint seemed inactive wrt Energy production as it did not eliminate any optimum solutions.

**Test constraint activity**

Each constraint was removed independently and tested with the Genetic Algorithm (GA) solver. As predicted, removing changed the optimum solution. When was removed the optimisers tended to full power and zero transparency as light requirements were not constricting the model. When was removed, interestingly, many of the optimal solutions produced did not exceed this constraint and it hence was not active. As predicted had no effect on the solution.

Therefore, to simplify the formulations, constraint and can be removed from the formulation.

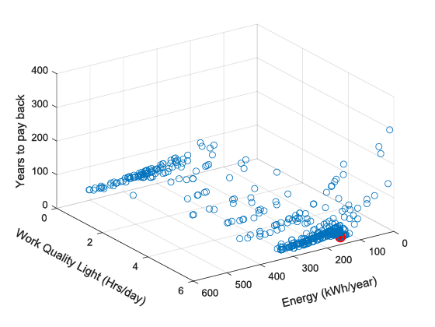
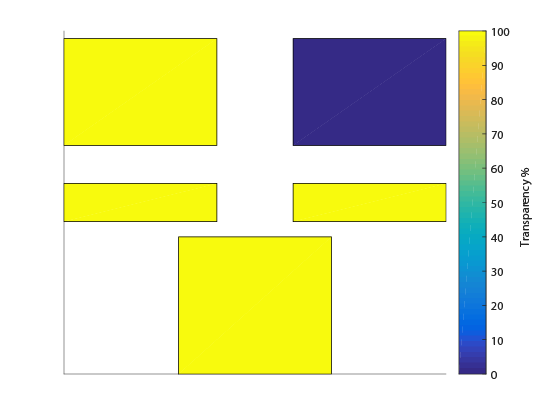
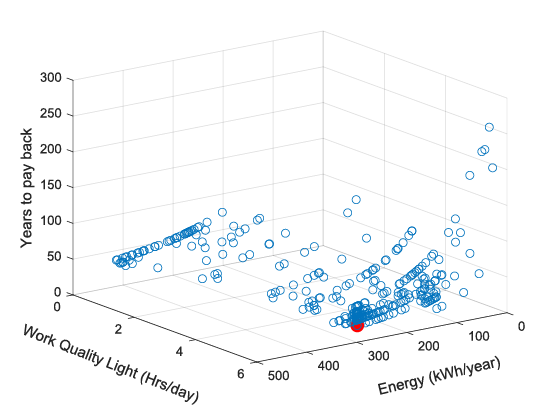
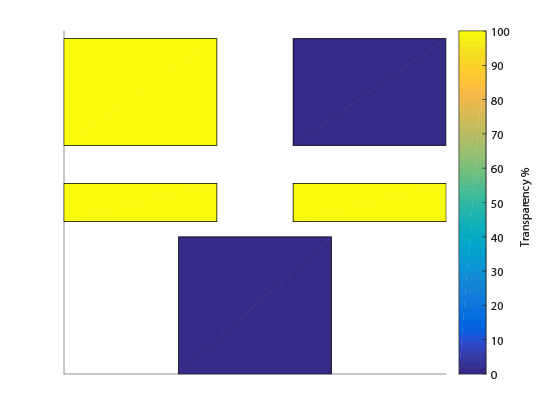
*Analyse the monotonicity or expected/known constraint activity to the extent possible. Simplify your formulations wherever possible.*

*If the functions are simulations (black boxes), conduct a DOE covering the design space and see if you can determine monotonicity or develop a useful metamodel.*

# Optimise

**Fmincon show that doesn’t work, as expected**

Because of the discrete and complex based nature of the problem space, it was decided to use non-gradient based optimisers. Genetic Algorithm (GA) and Particle Swarm (PS) optimisers were tested. The results of each optimiser are shown below.



|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Solver** | **Time to solve (s)** |  |  |  |  |  |  |  |  |  |
| Genetic Algorithm | 7.094 | 0 | 0.104 | 0 | 0 | 0.104 | **22.581** | 2600 | 298.3 | 6 |
| Particle Swarm | 0.76804 | 0 | 0.104 | 0 | 0 | 0 | **21.192** | 1300 | 158.92 | 6 |

It should be noted at this point that both solvers are stochastic, so it is unlikely to produce exactly repeatable results. However, it was found that the GA produced far more variation between optimised solutions. Often on first trial the GA, no feasible answers were found. In addition the GA took significantly longer to solve compared to Particle Swarm.

*Test two different optimisation algorithms using MATLAB. Explain how you set this up and solved it and show the results (both optimum* ***objective function*** *and optimisers* ***variables****).* **Conduct post optimal analysis (e.g. sensitivity analysis and/or parametric study)**

# Optional: Optimise with an advanced formulation (rename this heading)

**Here I can do a multiobjective GA of cost and energy.**

Re-formulate the problem in at least one of the following ways: (1) Multi-objective optimisation, (2) Robust design optimisation, or (3) Reliability-based design optimisation. Present the formulation, solve it, and discuss the results. If you chose a multi-objective problem, this must include a Pareto frontier. (Note: this can be counted as the second optimisation method if you only have one for Subsection 3.4).

# Discussion

**Briefly summarise this subsystem’s optimisation. Discuss which method seemed to work best, and/or discuss the pros and cons of each. Discuss some of the challenges, design implications, and how the analysis could be improved in the future for application in the real world.**

# Subsystem 2 (rename this heading, and copy the subsection titles from Section 3)

# System-level optimisation

Describe the strategy for solving the system-level optimisation problem. Present a new, more precise formulation if needed, with justifications for any models, parameters, and assumptions.

Explore the problem space, and then solve the system-level problem. Justify the solution method.

Present the results, discuss what they mean, and describe some of the challenges and future work needed for application in the real world.

# Conclusion

Briefly and quantitatively summarise what was achieved in the study. Was the goal is met, how, and by how much was the system optimised?

Briefly summarize the greatest challenges in system design and optimisation, and summarise key lessons learnt.

# References

List citations here in numbered style; [1] … [n]. Refer to all of them in the text using numbers, e.g. [1].

# Appendix A. Nomenclature

Define all symbols that you use, particularly for the mathematical model development. Make sure you use a consistent nomenclature and set of symbols in subsystems. (It may also be convenient to divide the symbols list to subsystems.)

Note:

1. Upper limit: 8 pages for groups of 2 members (11 pages for the group of 3), excluding References and Appendix of Nomenclature.

2. Except for ‘Appendix A. Nomenclature’, no other Appendices are accepted.

References

(1) Polysolar. *PS-M-NX Series panels - Product Specifications for a-Si/μc-Si thin-film glass/glass laminate BIPV glazing units.* Available from: <http://www.polysolar.co.uk/documents/PS-M-NX%20Technical%20Specification%20sheet.pdf> [Accessed 05/12/2018].

(2) Ofgem. *Feed-In Tariff (FIT) rates.* Available from: <https://www.ofgem.gov.uk/environmental-programmes/fit/fit-tariff-rates> [Accessed 12/11/2018].

(3) National Optical Astronomy Observatory. *Recommended Light Levels.* Available from: <https://www.noao.edu/education/QLTkit/ACTIVITY_Documents/Safety/LightLevels_outdoor+indoor.pdf> [Accessed 12/11/2018].