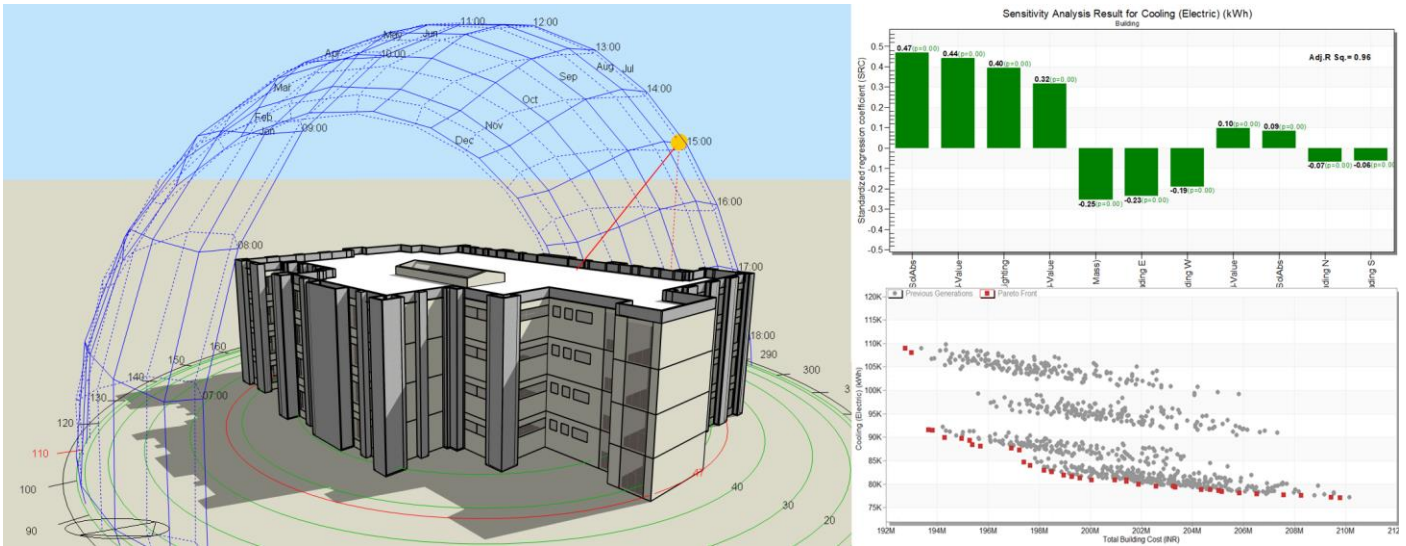


# Sensitivity Analysis to Simplify and Speed up Optimisation for a Teaching Building in South India



## Project Details

**Objective:** This Sensitivity Analysis (SA) study is developed on a previous optimisation case study: [Optimising the Fabric and Service Design for a Teaching Building in South India](#). The previous study demonstrated how the architectural and system design solutions that offer the best energy performance at the lowest cost were identified as part of the design process. In this study, an SA is carried out as a preliminary step to significantly improve the clarity and accuracy of the design optimisation outputs.

**Building:** One of 6 typical teaching buildings in a college campus, 4-storey, 5300 m<sup>2</sup>

**Location:** Southern India

**Climate:** Hot and humid, hottest periods from March to May and Monsoon rains from June to October

**Credits:** Written by [Chad Isnor](#), P.Eng for a project by [PSI Energy Pvt. Ltd.](#), New Delhi, India ( )

## Introduction

Design-stage decision-making requires interpretation of large amounts of complex data. There can be a huge number of potential combinations of variables and this gives rise to long simulation times and cumbersome result interpretation. This design-stage study applies the Sensitivity Analysis (SA) method to identify the building fabric options that have the greatest influence on the building Cooling Energy and Capital Costs.

A SA can be used to identify the most influential Design Variables from a previously defined list to help support design decision making, value engineering, optimisation studies and understanding risk. Any ambiguous and/or misleading variables can be identified and omitted from subsequent analysis

allowing the decision-making process to focus on the most important variables, unencumbered by less relevant factors.

It also shows how to check the quality of the SA results and provides guidance on how to proceed in cases where the quality check indicates a low level of confidence in the results.



**Figure 1:** Teaching block buildings showing recessed windows on the North elevation

## The Problem

The purpose of a Sensitivity Analysis is to gain a detailed understanding of the relationship between the various Design Variables and the KPIs of interest. The technique provides a systematic way to rank the variables by the relative importance for each design KPI output. It can be applied as a precursor step to improve the efficiency of an optimisation analysis by pre-screening design variables. Removing non-influential variables identified by SA decreases the optimisation runtime by reducing the “search space”. In addition, any non-influential variables add noise to the results, making it challenging for both the optimisation algorithm and the user to identify trends. With only the most influential variables included, the optimisation results are clearer and so can be more easily interpreted and communicated.

### Advantages of Sensitivity Analysis

- » Determines which of the Design Variables have a significant impact on the optimisation outputs.
- » Assesses the direct or inverse relationship of Design Variables with the outputs.
- » Provides options to reduce optimisation problem complexity by suggesting the variables that can be removed.

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Envelope	Wall	Insulation (Type)	None	Air	XPS Inside			XPS Middle			XPS Outside		
		Thickness (mm)	-	50	25	50	75	25	50	75	25	50	75
		U-value (W/m <sup>2</sup> K)	0.56	0.50	0.41	0.33	0.27	0.41	0.33	0.27	0.41	0.33	0.27
	Window	U-value (W/m <sup>2</sup> K)	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0			
Roof	Insul. Thk.(mm)	50			68			75					
	U-value (W/m <sup>2</sup> K)	0.58			0.46			0.42					
Partition	Thickness (mm)	115			230			345					

Shading	North	IMG	OH (m)	1	0.30	3	0.30	5	0.30	7	0.90
			SF (m)	0.00	0.00	0.30	0.60	0.60			
	South	0	0.00	2	0.30	4	0.30	6	0.60	8	1.20
	East	0.00	0.15	0.45	0.60	0.60					
West	0.00	0.15	0.45	0.60	0.60						

Surface Finishes	Wall Sol Absorbance	0.50	0.55	0.60	0.65	0.70
	Roof Sol Absorbance	0.30	0.45	0.60	0.75	

Systems	Lighting	CFL	T5	LED
	HVAC	Split	Air Cooled	Water Cooled

**Figure 2:** Matrix of Design Variables and options for the analysis

Figure 2 above summarizes the full list of variables considered in the design problem along with their corresponding options. The variables and design options that influence Cooling Energy and Capital Cost and were considered in this analysis were:

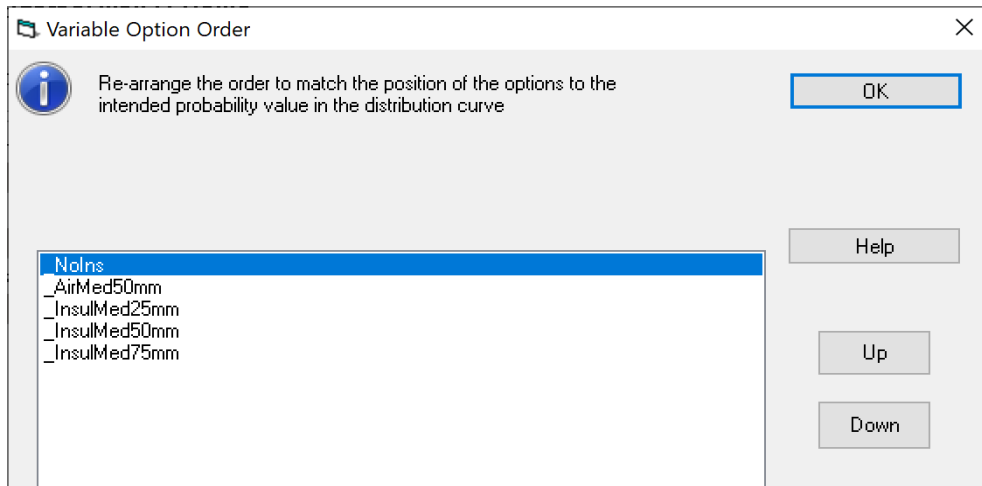
- » **Envelope thermal performance:** The possible envelope performance improvements were analysed by varying insulation thicknesses in the walls and roofs and the window U-values.
- » **Thermal mass:** The effect of thermal mass was explored by changing the location of insulation in the external walls and varying the thickness of the brick partition wall.
- » **Shading:** Various shading options were applied to limit the direct solar gains. This offers a low-cost way of reducing gains and reduces the need for a more expensive glazing solution with solar control.
- » **Surface finishes:** Reflective surfaces reduce the Cooling Energy use and have negligible cost implications. Surface finishes were modified by changing the solar absorptance of the outermost material of the roof and external wall surfaces.
- » **Systems:** On the systems side, various lighting and HVAC systems were analysed. Lighting is a source of significant heat gains, and the selection of an HVAC system also involves a trade-off between Capital Cost and efficiency.

## Sensitivity Analysis Setup

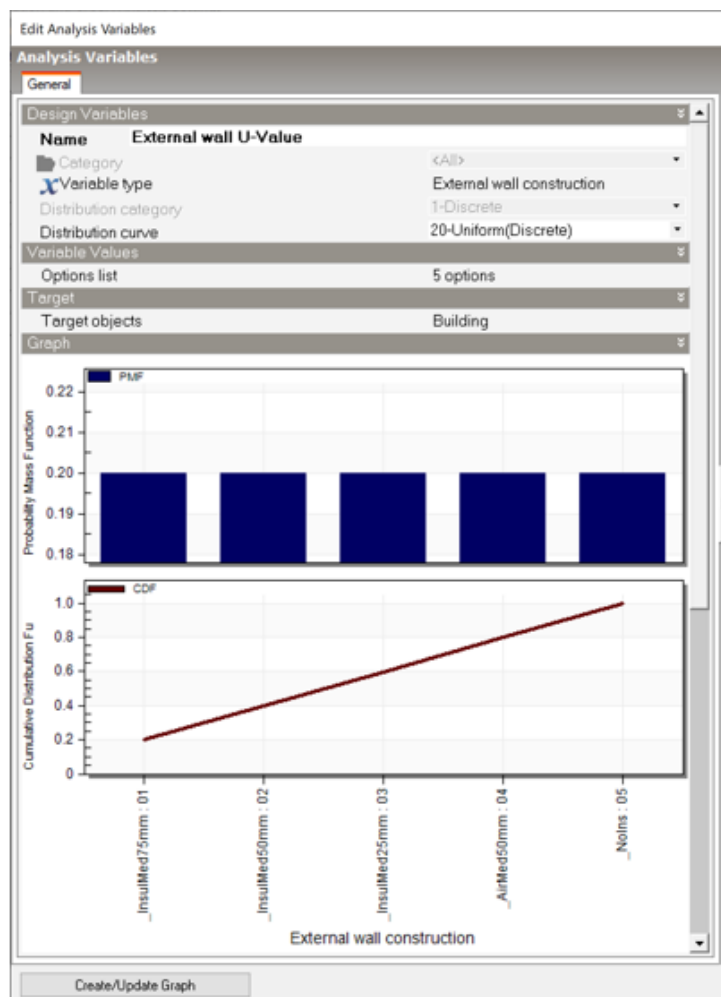
This section explains some details of how the SA studies were set up. You can skip to the [Results and Analysis section](#) if you are mainly interested in gaining a higher-level view of how Sensitivity Analysis can be applied to projects.

It is good practice to carry out a separate SA for each design KPI output because Design Variables can influence each output differently. The order in which Design Variable options are selected for each output is important. The options should be arranged according to their value. For example, the wall options in the SA list should be arranged from low to high U-value when Cooling Energy is the selected output. For the Capital Cost KPI on the other hand, the walls should be listed in order of increasing cost. In the next two sub-sections, we will look at the problem definition for the two outputs used in this analysis - Cooling Energy and Capital Cost.

### Cooling Energy SA Setup



**Figure 3:** Selection Sequence Dialogue - Variable Option Order of External Wall U-value for Cooling Energy SA



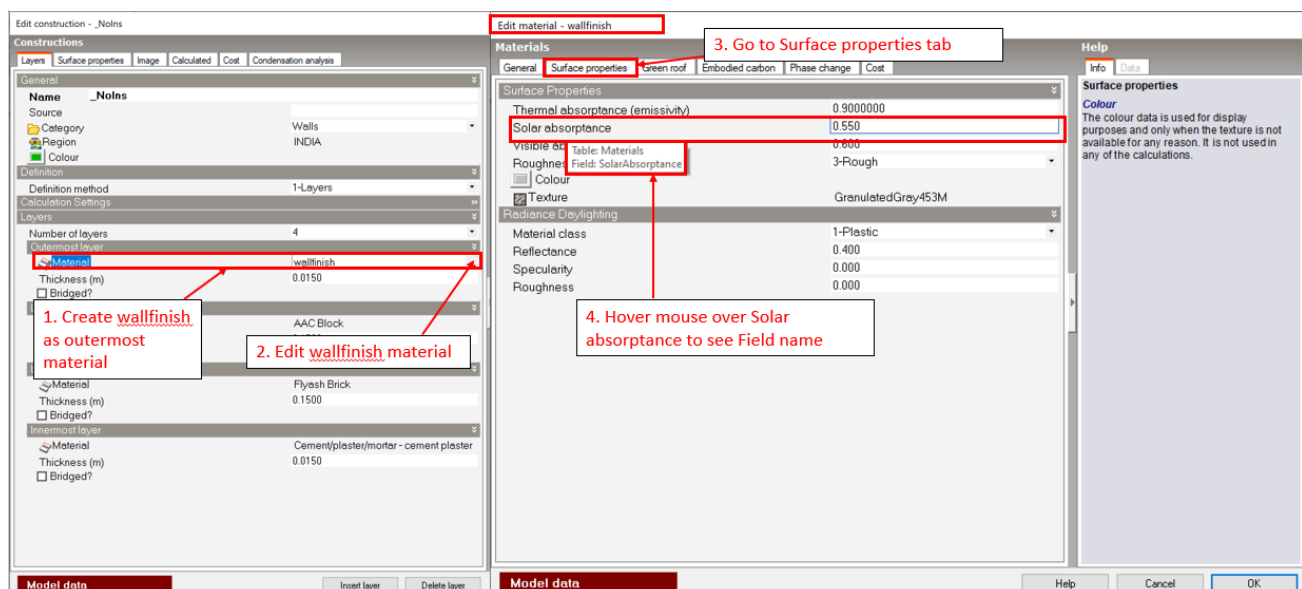
**Figure 4:** External Wall U-value Design Variable Setup with Uniform(Discrete) Distribution Graph

For the Cooling Energy SA, variables for envelope parameters, shading, and systems were defined using the standard variable selection setup where various options are selected in an appropriate sequence. For example, in the Design Variable for *External wall U-Value*, wall assemblies were arranged by increasing U-value order (

## DesignBuilder Case Study

Figure 3). A discrete uniform distribution curve was selected for the Design Variables because each option is equally likely to occur (Figure 4). A similar process was followed for design variables for *Glazing U-Value*; *Roof U-Value*; *Partitions (Thermal Mass)*; *Shading N/S/E/W* and *Lighting*.

The setup of two variables: *Wall solar absorptance (WallSolAbs)* and *Roof solar absorptance (RoofSolAbs)* required a different approach because they involve changing the property of a wall or roof construction material instead of a model data attribute. In a typical approach, new constructions would be created with different external finishes. However, in this instance, the design team was exploring 2 wall properties – U-value (5 options) and external finish (5 options) which relate to the same construction model object. Parametric modelling for this could have been accomplished by having a single wall variable with 25 options, pairing each of the surface finish options with each of the wall construction options. However, this would not have worked for a SA. Separating the external finish from the U-value property makes it possible to assess the impact of each Design Variable when viewing the results as these are 2 separate design decisions. Custom Scripts are used to target specific model components and use their properties as input variables. In this case, a script was used to specifically target material solar absorptance while the standard External Wall Construction variable modifies the U-value.



**Figure 5: External Finish (wallfinish) setup and Solar Absorptance Input Field**

Custom Scripts utilise the DesignBuilder API to adjust target model objects and their properties. They can be used to directly modify any aspect of the model, including individual component properties such as Solar Absorptance. In this setup, a custom material called *wallfinish* was created and selected as the outermost layer of the external wall assembly. The Solar Absorptance (the material property which was used as a custom variable) of the *wallfinish* material is shown in

**Figure 5: External Finish (wallfinish) setup and Solar Absorptance Input Field**

. This is a material database item and the image illustrates how hovering the mouse over the appropriate dialog label displays the exact property location in the tooltip, the table and the field name. In this case, the table is '*Materials*' and the field name is '*SolarAbsorptance*'. Therefore, to modify the external finish, the script must update the *SolarAbsorptance* field in the *wallfinish* material, which is stored in the *Materials* database table.

**Tip:** Attribute and field names such as SolarAbsorptance in

Figure 5: External Finish (wallfinish) setup and Solar Absorptance Input Field

**Error! Reference source not found.** are displayed in DesignBuilder when the cursor hovers over the option. To enable this, on the menu bar, navigate to Tools > Program Options. Then on the Interface tab, enable 'Show Tooltips in Model data' and 'Show attribute names in tooltips'.

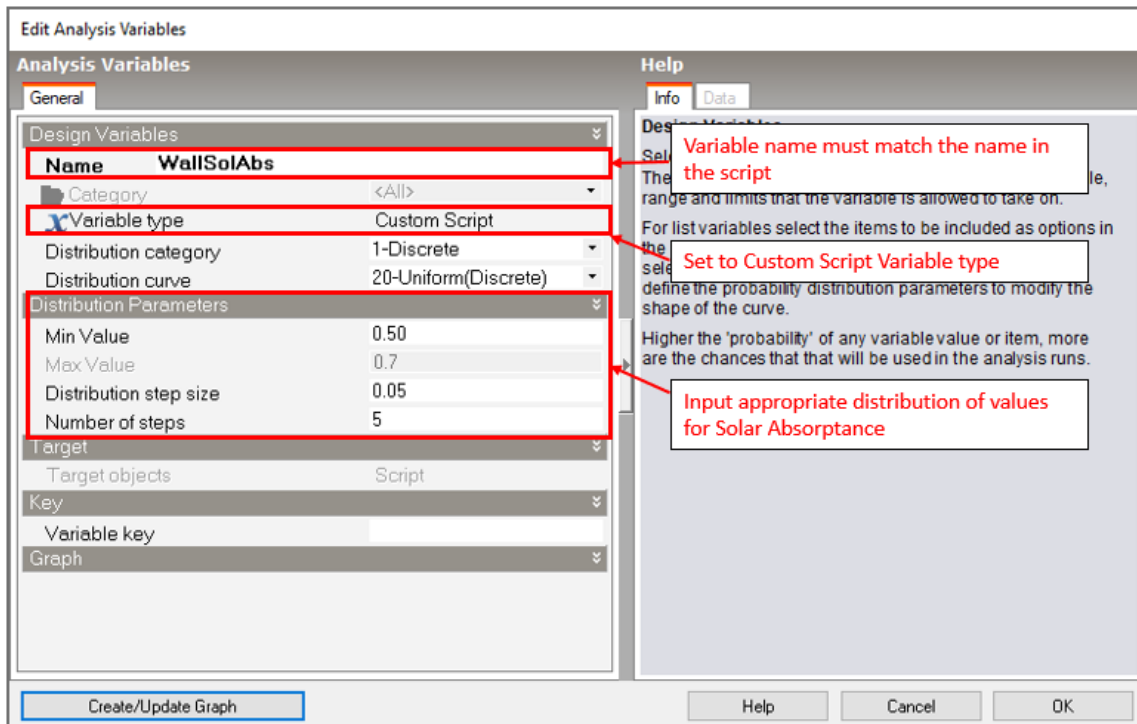


Figure 6: Key aspects in setting up WallSolAbs Custom Script Variable Type

Figure 6 shows how the various settings for this Design Variable were defined. The name of the variable *WallSolAbs* is important because it was referenced in the script to identify the exact variable to be modified during the SA.

A similar process was used to create the *RoofSolAbs* variable. Finally, to complete the setup, a simple Python Script was written to find and update external finish design variables (*RoofSolAbs* and *WallSolAbs*) in the SA. The Python Script below was used to vary the solar absorptance of both the roof and wall external surface finishes.

```
# The on_design_variable_changed hook point is called when the model is being prepared for the
# simulation, once every time of each variable.
# opt_var_id, passes the id of each variable
# The variable_current_value passes the sampled value from the SA engine of this variable to be
# used for each iteration.
def on_design_variable_changed(opt_var_id, variable_current_value):

    # Accessing site object
    site = api_environment.Site

    # Gets the OptimisationVariables table located at site level, which has
    # the list of Design Variables (list on the Parametric, Optimisation UA/SA
    # Settings dialog)
    table = site.GetTable("OptimisationVariables")

    # Gets variable record from OptimisationVariables table based on its ID
    record = table.Records.GetRecordFromHandle(opt_var_id)
```

```
# Gets the name of the variable from the record selected.
opt_variable_name = record["Name"]

# If RoofSolAbs is the name in the record of the Design Variable, the
# following code is executed
if opt_variable_name == "RoofSolAbs": # name must match variable in DB

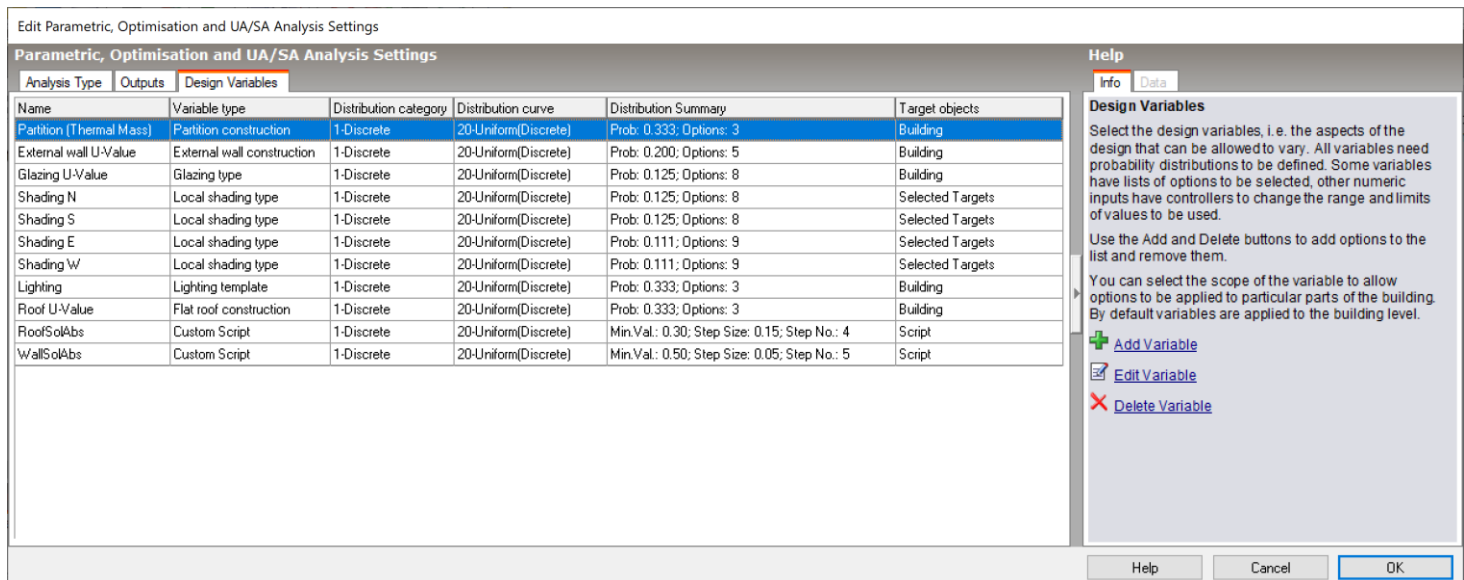
    # Find the materials database table, stored at the site level
    table_mat = site.GetTable("Materials")

    # Find rooffinish material in the database and
    # rooffinish Material must be there in the materials library and part
    # of constructions defined in the DB model
    record_mat = table_mat.Records["rooffinish"]

    # Find and update rooffinish Solar Absorptance value to current value
    # identified for this variable by the SA engine
    record_mat["SolarAbsorptance"] = variable_current_value

# If WallSolAbs is the name in the record of the Design Variable, the
# following code is executed, is it Same as RoofSolAbs
elif opt_variable_name == "WallSolAbs":
    table_mat = site.GetTable("Materials")
    record_mat = table_mat.Records["wallfinish"]
    record_mat["SolarAbsorptance"] = variable_current_value
```

The full list of Design Variables used for Cooling Energy SA is displayed in Figure 7 below.



Name	Variable type	Distribution category	Distribution curve	Distribution Summary	Target objects
Partition (Thermal Mass)	Partition construction	1-Discrete	20-Uniform(Discrete)	Prob: 0.333; Options: 3	Building
External wall U-Value	External wall construction	1-Discrete	20-Uniform(Discrete)	Prob: 0.200; Options: 5	Building
Glazing U-Value	Glazing type	1-Discrete	20-Uniform(Discrete)	Prob: 0.125; Options: 8	Building
Shading N	Local shading type	1-Discrete	20-Uniform(Discrete)	Prob: 0.125; Options: 8	Selected Targets
Shading S	Local shading type	1-Discrete	20-Uniform(Discrete)	Prob: 0.125; Options: 8	Selected Targets
Shading E	Local shading type	1-Discrete	20-Uniform(Discrete)	Prob: 0.111; Options: 9	Selected Targets
Shading W	Local shading type	1-Discrete	20-Uniform(Discrete)	Prob: 0.111; Options: 9	Selected Targets
Lighting	Lighting template	1-Discrete	20-Uniform(Discrete)	Prob: 0.333; Options: 3	Building
Roof U-Value	Flat roof construction	1-Discrete	20-Uniform(Discrete)	Prob: 0.333; Options: 3	Building
RoofSolAbs	Custom Script	1-Discrete	20-Uniform(Discrete)	Min.Val.: 0.30; Step Size: 0.15; Step No.: 4	Script
WallSolAbs	Custom Script	1-Discrete	20-Uniform(Discrete)	Min.Val.: 0.50; Step Size: 0.05; Step No.: 5	Script

**Figure 7:** Cooling Energy Design Variables for SA. HVAC System was removed. See results section for explanation.

### Setup changes required for Capital Cost Analysis

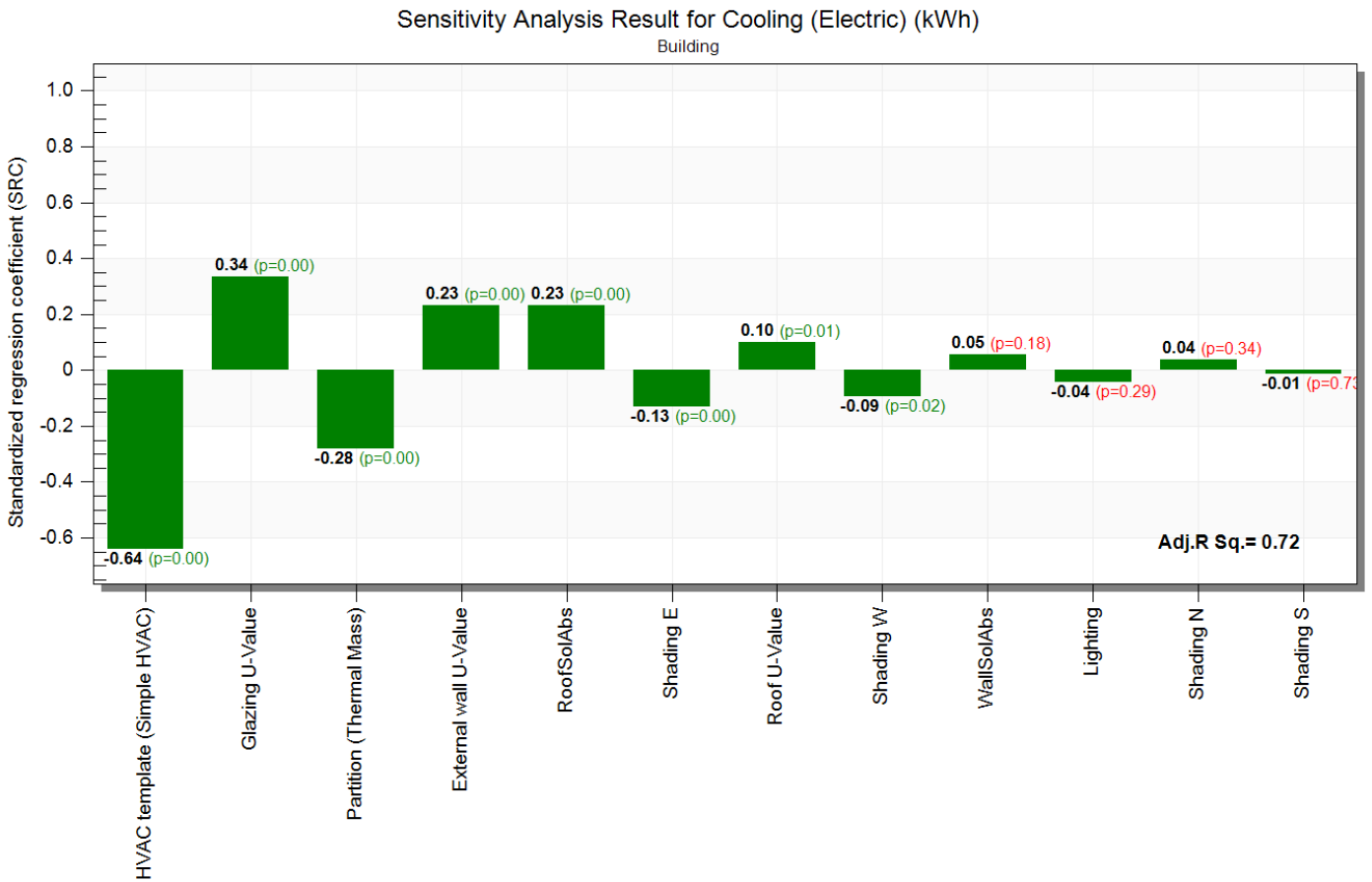
It is best practise to perform a SA for each output separately as explained earlier. In this case, some further changes to the problem setup were required for the Capital Cost SA:

- The variable options were arranged in increasing order of cost.
- The roof and wall solar absorptance variables were removed from Capital Cost SA because the change in the price of materials with different solar absorptance was negligible.

## Sensitivity Analysis Results and Analysis

### Initial results

An initial SA for cooling demand (200 runs) was carried out with all of the Design variables described in Figure 2 **Error! Reference source not found.** and the results are shown below in Figure 8.

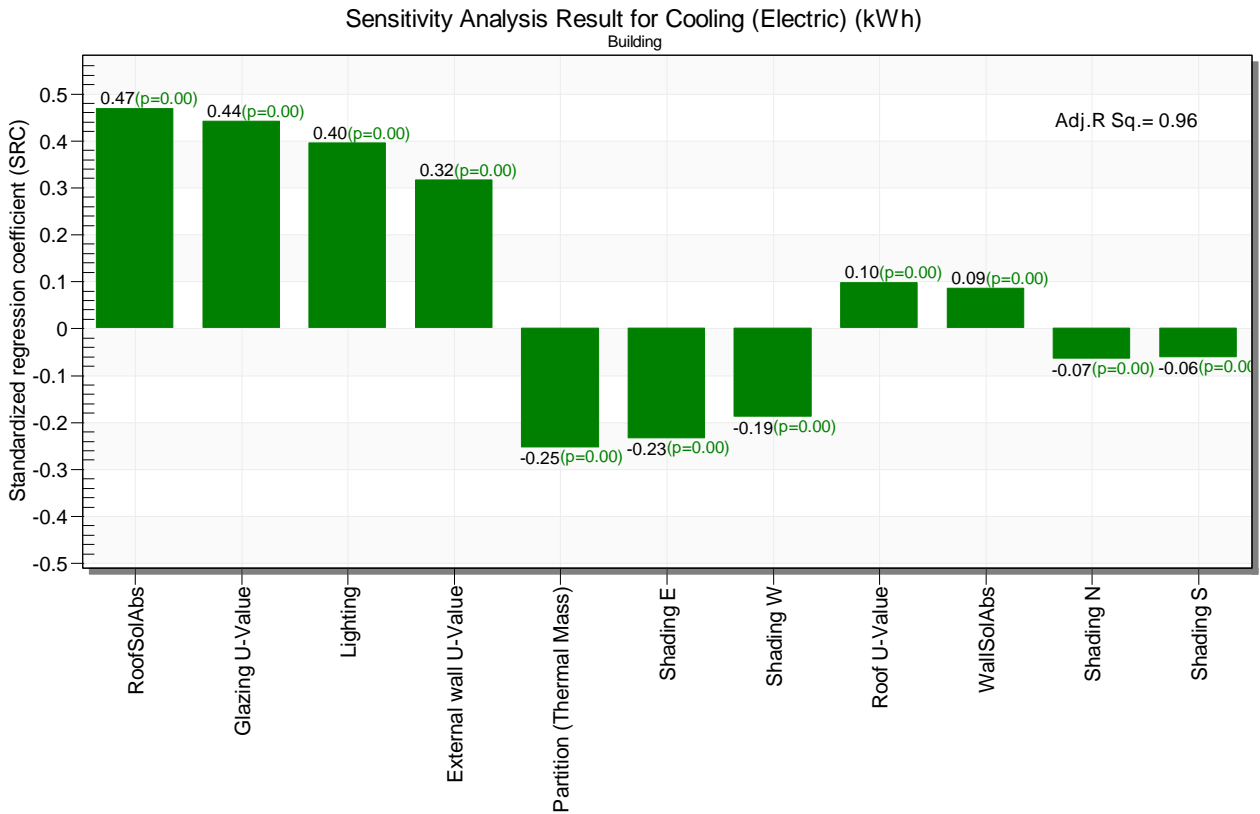


**Figure 8:** Cooling Energy Sensitivity Analysis Results with HVAC

In the results for this Cooling Energy SA, the HVAC system design variable was dominant, with SRC values significantly higher than for the other variables. Also, the p-value for 4 of the variables having low SRC was not within acceptable levels and the Adjusted R-squared output was low at 0.72. These statistics indicate the degree of confidence of the results and, in this case, they warn us to be cautious. More information on how to interpret SA results can be found in the [DesignBuilder Program help](#).

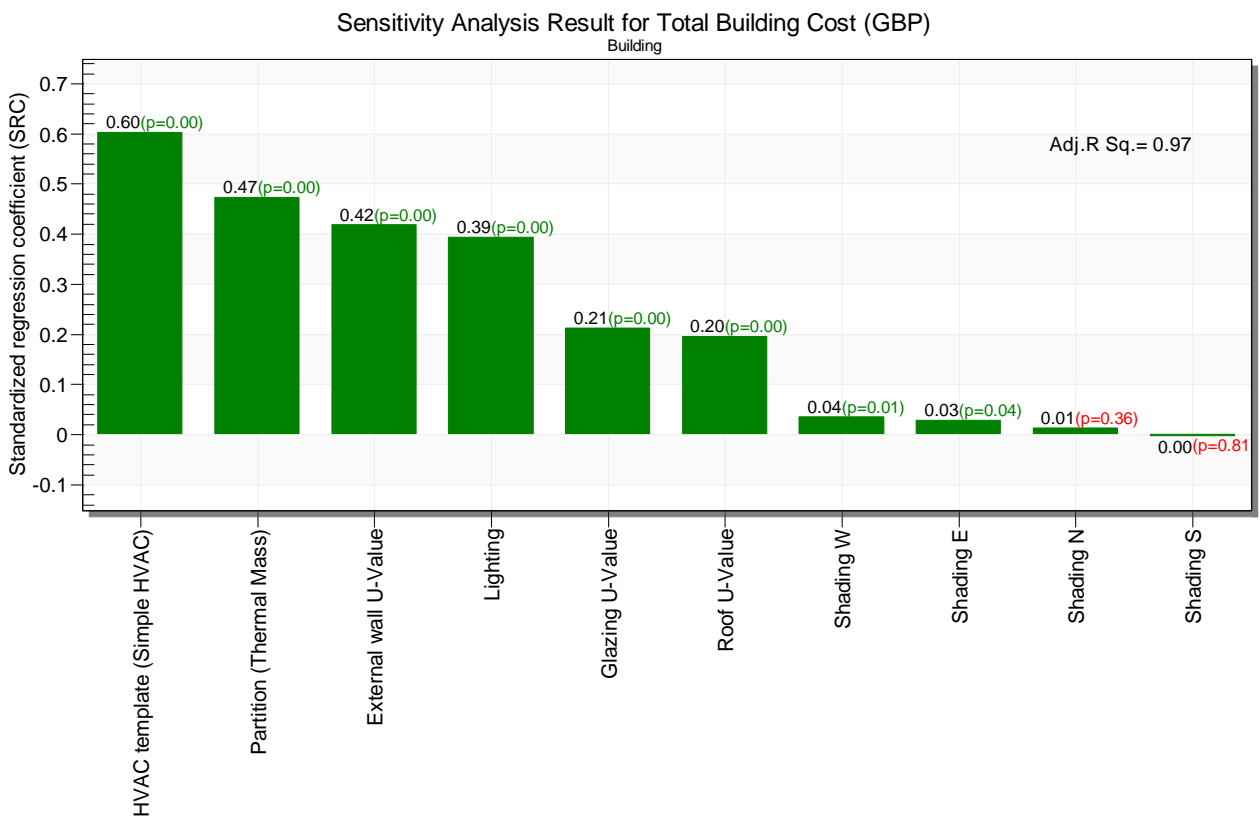
More simulations could have been run to improve these results. However because the p-values of high SRC variables is <0.05, and the variables are not inter-dependent, we can remove the dominant variable and re-run the SA to determine the significance of the remaining variables with greater certainty. Therefore another iteration of Cooling Energy SA was carried out, with the dominant HVAC System variable removed from the variables list.

Results for the updated Cooling Energy SA without the HVAC Systems variable are displayed in Figure 9. This time the high Adjusted R-squared value (close to 1) and p-values <0.05 indicate that we can be confident in the results. Overall, for cooling energy, the HVAC System, Roof finish, Window U-value, Lighting, Wall U-value, Partition Thermal Mass, and shading on East and West facades variables are significant. Roof U-value, Wall solar absorptance and shading on North and South facades have a less significant impact.



**Figure 9:** Cooling Energy Sensitivity Analysis Results without HVAC

Results for the Capital Cost Sensitivity Analysis are displayed in Figure 10 below. Note that the ranked order of influential variables is different compared to the Cooling Energy results shown in Figure 9.



**Figure 10:** Capital Cost Sensitivity Analysis Results

Taken together, the SA results for Cooling Energy and Capital Cost can be used to identify the most influential variables for both objectives and can also inform any subsequent optimisation studies that include these variables and the Cooling Energy and Capital Cost objectives. The process to select variables for the subsequent optimisation analysis can be summarised as:

- » Design variables with high or medium importance for both the outputs in the SA results are included.
- » Design variables with low importance for both outputs can be removed from further analysis and designers can choose a suitable fixed setting.
- » Design variables with high or medium importance for one output and low importance for the other can also be removed. For example, roof solar absorptivity has no effect on cost, but it does affect cooling energy, so it was fixed to an appropriate value to minimise cooling energy (in this case based on the reflective white roof), and the associated Design Variable was removed from the study. In general, the recommended fixed value for such variables will be the one that best meets the design objective for which it is most sensitive for.

Table 1 below illustrates the selection process. The variables with overall significant influence are highlighted in green in the final column (Wall U-value, Roof U-value, Window U-value, Partition Thermal Mass, HVAC System, Lighting System). The results indicate that the number of variables to be used in subsequent optimisation studies can be reduced from 12 to 6.

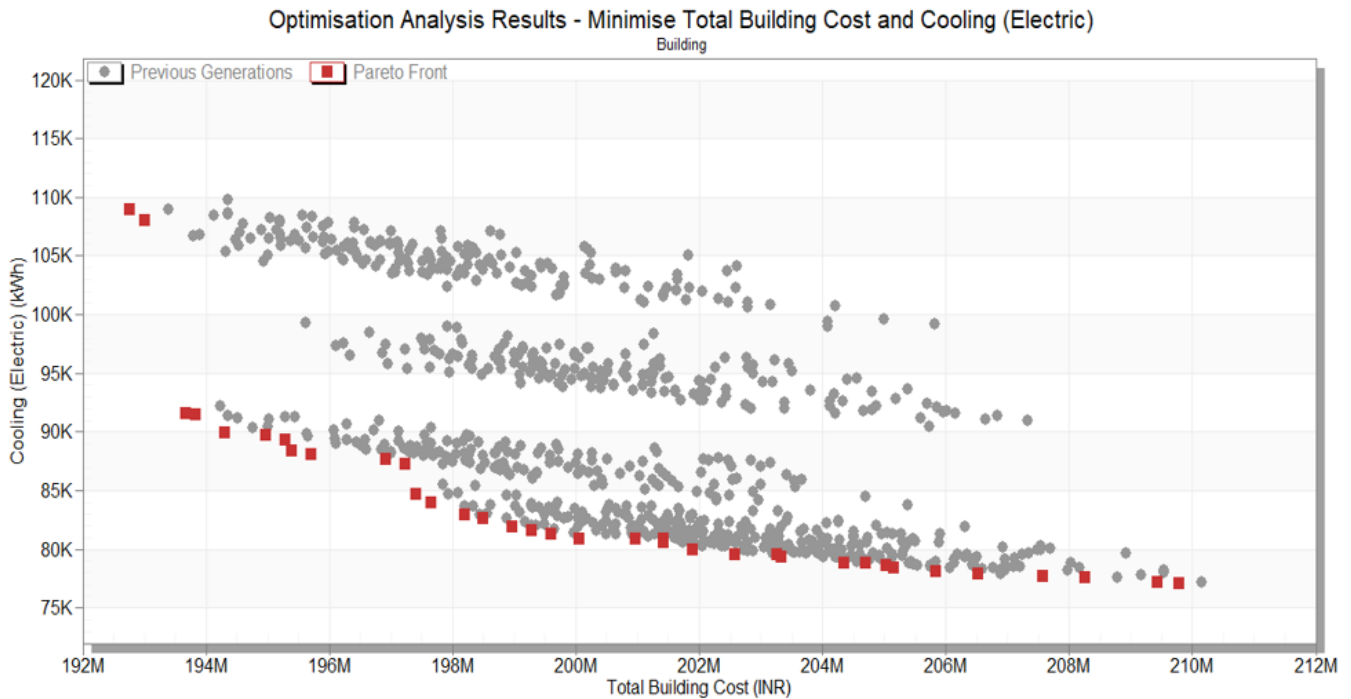
**Table 1:** Selection Process of Most Influential Variables Showing the Influence of each Design Variable on Cooling Energy and Cost Individually and on Both

Design Variables	Cooling Energy	Cost	Influential for Both
Wall U-value	High	High	Yes
Roof U-value	Med	High	Yes
Window U-value	High	High	Yes
Partition TM	High	High	Yes
Shading N	Med	Low	No
Shading S	Med	Low	No
Shading E	High	Low	No
Shading W	High	Low	No
Wall Finish	Med	Low	No
Roof Finish	High	Low	No
HVAC System	High	High	Yes
Lighting System	High	High	Yes

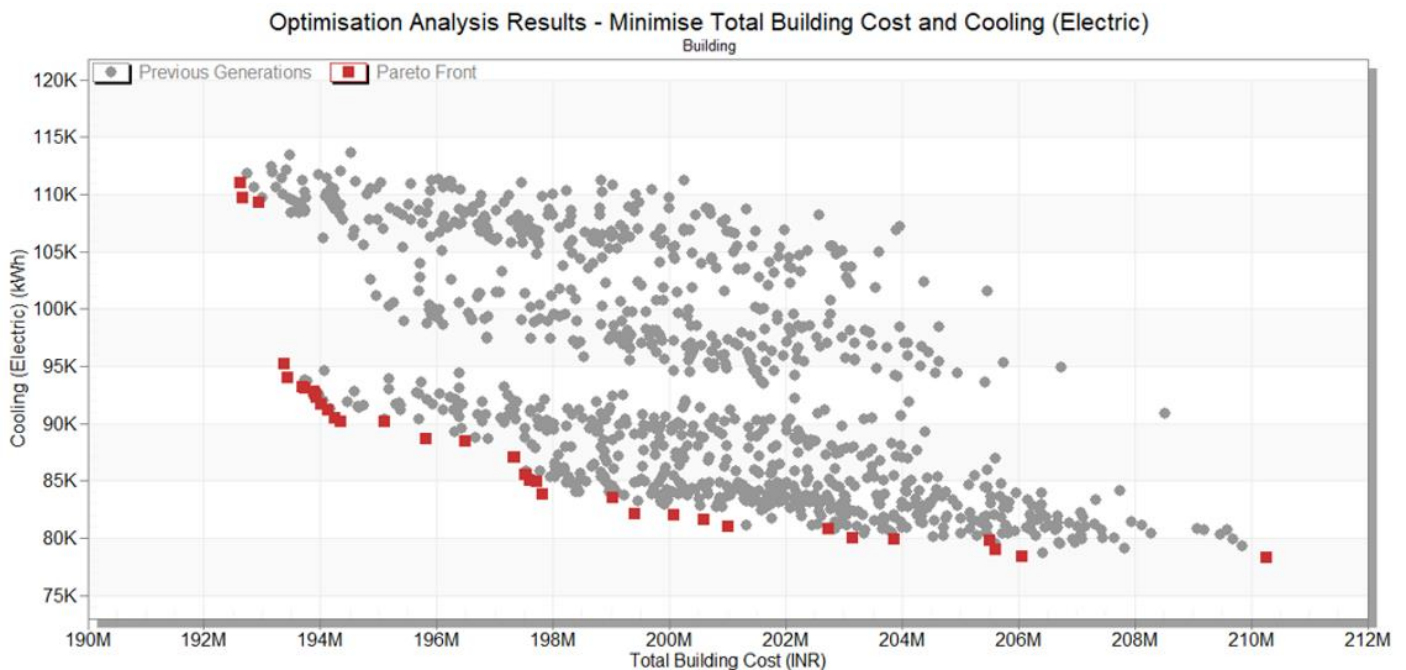
## Optimisation Results

Figure 11 shows the results of the optimisation after the SA pre-screening, using the 6 “Influential for Both” Design Variables revealed by the Sensitivity Analysis. Each dot represents one of the individual designs simulated. The red dots show the optimal solutions that occupy the Pareto front. The

optimisation took 9 hours. Adding the 3 hours for the SA, the overall simulation time was 12 hours.



**Figure 11:** Optimisation Results after SA pre-screening



**Figure 12:** Full Optimisation Results Stopped After 12hrs

For comparison, Figure 12 above shows the results of the full optimisation used in the [previous case study](#) which includes all 12 Design Variables. The optimisation was stopped after 12 hours with just over 1000 simulations completed to allow a direct comparison with the SA pre-screening approach. The results of the optimisation with SA pre-screening (Figure 11) are visibly cleaner with just the most influential variables included in the study. There is significantly reduced noise compared to the full

optimisation. This is due to the removal of the less influential shading and external finish variables from the analysis.

## Conclusions

Sensitivity Analysis was used to identify the most influential Design Variables and the number of variables was reduced from 12 to 6 for the new optimisation analysis. The key findings of this study are:

- The SA provided a systematic pre-processing step that significantly improved the clarity and accuracy of the design optimisation study and reduced simulation times.
- It achieved this by helping to identify and eliminate the Design Variables that were unimportant for one or both of the outputs and reducing and refining the search space.
- The optimisation results as a result of this study were visibly cleaner and had more refined Pareto fronts. This made the trend and pattern analysis significantly faster to process and easier to understand.
- Reducing the number of Design Variables did not affect the conclusions of the optimisation study but it did allow the assessment to be made with greater confidence and clarity.

Building-specific insights and analysis of the optimisation itself are not covered in this case study. For specific results on how optimisation was used to inform design decisions in the actual building please review the conclusions of the [previous case study](#).

## Credits



The case study was compiled by Chad Isnor, P.Eng ([linkedin.com/in/chadisor](https://www.linkedin.com/in/chadisor)) as part of an industry guided learning opportunity provided by DesignBuilder. Chad is a UCL graduate in MSc Smart Buildings and Digital Engineering with an interest in building performance modelling.

The case study building was a project by PSI Energy ([www.psienergy.in](http://www.psienergy.in)) and was delivered by them with support from project architects, SD Sharma & Associates ([www.sdsa.co.in](http://www.sdsa.co.in)).



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PSI Energy also conducts certification-based, training programs for university students and industry professionals on green building and sustainable habitats design (including design, thermal comfort, lighting, HVAC, solar energy systems, GRIHA, ECBC, etc).

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