Modelling the Heat Loss of Buildings

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Project Aims

This project aspired to **model the energy consumption** of the Kelvin Building to assess **how much energy is required to heat** it over the course of a year.

This involved learning **how to create a model** and determining which are the important aspects to consider when modelling the heat loss from a building.

The idea was to create a **very basic model** of the Kelvin Building and to **increase its complexity** as the project progresses.

Part of the project was to assess whether increasing the intricacy of the model yielded a suitably different result in comparison with making more crude and basic assumptions.

Guaging how much energy is used to heat the Kelvin Building was done by **equating how much energy the building loses with how much energy is required to heat the building.**

Heat Loss and Gain

There are two major processes by which any building loses heat: **conduction** and **ventilation**.

Conduction is the transfer of heat over a temperature gradient from one body to another.

In the case of buildings, heat is lost by **conduction through the walls, roof, floor and windows**. These components have a **U-Value** which **describes how well they conduct heat.**

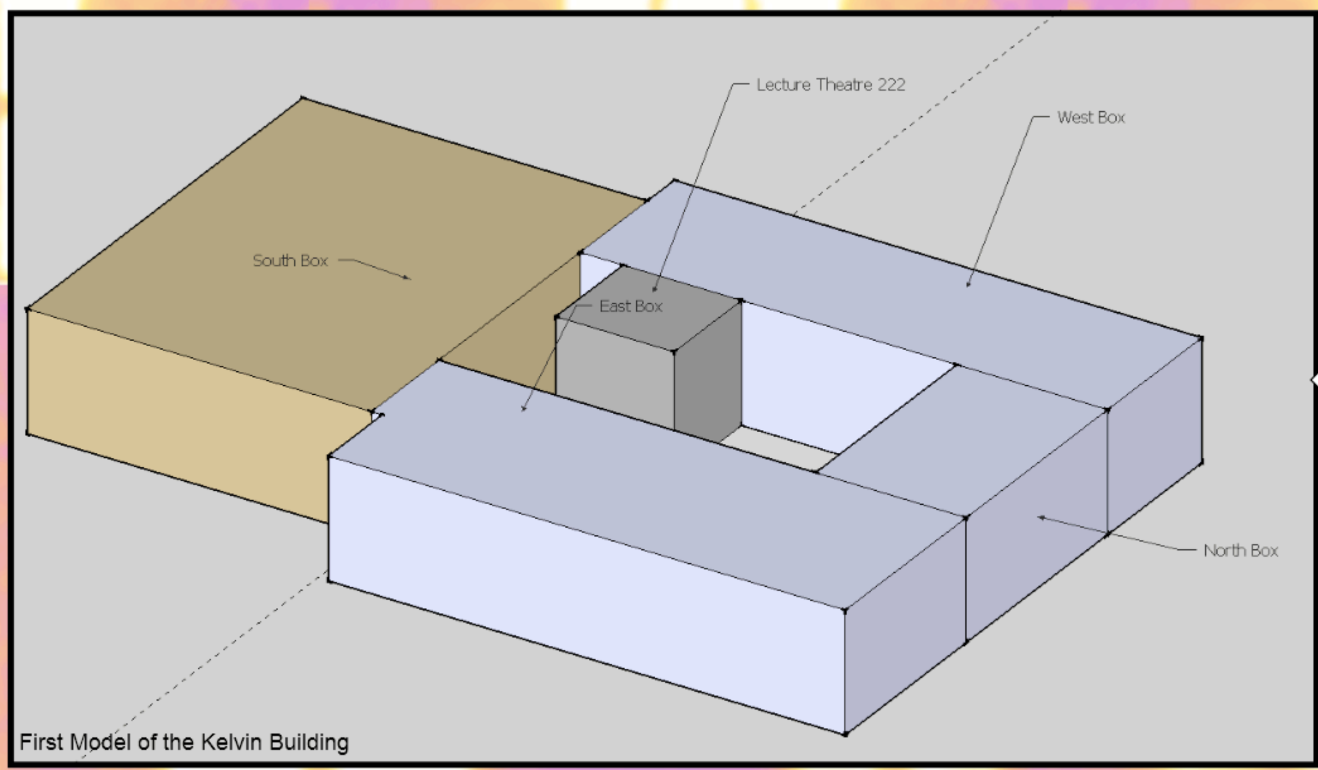
Ventilation heat loss accounts for the **rate at which warm air inside the building is replaced with cold air** from outside. This is often through entrances and cracks in the walls and windows.

In this model, the building **gains heat** through **solar radiation** and from the **waste energy of its contents**.

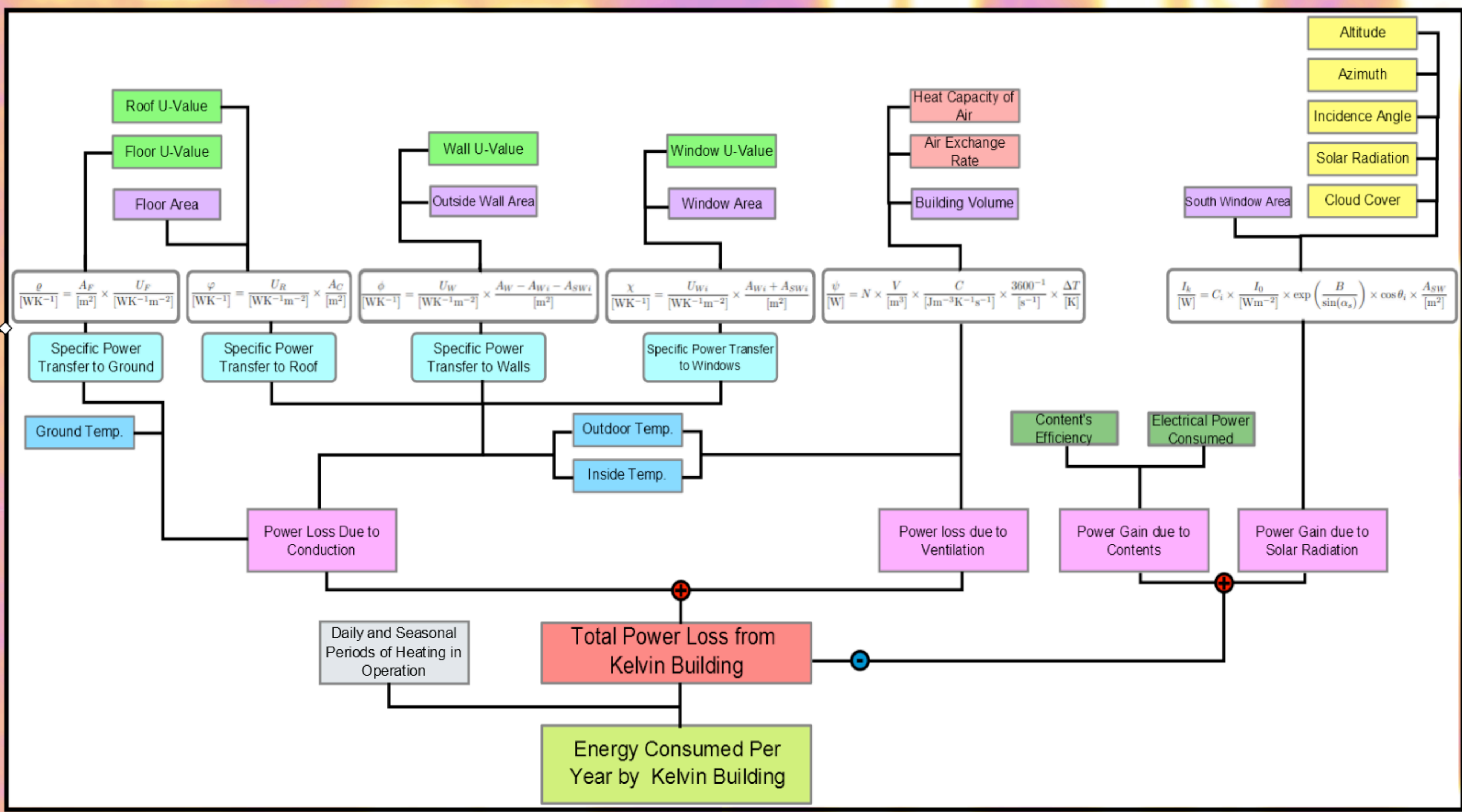
Heating due to **solar radiation** is largely **collected from south-facing glass surfaces** on the Building

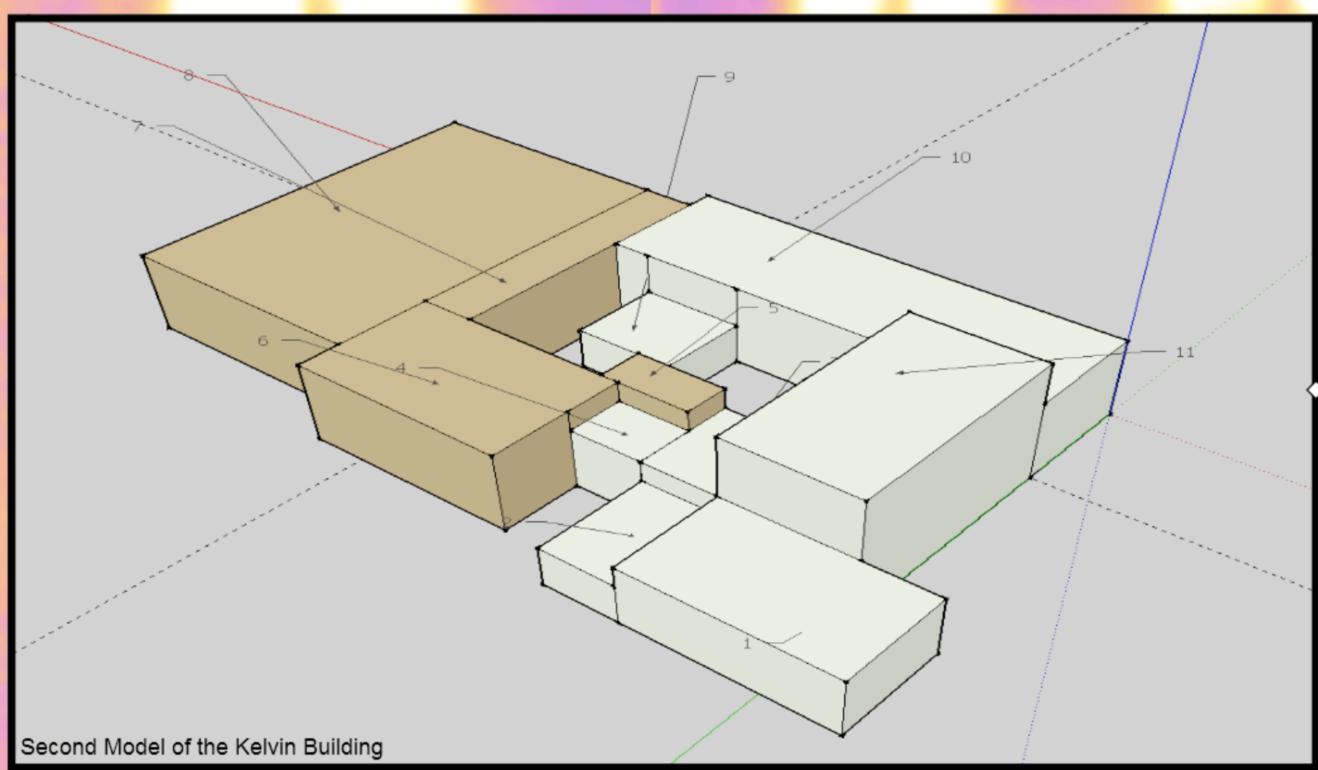
The contents of the building will also replenish some heat as a by product of their function. Given the large number of electrical devices in the building, this contribution could be significant.

The flow diagram to the left describes the process by which the Kelvin Building's energy consumption was calculated.



First Model of the Kelvin Building





Second Model of the Kelvin Building

First Model

The first model was made to be **basic** and based on **rough estimates** and approximations.

This refers both to how the construction of the Kelvin Building was replicated and the method by which heat loss was calculated.

The image to the left illustrates the construction of the first model of the Kelvin Building.

In reality, the Kelvin Building has an **eccentric construction**. It contains many extensions, built in different decades.

The first model splits the Kelvin Building up into **five basic sections**. Each one is an empty box of equal height.

Estimations of the size and window area of the each box were made from images of the building.

The programming of code was carried out in **Matlab.**

Second Model

During the creation of the second model, **many advancements** were made.

The first change was in the **complexity of the structure** of the Kelvin Building.

More boxes were used to reconstruct the building and floor plans were used to determine the exact number and dimension of windows.

These changes saw a **4% increase** in the estimated energy consumption.

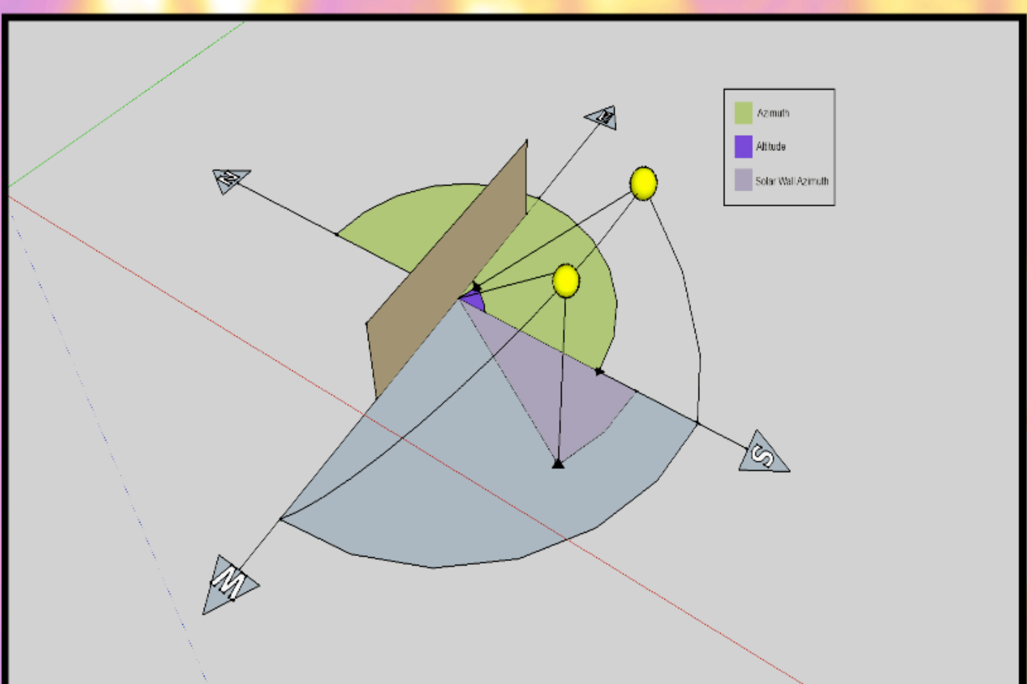
The **outside temperature** of the building's surroundings **is crucial** in the calculation of heat loss.

The first model used **monthly average temperatures** and assumed that each day within each month had the same temperature, throughout the day.

To improve upon this, **temperature data**, recorded **every five minutes** throughout the year, obtained from Glasgow University's observatory was implemented.

This allowed for a **more accurate representation of the temperature** over the course of the day and allowed data for the working hours of the University to be used exclusively.

The detailed look at temperature accounted for a **15% decrease** in the estimated yearly energy consumption.



Example: Solar Radiation

The area of the model which recieved the **most sophistication** was the way in which the **solar heat gain** was calculated.

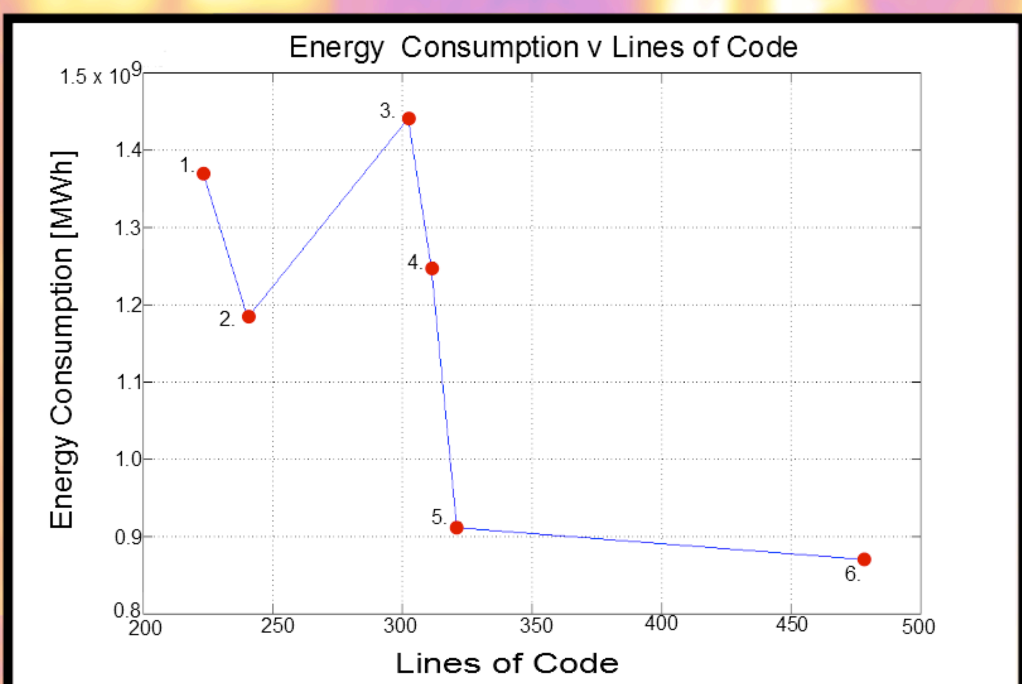
In the first model, the solar radiation incident on the building was assumed to be the same as the average monthly value incident on the horizontal plane in Glasgow.

In the second model, the **solar radiation reaching the building was calculated, from first principles**, every five minutes of each day.

This involved **calculating the path of the Sun**, as illustrated above, and combining this with the **orientation of the building** to determine **the angle of incidence** with which radiation strikes the windows.

Unpredictable elements such as clouds could not be modelled but were factored in by considering the average clearness factor of the sky.

Modelling the solar radiation in this way increased its deduction from the energy consumption from **28 MWh to 69 MWh**.



Example: Code Evolution and Energy Consumption

The graph above details how the calculated energy consumption of the Kelvin Building changed as the model become more and more complex.

1. The **first model** yielded a result of **1369 MWh** per year required to heat the building.

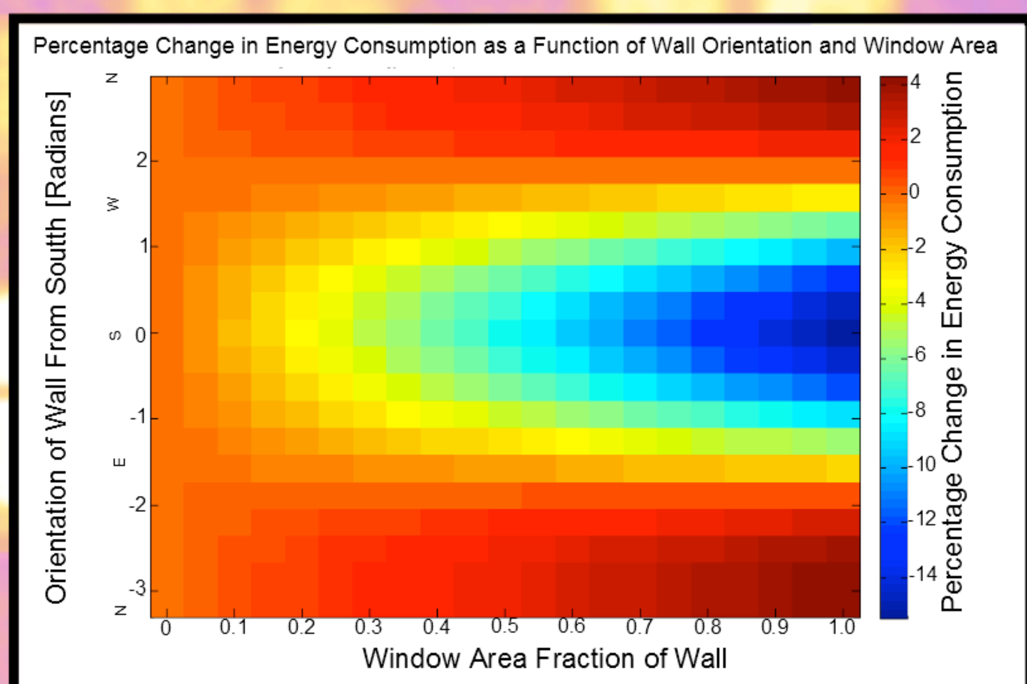
2. Improving the **temperature data** saw the energy consumption fall to **1183 MWh**.

3. Adding in the **new dimensions** for the Kelvin Building saw a rise in energy consumption to **1441 MWh.**

4. Combining the **new dimensions** and **new temperature data** resulted in **1246 MWh** of energy being consumed per year.

5. Incorporating the **internal contents** of the building saw a large change in energy consumption to **911 MWh** for a small increase in coding.

6. Introducing a complex model to calculate **solar heat gain** only yielded a small decrease in energy to **870 MWh**.



What We Have Learned

The model created during this project allows for a rigorous calculation of the energy required to heat the Kelvin Building but the methods and code used could also be **applied to any building** or structure given its location and dimensions.

We have discovered the main processes by which a building loses and gains heat and how to model these mathematically in a programing language.

An example of how the model progressed was in its evolution from assuming monthly values for the solar radiation incident on the building to calculating the Sun's position relative to the building every five minutes.

The development of the code saw a **36% change** in estimated energy consumption from start to finish.

An example of how this model can be applied is illustrated by the graph above. It describes the percentage change in energy consumption of varying the window area on the wall of a building, depending on the wall's orientation with respect to the points on a compass.

With Thanks to Dr. Stefan Hild