the gaia project
realistic environmentalism

Project Guide: Energy Efficient Building Design

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Sustainable Building

A guide to designing, building and testing energy efficient buildings at the scale model level.

The Gaia Project is a charitable organization dedicated to providing project based learning opportunities in the areas of energy, environment and sustainable engineering.

We develop projects, provide professional development, technical support and ongoing project support for teachers and students. Our projects aim to incorporate three key principles, which symbolise our focus on realistic environmentalism.

1. **Data Informed Decisions** – We want students to be able to explain why, and quantify the effect of each decision they made along the way to their final solution.
2. **Economic Assessments** – We expect students to be able to assess the cost effectiveness of their solutions, and be able to optimize their projects with limited budgets.
3. **Environmental Impact and Lifecycle Assessments** – We need students to take a holistic view to their projects. This means looking at their projects from cradle to grave, as opposed to just examining the use phase, and acknowledging that greenhouse gas reduction is not the only environmental issue at stake.

For more information, please visit www.thegaiaproject.ca

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Energy Efficient Building Design

This project is designed to introduce students to the principles of energy efficient building design. The energy auditing project gives students a very hands-on look at managing electrical loads; however, the impact and control that can be had over heating loads in a large building without major infrastructure changes is limited.

This project allows students to make some of those major infrastructure changes on a small scale and measure the impacts of the changes. The model may not be truly scalable to a full size building, but the lessons and principles should still apply.

Equipment

The basic equipment for the energy efficient building design allows students to quickly interchange parts to test different variables associated with building design. This includes:

- Wall Thickness
- Insulation Type
- Number / Size of Windows
- Number of Panes in Windows
- Roof Pitch
- Wall Surface Colours
- Orientation
- Method of Heating

The following headings describe how to build a 2’ x 3’, single story scale model home, with a variable pitched roof. The design can easily be manipulated for other sizes and layouts.

Testing Rig

The testing rig consists of four vertical posts representing the corner of the building mounted to a base.

The base is constructed from ½” plywood and is 42” x 30” in size. On each corner of the base a 4” x 4” piece of ½” plywood is used as a foot pad. The cutting diagrams for these two pieces are shown in [1] and [2] below.

Figure 1: Cutting Diagram for Base (1/2” plywood) – 1 Required

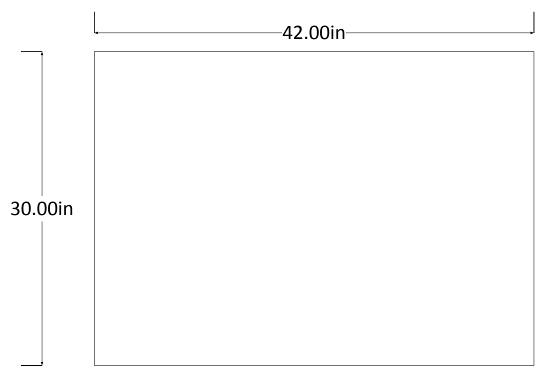
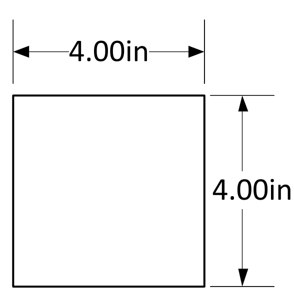


Figure 2: Cutting Diagram for Foot Pads (1/2” plywood) – 4 Required



The vertical posts are made from 4” x 4” lumber cut to 12” in length. Each of these contains vertical slots allowing for wall sheets to be inserted. These slots are ¼” wide, allowing ¼” thick plywood to be inserted, and can be achieved using a router or a table saw. Four slots are made on two sides of the vertical post. The other three slots are ½” deep, while the innermost slots are only ¼” deep so as not to interfere with each other. The cutting diagram for this can be seen in [3], while the actual part can be seen in [4] and [5]

Figure 3: Cutting Diagram for Corner Posts (4” x 4” Lumber) – 4 Required

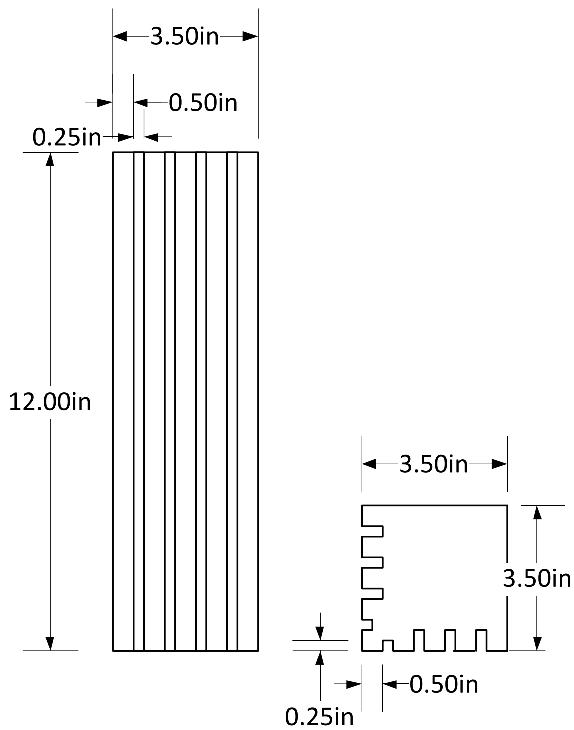


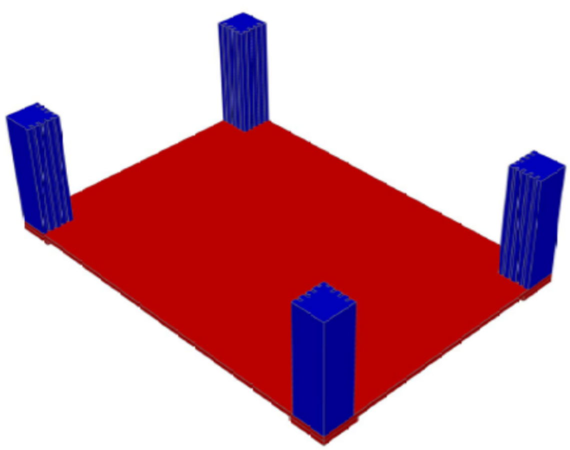
Figure 4: Corner Post

Figure 5: Corner Post Top View

The corner posts are fastened to a base at each corner directly above the foot pads using 3” lag bolts. The assembled testing rig can be seen in [6] and [7].

Figure 6: Corner Post in position on Base

Figure 7: Corner Post in position on Base (3D CAD Model)



Wall Sheets

The wall sheets are made from ¼" plywood (or similar). Different wall sheets need to be made for the inner and outer wall slots, due to the different depths of the slots on the testing rig vertical posts.

It is anticipated that the majority of the time, the home will be set up with an inner and outer wall panel, allowing insulation to be inserted in the space created between them. For this reason, it is recommended to build wall panels in pairs (an inner and an outer), and to label them accordingly as a pair.

The dimensions for the wall sheets can be seen in [8], [9], [10] and [11] and they can be seen in position in [12], [13] and [14].

Figure 8: Cutting Diagram for inner and outer short wall with no window (1/4" plywood)

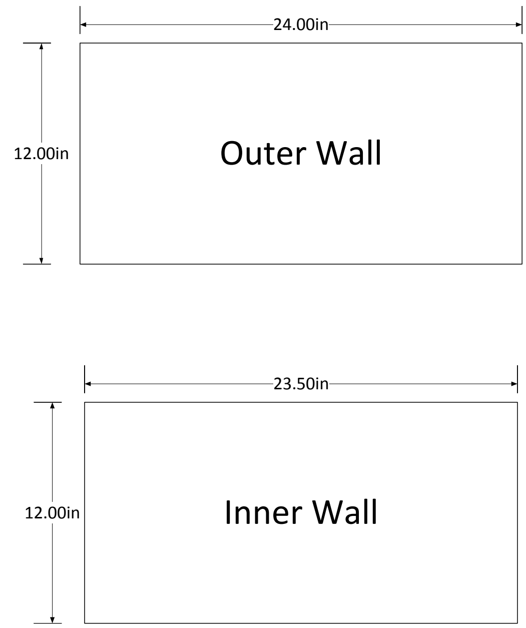


Figure 9: Cutting Diagram for inner and outer long wall with no window (1/4" plywood)

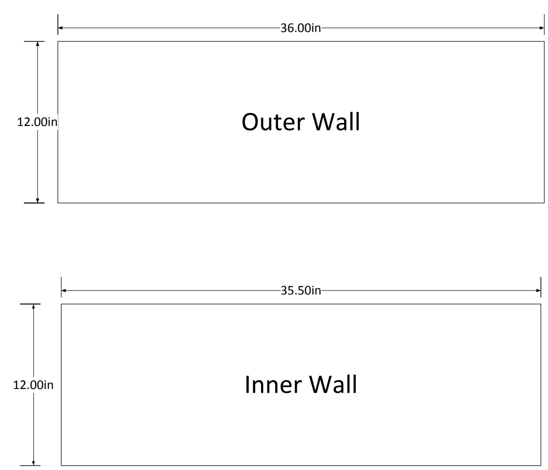


Figure 10: Cutting Diagram for inner and outer short wall with small window (1/4" plywood)

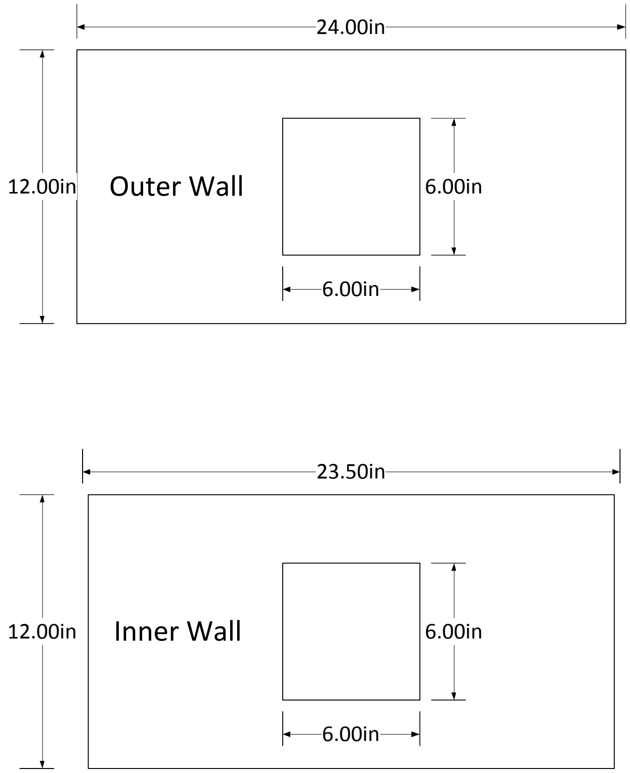


Figure 11: Cutting Diagram for inner and outer long wall with small window (1/4" plywood)

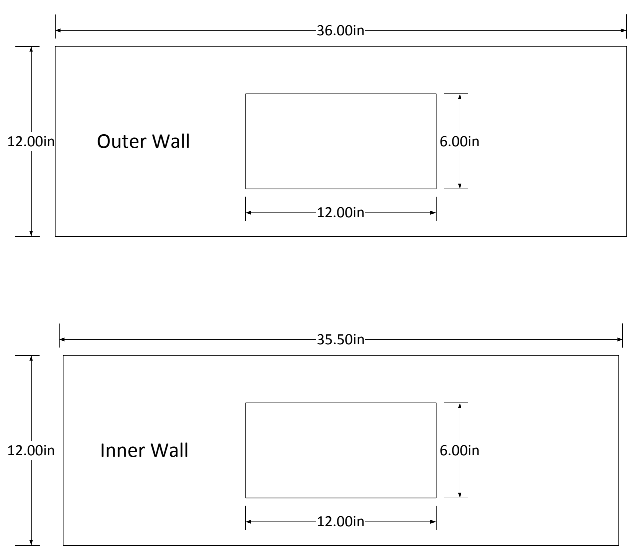
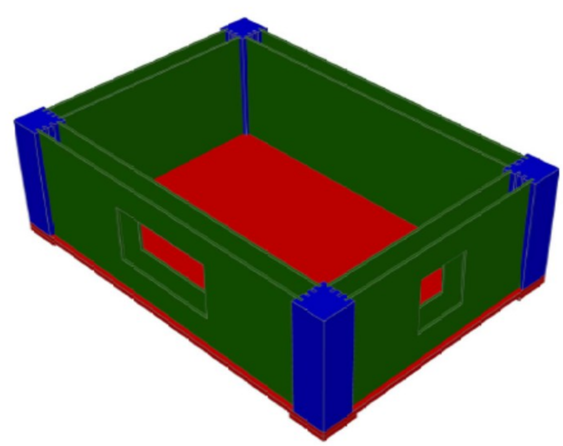


Figure 12: Inner and Outer Walls in place

Figure 13: Inner and Outer Walls in place (Top View

Figure 14: Inner and Outer Walls in place (3D CAD Model)



Windows

Like the main testing rig, the windows are configurable, allowing for different numbers of panes and space between them. The frames for these windows (large and small) are constructed from ½" plywood. In order for the window panes to be inserted, we need to add slots to the frame. Like the testing rig, these are ¼" wide, and ¼" deep. The cutting plan for both window frame sizes can be seen in [15] and [16].

Figure 15: Cutting Diagram for large window frame (1/2" plywood) – 2 of each piece required per frame

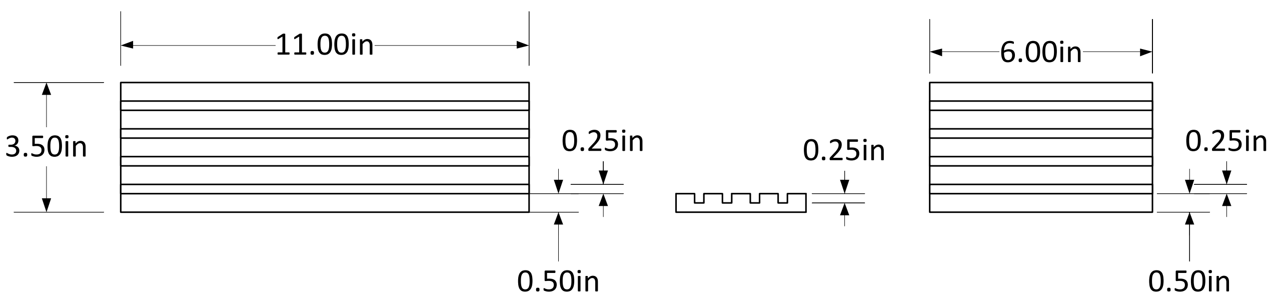
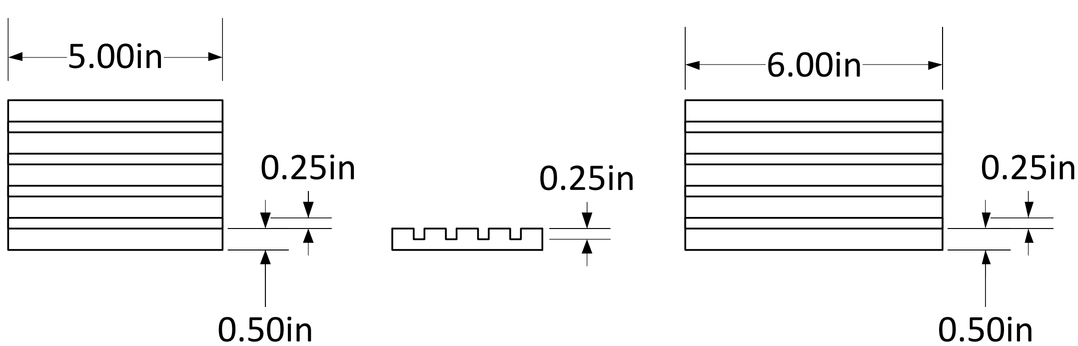
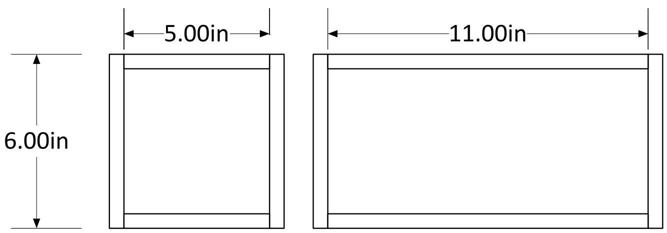


Figure 16: Cutting Diagram for small window frame (1/2" plywood) – 2 of each piece required per frame



These are then assembled as per [17]. Only three sides should be permanently fastened so that the top of the window frame can easily be removed to change window panes.

Figure 17: Assembled Window Frames

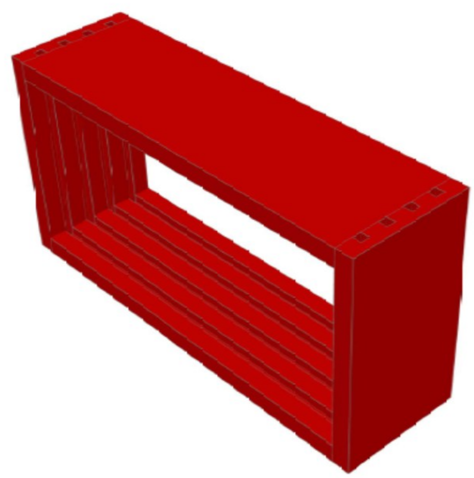


The assembled window frame can be seen in [18], [19] and [20].

Figure 18: Assembled Window Frames

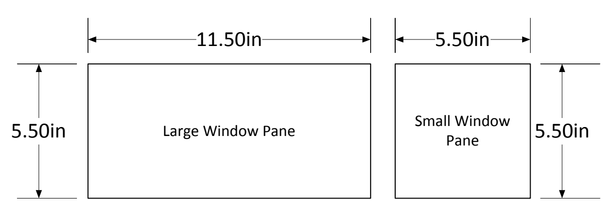
Figure 19: Assembled Window Frames

Figure 20: Assembled Window Frames (3D CAD Model)



Window panes are cut from ¼" plexiglass according to [21].

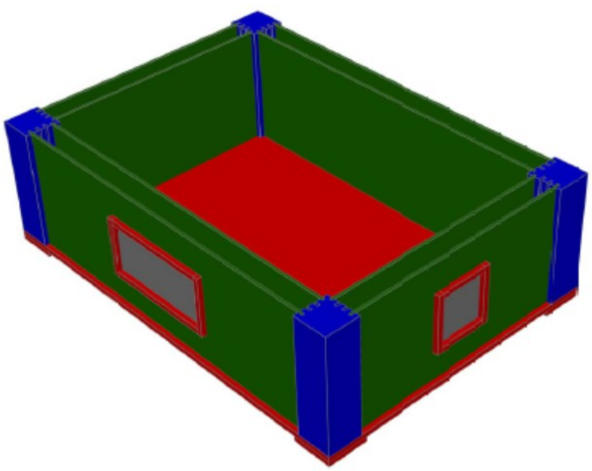
Figure 21: Window Pane Cutting Diagram (1/4" Plexiglass)



The window frames can be seen in place in the building in [22] and [23].

Figure 22: Window Frames in place

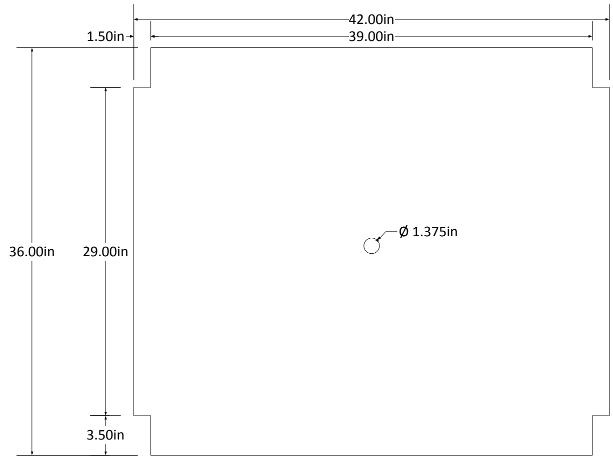
Figure 23: Window Frames in **place (3D CAD Model)**



Ceiling Panel

A ceiling panel made from ¼" plywood is required to allow for attic type insulation. This panel measures 42" x 36" and needs to have notches cut into it according to [24] in order to allow for the variable pitch roof to be mounted. The overhang of the ceiling panel over the walls is necessary to allow it to meet up with the bottom of the variable pitch roof. A hole is drilled into the centre of the panel to allow a light bulb to be suspended through it as a heating source.

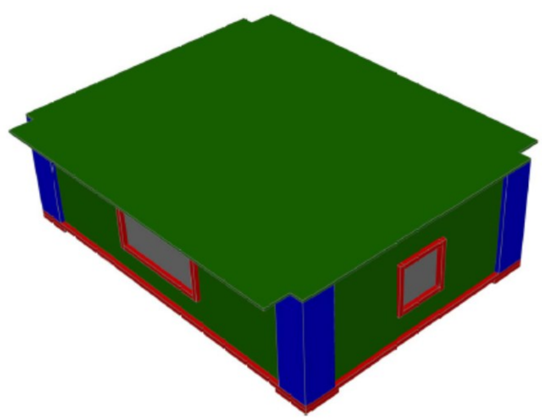
Figure 24: Cutting diagram for Ceiling Panel (1/4" plywood)



The ceiling panel can be seen in place in [25] and [26].

Figure 25: Ceiling panel in place

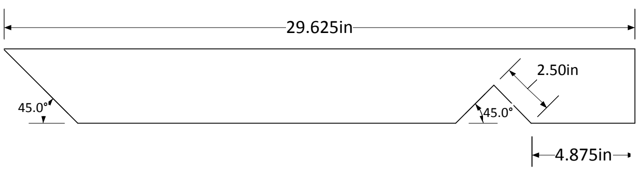
Figure 26: Ceiling panel in place – 3D CAD Model



Roof Trusses

Two variable pitch roof trusses need to be constructed to allow a pitched roof to be added to the testing rig. The cutting plan shown in [27] allows a roof with a maximum pitch of 45". Additional notches can be cut into the trusses to allow lower angle roofs. This is cut from 2" x 4" lumber.

Figure 27: Roof Truss Cutting Diagram (2" x 4" Lumber) – 4 Required



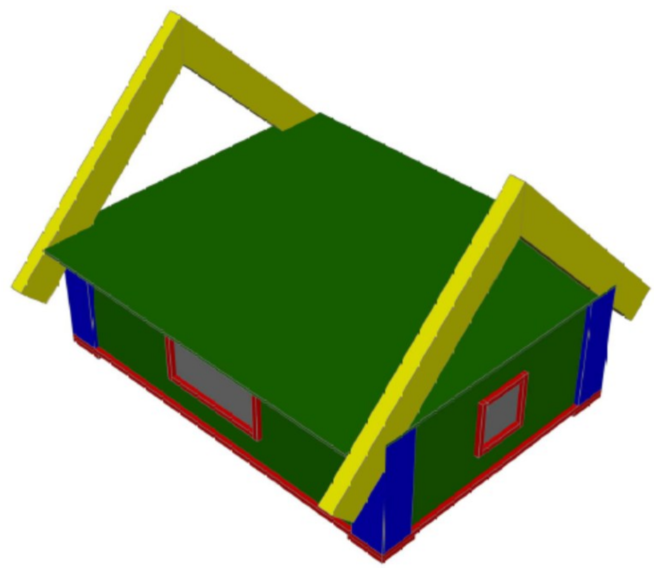
A small hinge is used to join the two sides together and allow it to open and close, while Velcro has been used on the top surface to allow for future attachment of roof panels. This can be seen in [28].

Figure 28: Hinged Roof Trusses

The roof trusses can be seen in place in [29] and [30].

Figure 29: Roof Trusses in place

Figure 30: Roof Trusses in place – 3D CAD Model

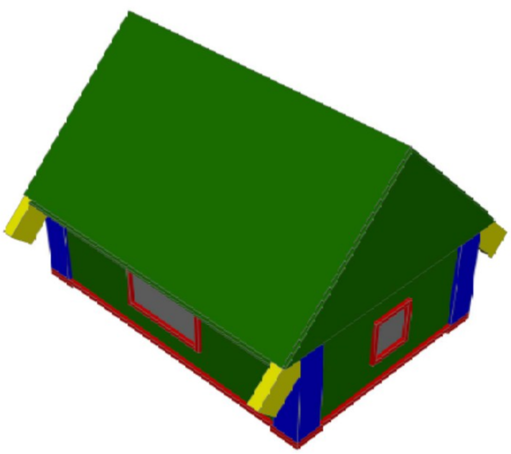


Roof Panels

Roof panels can be cut to size according to the pitch of the roof and fastened in place using Velcro. The attached roof panels can be seen in [31] and [32].

Figure 31: Roof Panels in place

Figure 32: Roof Panels in place – 3D CAD Model



Heat Source

The most straightforward heat source to use is an incandescent light bulb in the hole cut into the centre of the ceiling panel. This can be seen in [33] and [34].

Figure 33: 100W Incandescent bulb as heating source

Figure 34: 100W Incandescent Bulb in Ceiling Panel

Testing

Thermal Retention

Thermal retention is the ability of a building to retain heat. A well designed and insulated building will have less heat loss in the winter, and less heat gain in the summer.

Using the heat source, the building can be heated up to a pre-defined temperature (say 50ºC), and allowed to cool back down to room temperature.

The Xplorer GLX and a temperature sensor suspended in the middle of the room, we can monitor the rate at which the building loses heat, and the time required to return to room temperature. The longer the time taken to reach room temperature, the better the thermal retention.

Heat Distribution

We can expand the testing beyond simple thermal retention by including additional temperature probes. Placing additional probes in corners, and at higher and lower elevations will allow students to monitor whether their design allows for effective heat distribution around the building, or whether it encourages hot and cold spots.

For example, a house may retain heat within its shell effectively, but it is not particularly useful if all of this heat is located in the attic space, as this is not usually a space where we require heat.

Wall Temperatures

We can use surface temperature probes to monitor interior and exterior surface temperature, and even temperature inside a wall so that we can observe the temperature gradient across the wall.

Variables

There are a number of variables we can change between testing runs to see if a change in the thermal performance of the house occurs, and if so, by how much. These include:

Wall thickness

We can increase the thickness of walls using the slots on the vertical posts of the testing rig. This can range from a single wall panel, to two wall panels (interior and exterior) spaced as far apart as possible. **The innermost slot on the vertical posts should always be used for the innermost wall so that the interior of the house is always the same size**. This allows for more accurate comparisons between designs.

Type of Insulation

Different types of insulation can be used inside the wall spacing and above the ceiling panel. Types could include:

* Household (pink) insulation
* Styrofoam
* Newspaper
* Straw
* Air
* Sawdust

Amount of Insulation

We can vary the amount of insulation used, from loosely packed material with air pockets, to tightly packed material.

Number/Size of Windows

By changing the wall sheets, we can vary the number, type and position of windows in the building

Window Panes

Both the number of window panes and the spacing between them can be varied just as the wall thickness could be varied.

Roof Pitch

Using the variable pitch roof, we can see if the pitch of the roof has any impact on the thermal performance of a home.

Surface Colour

Painting surfaces different colours may have an impact on the thermal performance of the building due to the ability of different coloured surfaces to absorb and reflect heat. Reflective material could also be used on a surface.

Method of Heating

Geothermal

Circulating hot/warm water in tubing beneath the floor will allow basic simulation of a geothermal in-floor heating system.

Solar

By removing the light bulb as a heating source from inside the home, and using it outside of the home (or a heat lamp), we can see how heat applied to the home externally (from the sun) would be absorbed by the home. In this case we are looking to see how the home heats up, or if it reduces the cooling of a home that has already been heated. The orientation of the building relative to the source of heat may be important here.

Forced Air

Iinserting a small fan into the home (computer fans are readily available and can easily be powered using the variable power supply) may assist in simulating a forced air heating system in a home.

CAD Model

3D CAD Model

http://www.thegaiaproject.ca/projects/energy-efficient-building-design

A 3D CAD model of the design shown in this guide

Additional Resources

Calculating Savings: The Gaia Project

http://www.thegaiaproject.ca/sites/default/files/teacher-resources/additional-resources/calculating-savings.pdf

Shows how to calculate savings, perform simple cost / benefit analyses as well as complex Net Present Value Analyses