Case Study

Thermal and Structural Analysis of a Greenhouse with Ansys Discovery and Parametric Studio

Developed and curated by the Ansys Academic Development Team in collaboration with Parametric Studio

Alfred Oti[1], Nick Stefani[2,3], Chris Whitmer[4]

[1]Ansys Academic Development Team
[2]Ansys ACE
[3]Open University, UK
[4]Parametric Studio

education@ansys.com

Summary

This case study showcases how Ansys Discovery, and Parametric Studio can be coupled together to provide an interactive learning experience for STEM and first year students approaching fundamental engineering concepts for the first time. In this case study, we will conduct both structural and thermal analyses of a greenhouse.

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1. Introduction and Learning Outcomes

STEM is the term used to describe the integration of fundamental knowledge and transferable skills from the disciplines of Science, Technology, Engineering and Mathematics. The purpose of STEM is to equip students with a general foundation in the design, building, testing, and optimization of structures, products, technologies, and systems as solutions to real-world problems, needs, and wants. The learning outcomes of STEM include problem solving, creativity and design, thinking and analysis, communication and collaboration, data gathering and interpretation, and leadership and organization.

As students progress through STEM, the design, building, and testing of solutions becomes more complex. To supplement knowledge and skills students may use software to improve the efficacy and efficiency of their solutions. Ansys Discovery is a simulation-driven design tool that combines instant physics simulation, high fidelity simulation, and interactive geometry modeling in a single easy-to-use experience.

Alongside simulation software students may also use gamification software to find and develop solutions. Gamification is the application of elements from games design such as incentives, custom interfaces, and virtual environments to non-gaming activities. Parametric Studio is an Ed-Tech company specializing in engineering-centric and project-based STEM games, software, kits, and curricula for PreK-12+.

The combination of simulation and gamification software offers educators and students the means to design, build, test and optimize solutions that may otherwise be hindered by constraints. This case study will demonstrate how Ansys Discovery, and Parametric Studio can be used to construct a greenhouse and simulate the conditions needed to sustain the plants inside.

We chose to use a greenhouse because it is familiar to many people worldwide. A Greenhouse is a building used to grow plants. It is made of glass or plastic panels held together by a metal, plastic, or wooden frame. The temperature inside the greenhouse is usually warmer than that of its immediate surroundings. The greenhouse effect is often used as a simplified metaphor to explain climate change. As sunlight passes through the panels heat radiation is absorbed by the plants. When plants release the excess heat radiation, it is trapped by the panels and remains inside, raising the temperature of the greenhouse.

Using Ansys Discovery, we will perform a thermal analysis to monitor the temperature inside the greenhouse to ensure that plants are sustained during the day. At night, the temperature outside the greenhouse will fall. If the overnight temperature is too low does the greenhouse need heating? If so, how much is required? We will also perform a structural analysis to evaluate the integrity of the greenhouse structure. Could it be improved? How would it cope with snow, ice, and wind?

This case study is split into the following sections with learning aim and outcome listed below. Each section is presented as a tutorial showing how to build geometry and set-up simulations in Ansys Discovery.

- Geometry and materials: How to construct the greenhouse.
- Daytime Simulation: How to check the internal average temperature during the day
- Night-time Simulation: How to use the found day temperature and check the internal average Temperature during the Night
- Is overnight heating needed? How much?
- Structural Simulation: How to set up and apply snow, ice and wind loads. Is the greenhouse structure sound? Can the design be improved?

The Learning aim for this case study is:

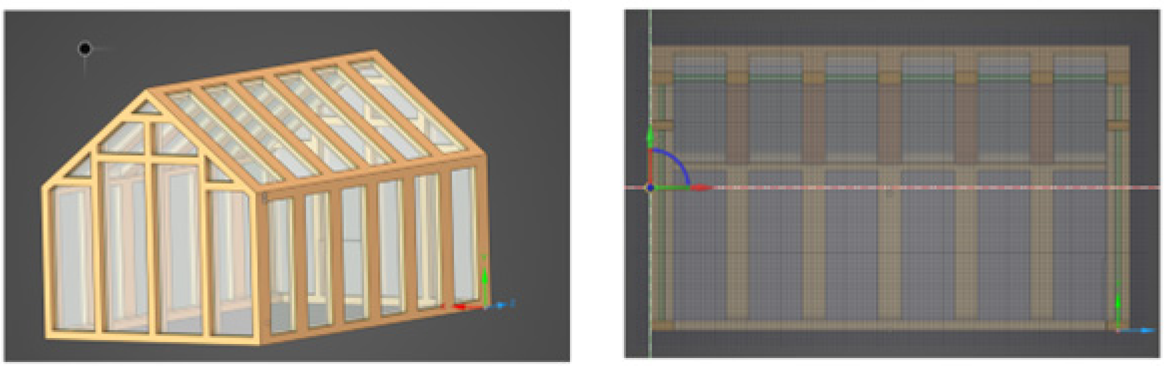
» Understand the basic underlying physics of thermal and structural simulations.

The aniticpated Learning outcome for this case study is:

» Perform basic thermal and structural simulations.

2. Geometry and Materials

The greenhouse is made of 76 mm x 184 mm pine wood frame and 40 mm acrylic plexiglass panels. To construct the greenhouse pictured below please read the 'Greenhouse Geometry Creation Tutorial' found in the "Folder 03 Tutorials". The completed greenhouse geometry is available in the same folder.



Frame: Wood (Pine)
Panels: Glass

- Maximum height 2.28m
- Minimum height 1.4m

- Length 3.8m
- Glass thickness 40mm

Figure 1: Greenhouse Dimensions

3. Daytime Simulation

The objective of the daytime simulation is to calculate the equilibrium average temperature of the air in the greenhouse. To perform the simulation, we need to make some data assumptions. The greenhouse is located at Ames, Iowa, USA, during the month of November the average daytime temperature is 9 °C. The greenhouse has a pine wood frame and glass window panels see Figure 1 for the dimensions. Solar irradiance values assume that surfaces are normal to the incoming light's direction.

To perform the daytime simulation with Ansys Discovery, we need to make some physics assumptions. Ansys Discovery cannot model radiation from the sun, so it is considered that the heat flux absorbed and released by the ground of the greenhouse corresponds to the total released heat within the greenhouse coming from the sun. Heat inside the greenhouse is also absorbed and released by the air, the greenhouse frame, the panels, and other things such as the blackbody radiation of hot objects, however this has been neglected for simplicity. Following these assumptions, radiation from the sun can be computed as a simple approximation of heating irradiance flux (W/m²), light view angle, and the transmission/reflection reductions expected for this solar flux. This number would be a rough approximation of the heat that is absorbed to heat the greenhouse. The rest is reflected away, either at the acrylic plexiglass panels or off the 50% white paint/highly reflective ground, and leaves the control volume of 49.681125 W/m².

Once the greenhouse geometry is constructed the material properties and boundary conditions for the daytime simulation can be set. Figure 2 shows the physics tree representing all the boundary conditions that have been set to solve the simulation. A video of how to set up and conduct the daytime thermal simulation can be found in the case study folder under the name 'Day Simulation Video' and a presentation of the boundary conditions can be found in the same folder under the name Greenhouse Thermal & Structural Simulation Tutorial.

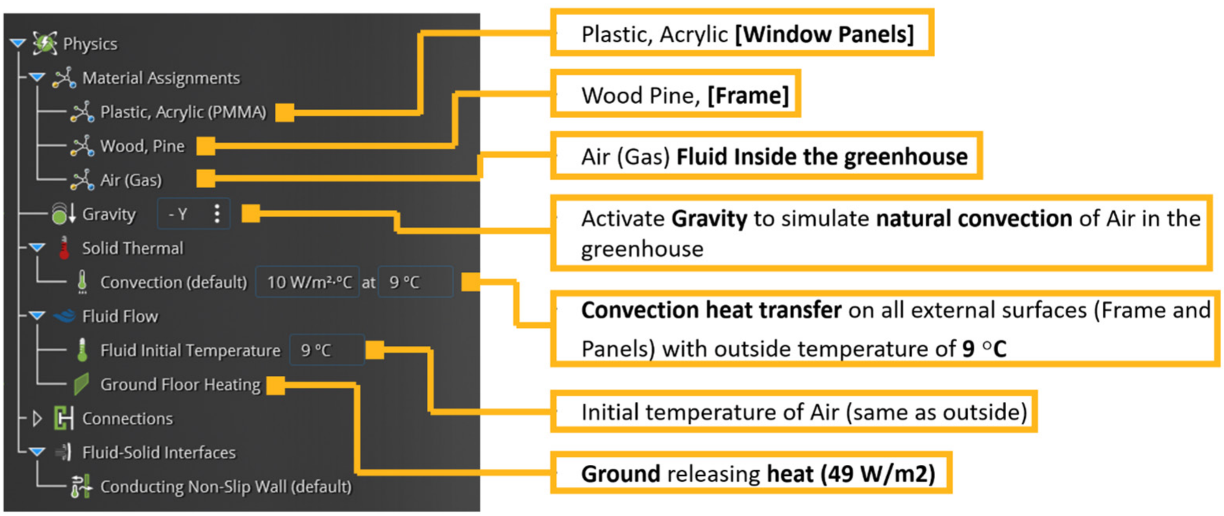


Figure 2: Daytime Simulation Setup

The results of the daytime simulation show an average equilibrium air temperature of 22.2 °C (see Figure 3, left). The temperature inside the greenhouse is warmer than that of the external temperature of 9 °C. The temperature field plot shows that the internal temperature of the greenhouse is homogeneous, with the slightly warmer heat radiating from the ground and the cooler air at the top. The direction of heat convection travels from the bottom right to the top left of the greenhouse then swirls upon contact with the roof.

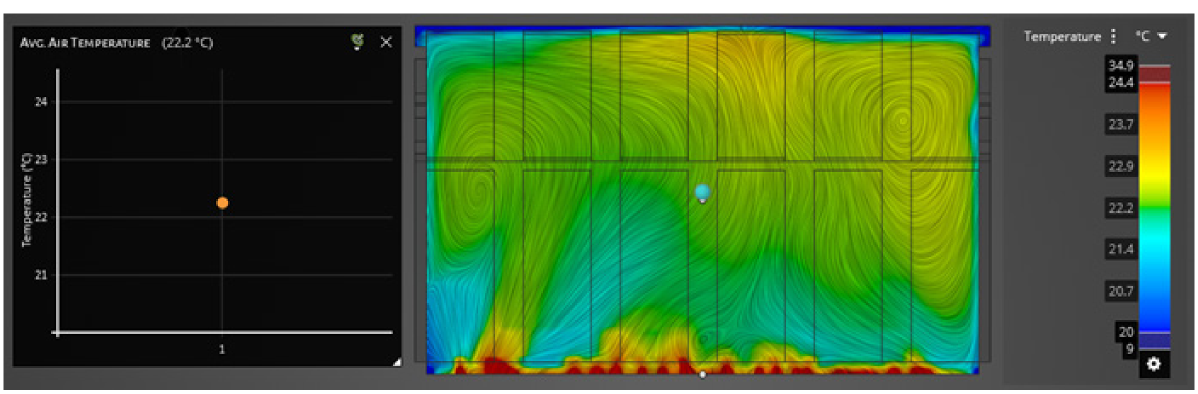


Figure 3: Daytime Simulation Results

4. Night-time Simulation

The objective of the nighttime simulation is to calculate the average temperature of the air in the greenhouse during the night. The data assumptions are as follows. First, the location and time remains Ames, Iowa, USA, during the month of November. However, the average external temperature at night is –1 °C [1]. The initial temperature inside the greenhouse is 20 °C, which is slightly lower than the daytime temperature to consider evening cooling [1]. The constant ground temperature is 12 °C, given by the average between 20 °C of the day temperature and 4 °C of the soil temperature (at 4 inches depth) [1].

Many of the physics assumptions remain the same as the daytime simulation. However, the convective heat transfer ambient temperature is –1 °C, the initial air temperature is 20 °C and the stationary wall (ground) temperature is fixed at 12 °C. A video of how to set up and conduct the night-time thermal simulation can be found in the case study folder under the name 'Night Simulation Video' and a presentation of the boundary conditions can be found in the same folder under the name Greenhouse Thermal & Structural Simulation Tutorial.

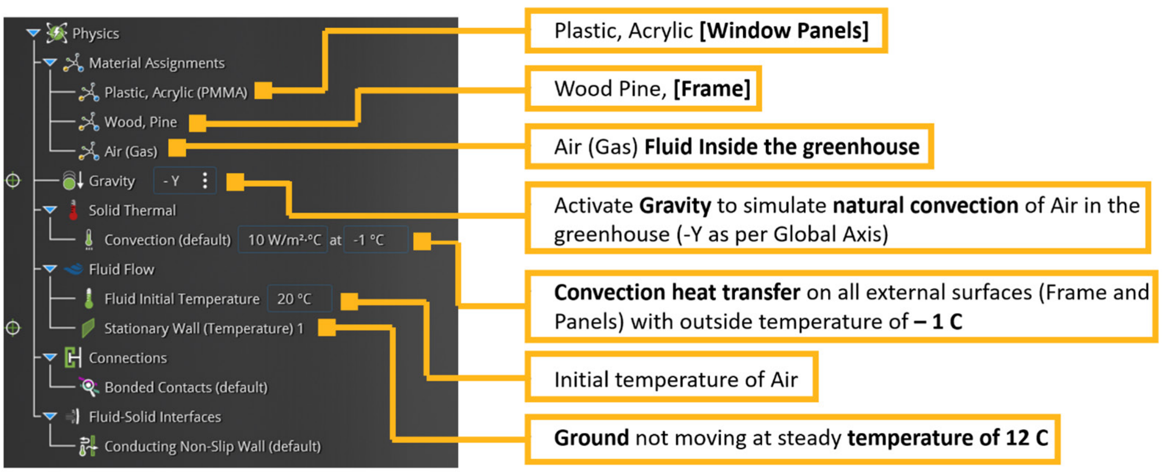


Figure 4: Night-time Simulation Setup

The results of the night-time simulation show average equilibrium air temperature of 4.87 °C degrees, which is too low and could harm the plants. However, the fall in the external temperature to –1 °C due to the absence of sunlight, means that there is too much dispersion of heat to sustain the plants at the required 12 °C.

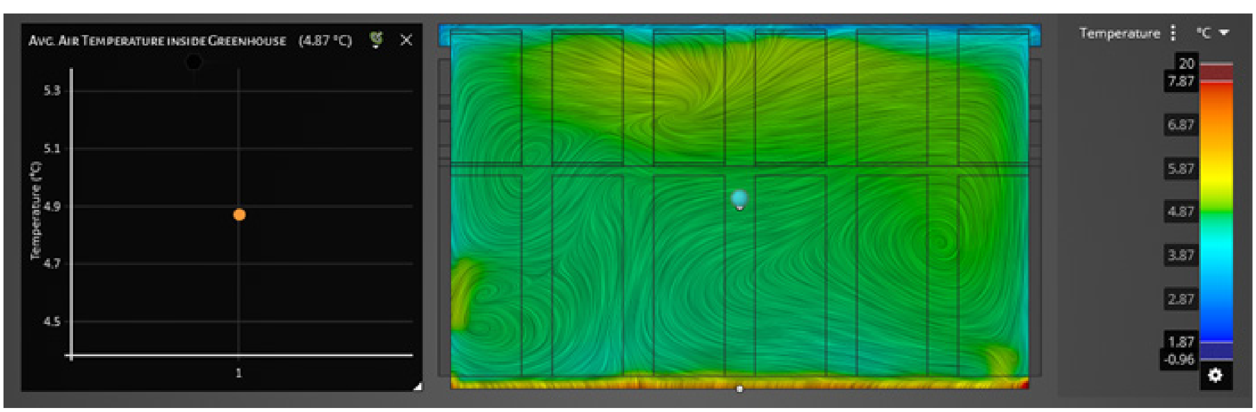


Figure 5: Night-time Simulation Results

5. Overnight Heating

Given the low temperature, the plants inside the greenhouse need an overnight source of heating. The objective of the overnight heating simulation is to calculate how much heating (in W) is required overnight to maintain temperature above 12 °C. The data and physics assumptions remain the same as in the night-time simulation with the addition of a heat source under the convection (default) in the physics tree.

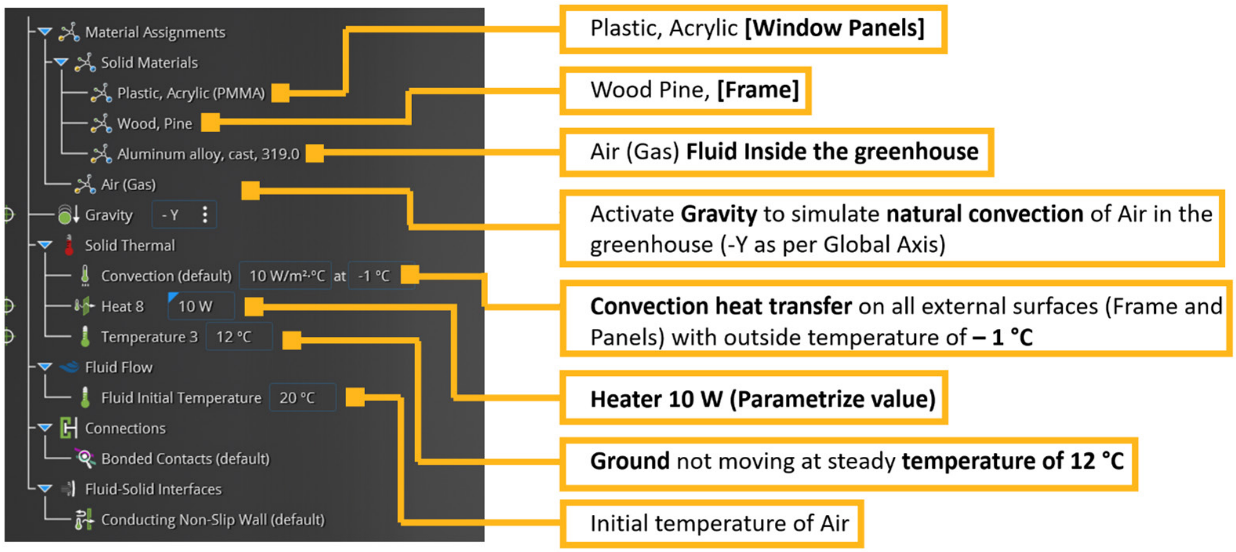


Figure 6: Overnight Heating Simulation Setup

The greenhouse geometry with the heater with dimensions of 0.495 m*0.495 m*0.1 m. can be found in the case study folder under the name Greenhouse Thermal Night Simulation with Heater Solved. A video of how to set up and conduct the daytime thermal simulation can be found in the case study folder under the name 'Overnight Heating Simulation Video' and a presentation of the boundary conditions can be found in the same folder under the name Greenhouse Thermal & Structural Simulation Tutorial.

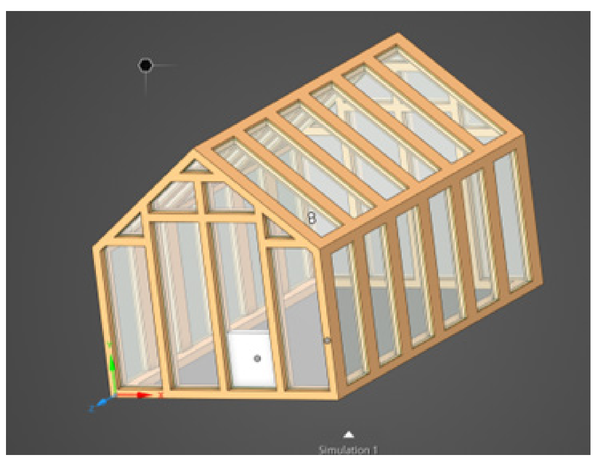


Figure 7: Overnight Heating Placement inside Greenhouse

To calculate the level of heating required, we conducted a parametric study that solved simulations back-to-back, starting with a power output of 10 W in the first simulation. In subsequent simulations, the power output was doubled in each variation, until a sufficient power output was reached. The results of the night-time with heating simulation show that the heater needs to have 400 W of power to maintain an internal temperature of 12 °C.

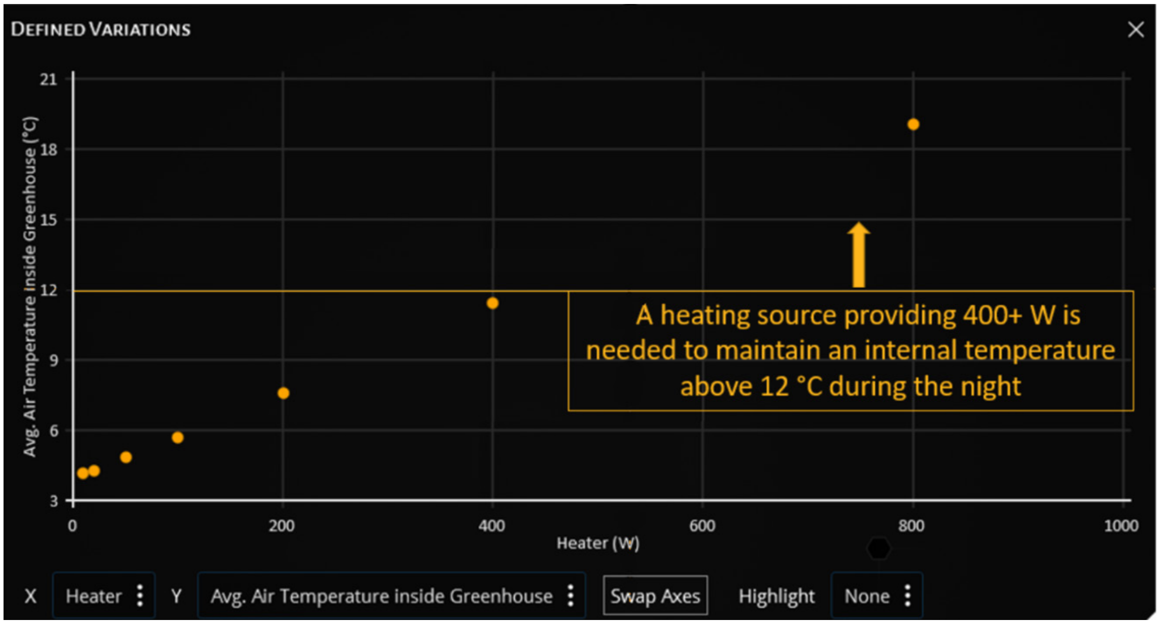


Figure 8: Overnight Heating Parametrization Results

6. Structural Simulation: Wind, Ice and Snow Loads

The objective of the structural simulation is to calculate how much load the greenhouse can withstand from snow, ice, and wind. The location and time remain Ames, Iowa, USA, in November. To calculate the snow load, we will assume that the maximum layer of snow that can accumulate on the greenhouse roof is 0.5 m. The roof of the greenhouse has a total surface area of 11.2 m^2, which when multiplied by 0.5m gives 5.6 m^3. Snow weighs approximately 50 kg per m^3, so when multiplied by 5.6 m^3 gives 280 kg as the total load on the greenhouse structure which is approximately 3kN.

We will assume that the maximum layer of ice that can accumulate on the roof is 0.1 m. Ice weighs approximately 920 kg/m^3, so the total load on the structure is 1030 kg which can be approximated to 10 kN. Given that the snow and ice load are on the same roof surface, only ice load will be simulated, as this is the worst-case scenario. The ice and wind loads are applied to the greenhouse as shown in Figure 9 (right side). The snow

Assuming a wind force of 35 m/s, representing gusts of 80 mph which is not unusual for the location, and a lateral area of 10.9 m^2 (that is a side wall and one side of the roof). the wind force acting on the side of the greenhouse can be calculated with the equation:

$$F_w = \frac{1}{2}\rho v^2 A \quad (1)$$

where:

F_w=wind force (N) A=surface area (m^2)

ρ=density of air (kg/m^3) v=wind speed (m/s)

Inputting our values into the equation gives us the following result:

$$F_w = \frac{1}{2} * (35)^2 * 10.9 = 7477N \rightarrow 7.4kN \quad (2)$$

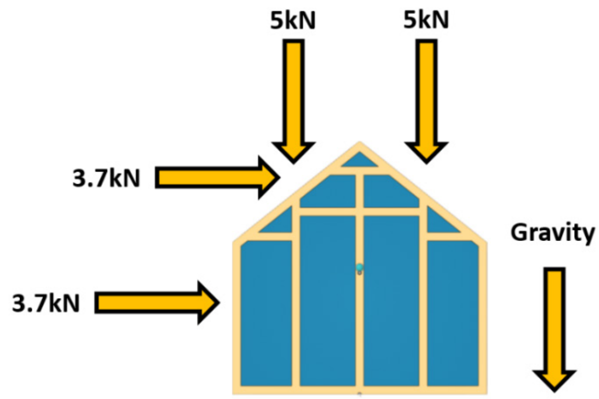


Figure 9: Application of Ice and Wind loads

A video of how to set up and conduct the daytime thermal simulation can be found in the case study folder under the name 'Structural Simulation Video' and a presentation of the boundary conditions can be found in the same folder under the name Greenhouse Thermal & Structural Simulation Tutorial.

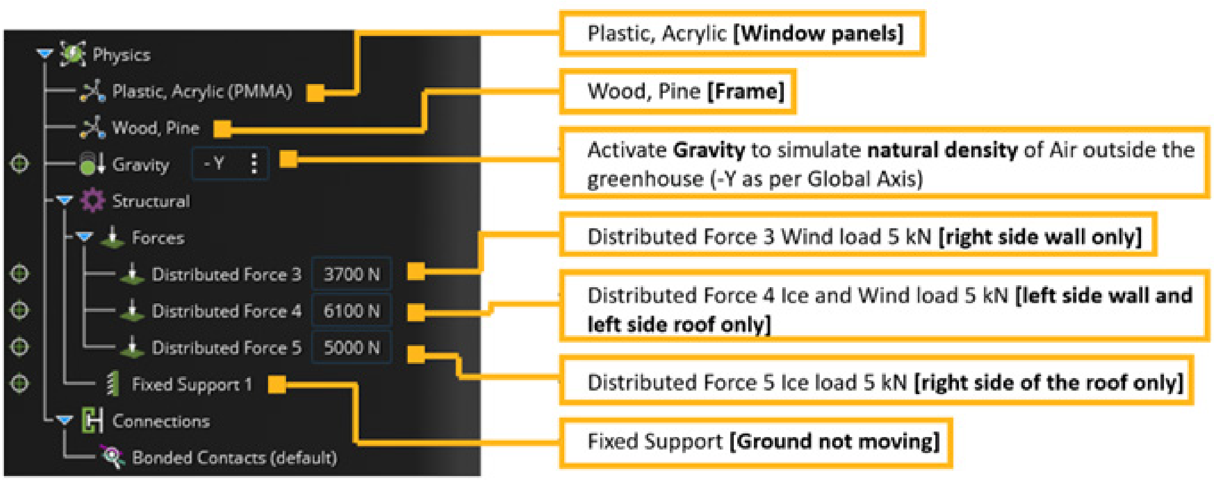


Figure 10: Structural Simulation Set-Up

One of the main indicators of structural soundness is the Factor of Safety (FoS) which measures the stress bearing capacity of a structure caused by loads placed upon it. Additionally, FoS may also represent the required legal margin of safety for a structure. An FoS of 1 represents the allowable limit of stress on the structure caused by loads. A structure with an FoS below 1 is considered unsound and may likely fail.

The structural simulation results indicate that the greenhouse is structurally sound with a high FoS, 81.2. This means we have over-engineered the product and can perform some optimization in order to cut costs, *etc*. Switching to cheaper materials and reducing the thickness of the frames and panels will reduce costs and environmental impact. In Ansys Discovery, it is possible to easily compare how changing materials and the thicknesses of the greenhouse frame and panels can affect the safety of the structure. Multiple design solutions can be solved in succession.

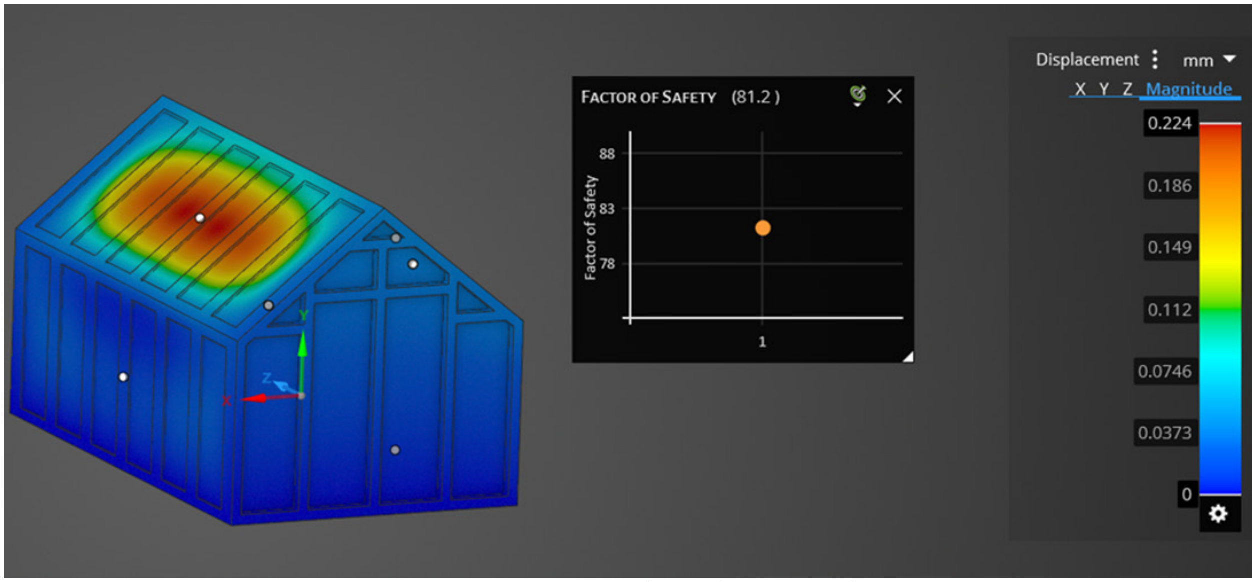
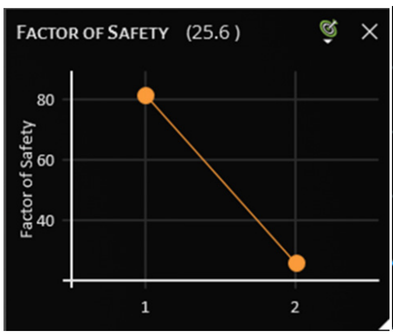


Figure 11: Structural Simulation Results

In the factor of safety chart (figure 12, left) the greenhouse frame was changed from pine wood to chipboard wood. Consequently, the factor of safety fell from 81.2 to 25.6. The table (figure 12, right) displays that further reduction of the panel and frame thicknesses lowers the factor of safety. The fourth reduction produced a FoS of 7.45 which is still quite strong and structurally sound.



	Name	Side Panels	Side Frame	Factor of Sa...
1	DV1	40 mm	76 mm	25.6
2	DV2	30 mm	76 mm	22
3	DV3	30 mm	38 mm	12
4	DV4	15 mm	38 mm	7.45

Figure 12: Structural Simulation Parametrization Results

7. Conclusions

This case study has demonstrated how Ansys Discovery and Parametric Studio can be in collaboration to provide an interactive learning experience for STEM and first year students approaching fundamental engineering concepts. Educators may use this resource to teach the concepts of geometry creation, editing and preparation for thermal and structural simulation including parametrization of boundary conditions and structural design.

References

[1] Iowa Environmental Mesonet, 2021, Average 4 Inch Soil Temperatures for Nov 29, 2021, IEM Time Machine Local: Nov 29th 2021, UTC: Nov 29th 2021, generated 02nd December 2021, 01:53 AM, viewed 21st September, 2022 https://mesonet.agron.iastate.edu/timemachine/#57.202111290000.

[2] The Greenhouse Case Study can be accessed on the Parametric Studio website at the following address https://www.parametricstudioinc.com/ansys

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Document Information

This case study is part of a set of teaching resources to help introduce students to structures, fluids, or heat transfer (physics areas supported by Ansys Discovery).

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ANSYS, Inc.
Southepointe
2600 Ansys Drive
Canonsburg, PA 15317
U.S.A.
724.746.3304
ansysinfo@ansys.com