JAYAPRAKASH CHANDRAN

M.S. MECHANICAL & AEROSPACE ENGINEER

ThermoPro: Advanced Insulation Analysis & Energy Optimization Tool

"Empowering smarter energy decisions with a tool that transforms insulation challenges into cost-saving, sustainable solutions for buildings, vehicles, and extreme environments."

PROBLEM STATEMENT:

Buildings lose significant energy due to poorly insulated walls, leading to higher energy bills, increased carbon emissions, and environmental challenges. Heat escapes through various ways: gaps in walls (convection), direct transfer through materials (conduction), or radiation from surfaces. However, developers, engineers, and facility managers often lack a user-friendly tool to assess how different insulation materials and setups perform under real-world conditions, such as varying weather, wind, or humidity.

Solution Goal:

This tool aims to simplify material selection and improve energy efficiency by:

- Helping users compare materials and identify the most energy-efficient and cost-effective insulation materials across different temperature ranges.
- Providing a clear view of how small adjustments in thickness and conductivity significantly influence insulation performance.
- Presenting all results in a single, streamlined view for quick and informed decision-making.

Features and Benefits:

With color-coded insights, downloadable results, and easy-to-read tables, this tool offers practical support for applications in construction, HVAC design, and energy audits.

Beyond Buildings:

This concept extends beyond buildings, offering solutions for factories, vehicles, airplanes, and even extreme climateresistant structures. By combining heat transfer science with an intuitive interface, it translates complex challenges into practical and user-friendly solutions that save energy and money.

App: https://thermopro-cqhj56ncanqdoajzfju2wx.streamlit.app/

➤ GitHub: https://github.com/JAYAPRAKASHCHANDRAN/thermoPro

APPROACH:

- > Dynamic Material Configuration: Users can input and compare multiple wall material configurations by specifying properties like thickness and conductivity.
- > Thermal Analysis: Calculates Effective (total) thermal resistance (R-value), heat flux per unit area, and total heat flux based on temperature differences and wall area.
- **Energy Cost Estimation**: Provides annual energy cost predictions by considering energy rates and operating hours.
- Interactive Visualization: Generates intuitive graphs to compare heat flux across materials, with dynamic legends and customizable axis labels.
- > Detailed Results: Displays heat flux, thermal resistance, and energy cost in an interactive table, highlighting the most and least effective materials.
- Insights and Export Options: Summarizes the best effective and least effective-performing materials and allows users to export results as a CSV file for reporting.



The system calculates:

- Heat Flux (W/m²): Heat transfer per unit area.
- Total Heat Flux (W): Total heat transfer across the entire area.
- Wall Area (m²): The total wall area is calculated to determine the heat transfer across the material.
- Thermal Resistance ($K \cdot m^2/W$): The material's resistance to heat flow.
- Annual Energy Cost (\$): Cost of operating under the given conditions.
- Comparison: The temperatures are compared (e.g., 250–300K) with either of the fixed temperatures and generate results in a single view.

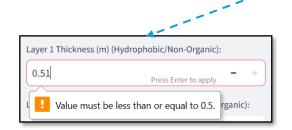
HOW TO USE THE WORKFLOW - 1:

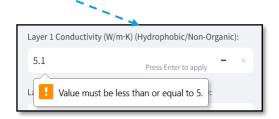
Input Materials and Properties

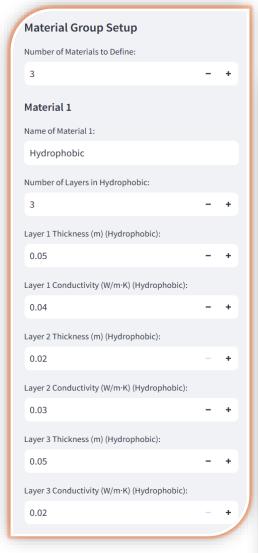
> Sidebar Configuration:

- User defines "n" materials (0 to n) with custom names.
- Add multiple layers for each material, specifying:
 - Thickness (m): The thickness of each layer.
 - Thermal Conductivity (W/m·K): A measure of how well the material conducts heat.
- Example:
 - Material: "Material A"
 - · Layers:
 - Layer 1: 0.05 m thickness, 0.04 W/m·K conductivity.
 - Layer 2: 0.02 m thickness, 0.03 W/m·K conductivity.

To ensure accurate thermal analysis the input values are kept within realistic physical limits. For example, if the thickness exceeds 0.5 meters or thermal conductivity goes beyond 5 W/m·K, the form displays clear error messages like "Value must be less than or equal to 0.5," guiding user to enter valid inputs.









HOW TO USE THE WORKFLOW - 2:

Select Baseline Material:

- Purpose: The baseline material serves as the reference point for comparison with other materials.
- •Dropdown: Users select a material (e.g., "Styrofoam") from the available list of defined materials.
- •Functionality: The baseline material will be used to calculate and compare thermal properties like heat flux, thermal resistance, and energy cost with other materials.

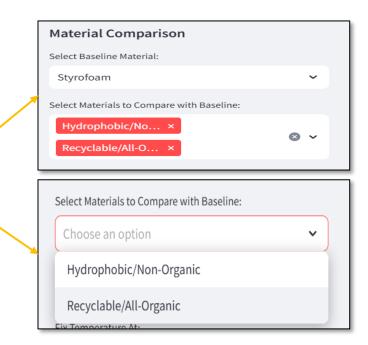
Material Comparison Select Baseline Material: Styrofoam Hydrophobic/Non-Organic Recyclable/All-Organic Styrofoam

Select Materials to Compare with the Baseline:

• **Purpose**: Allows the user to select one or more materials to compare against the baseline material.

•Multiselect Field:

- 1. In the example, "Hydrophobic/Non..." and "Recyclable/All-O..." are selected as comparison materials.
- 2. The materials in red indicate they've been chosen for the analysis.
- 3. The "X" allows the user to deselect a material.
- •Functionality: These selected materials will be compared with the baseline for metrics such as:
 - 1. Heat flux per unit area.
 - 2. Total energy cost.
 - 3. Thermal resistance effectiveness.

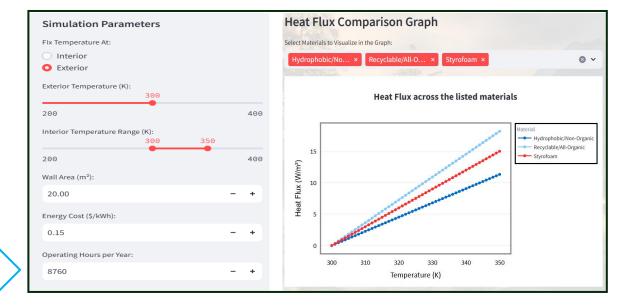


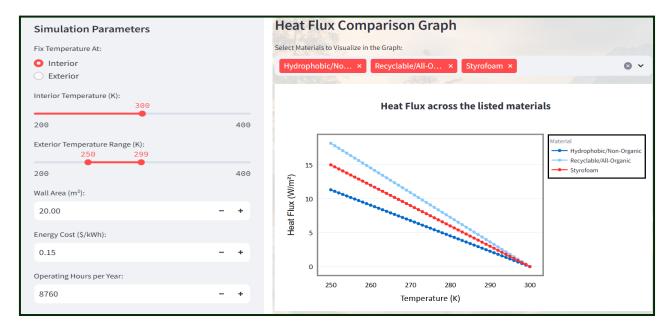
HOW TO USE THE WORKFLOW - 3:

User Defines:

- Fixed Temperature: Either "Interior" or "Exterior."
- **Temperature Range**: A range of varying temperatures to simulate real-world conditions.
- Wall Area: The area (in square meters) of the wall or structure being analyzed.
- Energy Cost (\$/kWh): The cost of electricity per kilowatt-hour.
- Operating Hours: Annual usage in hours.

Exterior Temp as "Fixed"





Interior Temp as "Fixed"

HOW TO USE THE WORKFLOW – 4:

The **Detailed Results Table** helps users compare materials across a temperature range (e.g., 250K to 298K) to identify the most energy-efficient and cost-effective options. It highlights key metrics like:

The table pops with "If the interior or exterior temperature is fixed, these values represent the range".

Color coding

Green: Represents the most effective material in terms of low heat flux.

Red: Highlights the least effective material with the highest heat flux.

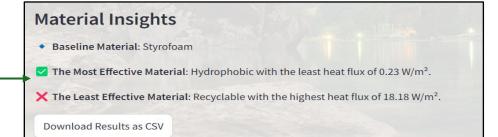
Blue: Marks the baseline material (used as the reference point for comparison).

Material Insights

The user gets a pop-up that says, "Across these temperatures, this material offers the most effective and least effective."

- 1. Baseline Material: Styrofoam, used as the comparison.
- 2. Most Effective: Hydrophobic/Non-Organic (heat flux: 0.23 W/m²), offering excellent insulation.
- 3. Least Effective: Recyclable/All-Organic (heat flux: 18.18 W/m²), less energy-efficient.
- 4. **Download:** Users can download the results as a CSV for further analysis or documentation.

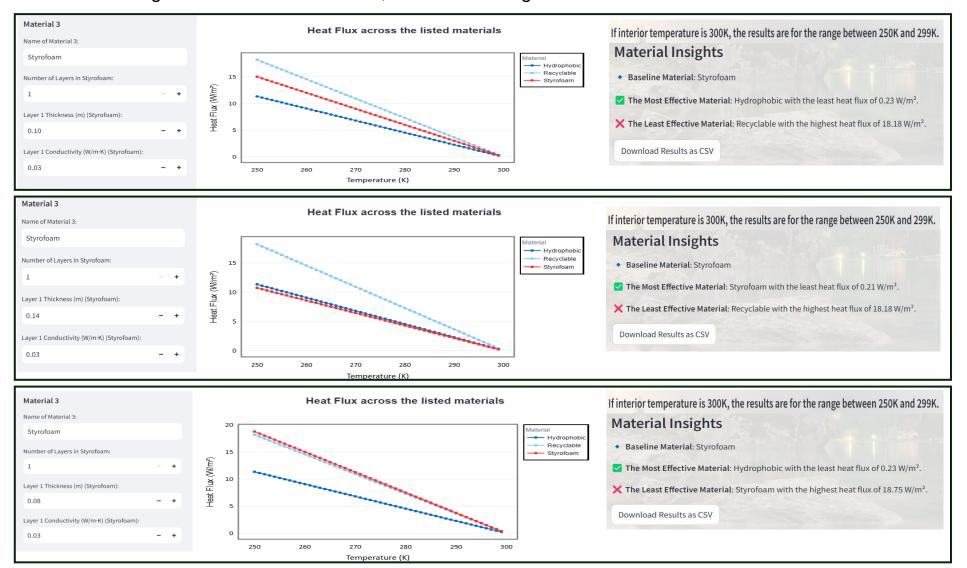
	Detailed Results Table												
4	If interior temperature is 300K, the results are for the range between 250K and 298K.												
Ī		Material	↑ Temperature (K	Heat Flux (W/m²)	Total Heat Flux (W)	Effective Thermal Resistance (K·m²/W)	Annual Energy Cost (\$)	Effectiveness					
	0	Hydrophob	250	11.320755	226.415094	4.416667	297.509434	Most Effective					
	49	Recyclable,	250	18.181818	363.636364	2.750000	477.818182	Least Effective					
	98	Styrofoam	250	15.000000	300.000000	3.333333	394.200000	Comparison					
	1	Hydrophob	251	11.094340	221.886792	4.416667	291.559245	Most Effective					
	50	Recyclable,	251	17.818182	356.363636	2.750000	468.261818	Least Effective					
	99	Styrofoam	251	14.700000	294.000000	3.333333	386.316000	Comparison					
	2	Hydrophob	252	10.867925	217.358491	4.416667	285.609057	Most Effective					
	51	Recyclable,	252	17.454545	349.090909	2.750000	458.705455	Least Effective					
	100	Styrofoam	252	14.400000	288.000000	3.333333	378.432000	Comparison					
▶	3	Hydrophob	253	10.641509	212.830189	4.416667	279.658868	Most Effective					
	52	Recyclable,	253	17.090909	341.818182	2.750000	449.149091	Least Effective					
	101	Styrofoam	253	14.100000	282.000000	3.333333	370.548000	Comparison					



* All data and material are used for reference only; actual value and name may differ.

HOW TO USE THE WORKFLOW - 5:

How small changes can affect the insulation, let's see the magic of the tool:

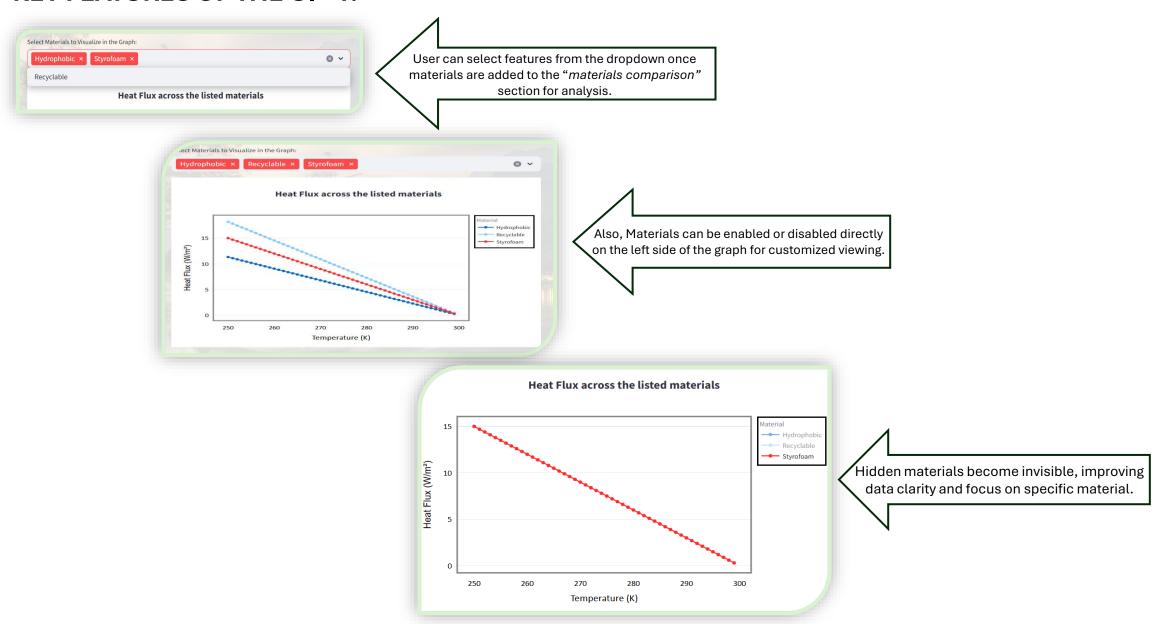


- > With a **0.10 thickness**, Styrofoam is neither the most nor the least effective material.
- When the thickness is increased to 0.14, Styrofoam becomes the most effective material, showing excellent performance across temperature ranges.
- > Reducing the thickness to 0.08 makes Styrofoam the least effective material, with poor performance highlighted in the graph.
- > The graphs clearly illustrate how changes in thickness affect heat flux and insulation performance.

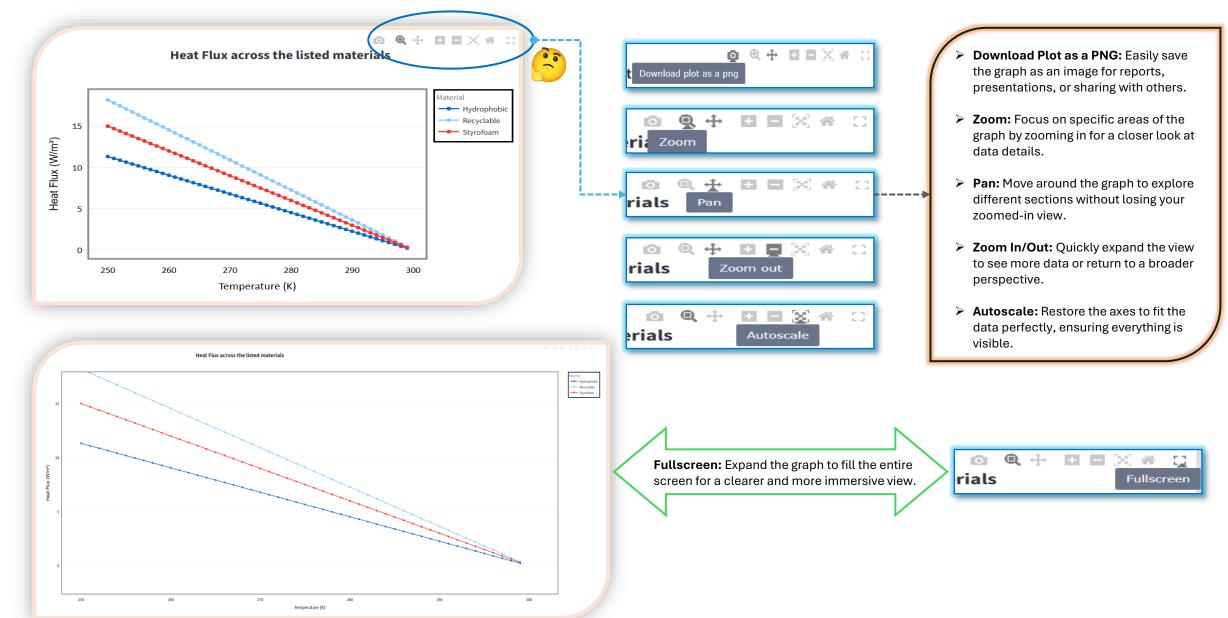




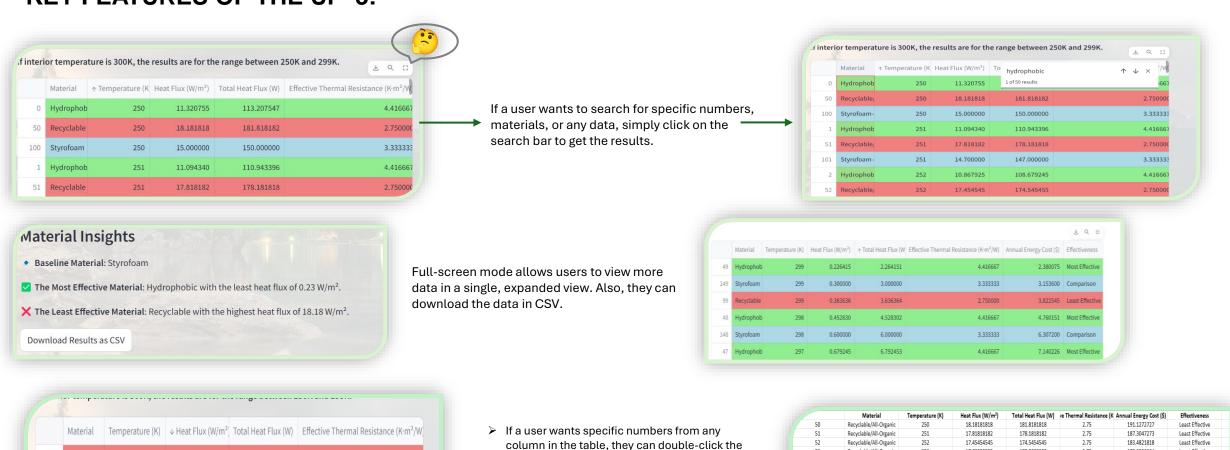
KEY FEATURES OF THE UI - 1:



KEY FEATURES OF THE UI - 2:



KEY FEATURES OF THE UI - 3:



								Material	Temperature (K)	Heat Flux (W/m²)		re Thermal Resistance (K		Effectiveness
	Material	Temperature (K)	J. Heat Flux (W/m²	Total Heat Flux (W)	Effective Thermal Resistance (K·m²/W)	➤ If a user wants specific numbers from any	50	Recyclable/All-Organic Recyclable/All-Organic	250 251	18.18181818 17.81818182	181.8181818 178.1818182	2.75	191.1272727 187.3047273	Least Effectiv
	Material	remperature (iv)	VIICACITAN (VI)III	, rotat ricat rtax (**)	Elicetive illerinaritesistance (itili / iv	1	51	Recyclable/All-Organic	252	17.45454545	174.5454545	2.75	183.4821818	Least Effec
						column in the table, they can double-click the	53	Recyclable/All-Organic	253	17.09090909	170.9090909	2.75	179.6596364	Least Effec
0	Recyclable,	250	18.181818	181.818182	2.750000	column heading to sort the data in ascending or	54	Recyclable/All-Organic	254	16.72727273	167.2727273	2.75	175.8370909	Least Effe
_						•	55	Recyclable/All-Organic	255	16.36363636	163.6363636	2.75	172.0145455	Least Effe
П	Demolable	251	17.010100	170 101010	2.750000	descending order based on the column title.	56	Recyclable/All-Organic	256	16	160	2.75	168.192	Least Eff
1	Recyclable,	251	17.818182	178.181818	2.750000		57	Recyclable/All-Organic	257	15.63636364	156.3636364	2.75	164.3694545	Least Effe
-						For example, double-clicking the "Heat Flux"	58	Recyclable/All-Organic		15.27272727	152.7272727	2.75	160.5469091	Least Effe
:2	Recyclable	252	17.454545	174.545455	2.750000	· ·	100	Styrofoam-only	250	15	150	3.33333333	157.68	Compari
necyclable)	232	11.757575	114.545455	2.130000	column displays an arrow near the title,	101	Recyclable/All-Organic Styrofoam-only	259 251	14.90909091 14.7	149.0909091 147	2.75 3.333333333	156.7243636 154.5264	Least Effe Compar	
_						indicating the column is sorted from least to	60	Recyclable/All-Organic	260	14.54545455	145.4545455	2.75	152.9018182	Least Effe
3	Recyclable	253	17.090909	170.909091	2.750000		102	Styrofoam-only	252	14.4	144	3.33333333	151.3728	Compar
, ,					greatest or vice versa. Users can also download	61	Recyclable/All-Organic	261	14.18181818	141.8181818	2.75	149.0792727	Least Effe	
						the data as an Excel file, eliminating the need for	103	Styrofoam-only	253	14.1	141	3.33333333	148.2192	Comparis
4	Recyclable,	254	16.727273	167.272727	2.750000		62	Recyclable/All-Organic	262	13.81818182	138.1818182	2.75	145.2567273	Least Effe
4						manual sorting.	104	Styrofoam-only	254	13.8	138	3.33333333	145.0656	Compari
.	Doguelable	255	16 262626	163.636364	2.750000		105	Styrofoam-only	255	13.5	135	3.33333333	141.912	Compar
O	Recyclable,	255	16.363636	103.030304	2.750000		63	Racurlahla/All_Ormanic	263	13 //5//5//5//5	13/15/15/15	2.75	1/11 //3/1919	Looct F



- The **ThermoPro** is designed to make material comparison and decision-making simple and intuitive. With features like sorting, searching, and downloading results, it ensures users can quickly access and analyze the data they need.
- The visually appealing graphs and detailed tables make understanding complex thermal properties straightforward, even for non-technical users.
- By focusing on ease of use and interactivity, this tool bridges the gap between technical analysis and practical decision-making, providing a seamless experience for everyone involved.