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Thermal Performance Evaluation of a G+1 Residential Building in Visakhapatnam

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ABSTRACT:

This paper analyses the thermal performance of a G+1 residential building in Visakhapatnam using Building Information Modelling (BIM) tools, such as Revit for architectural modelling and ArchiCAD for thermal performance evaluation. It first generates a detailed 3D model in Revit to capture its geometric and material characteristics. Then, the model is imported into ArchiCAD where multiple thermal simulations are carried out to evaluate energy consumption during indoor temperature fluctuations and overall thermal comfort. The evaluation considers assessing the overall impacts of solar gains, the effectiveness of insulation, and ventilation strategies. According to results, certain design decisions greatly impact thermal performance where passive design components may be beneficial for energy demand reduction. The results indicate that the integration of advanced BIM tools may promote better design choices that increase thermal comfort while limiting energy usage. Therefore, this study adds to the ongoing discussion on sustainable building practices in tropical climates, with a focus on the use of technology in architectural design to achieve optimal thermal performance. This research does not only point out the relative advantages of Revit over ArchiCAD, but it also outlines a framework through which future research work might be conducted in furthering the designs of residential buildings at such climatic conditions.

Keywords: Thermal analysis, Building information modelling (BIM), Thermal simulation software, Thermal comfort, Energy efficiency

Introduction:

The performance assessment of buildings, especially concerning their thermal behaviour, has become increasingly important in architectural design. This is particularly true in cities like Visakhapatnam, which dictates that the local climate largely impacts energy efficiency and occupation comfort. Research about G+1 residential buildings has been done with the help of sophisticated software tools such as Revit for preliminary modelling and ArchiCAD for detailed thermal performance assessment. By combining these advanced technologies, the research will make a comprehensive analysis about thermal behaviour in buildings in order to see how each element can be useful for improving the indoor environmental quality.

Thermal comfort is a complex concept and has some influencing factors such as temperature in air, humidity, the mean radiant temperature, air velocity, and ability of building materials to insulate. Each of these factors interacts in complex ways to influence the overall comfort levels perceived by an occupant. For example, mean radiant temperature is a significant determinant of the operative temperature, which is important for evaluating perceptions of comfort in a particular space [3][4]. Beyond that, personal preference and rate of metabolism further complicate personal comfort evaluations within a residence setting [5][6]. This complexity demands a detailed exploration of how these variables interact in particular climatic scenarios.

For the case of Visakhapatnam's particular climate, quantification of these variables' influence on thermal comfort becomes essential. The assessment process will further enable simulation and modelling-based analysis of building thermal performance with emphasis on improvement in terms of both energy efficiency and occupant satisfaction. This approach enhances design practices and contributes towards the development of sustainable environments in residential buildings within similar climatic regions. Simulation of various design scenarios will enable architects and builders to make informed decisions that are in line with the directives of energy efficiency.

Furthermore, the use of more advanced modelling techniques has placed a great deal of importance on the point where optimal performance in terms of thermal comfort and conditions can be achieved in residential architecture. Tools such as ArchiCAD's Energy Evaluation enable architects to track and even control architectural design parameters influential in building energy performance effectively[2][5]. This is a process of dynamic assessment for architects to create designs that not only meet but surpass the limits set by energy efficiency regulations and standards. This super leading approach used in these methodologies ensures that the buildings designed are capable of serving thermal demands defined by the local climatic conditions.

In this context, there is also an emphasis on using local climate data in building performance evaluation. Being a coastal city, Visakhapatnam has unique weather conditions that might influence the thermal comfort of buildings; hence, the analysis of historical climate data will be complemented by the computation of the same thermal simulations proposed for this study. The integration of such an approach would ensure the aesthetic appeal of buildings does not sacrifice functionality in actual usage.

Methodology:

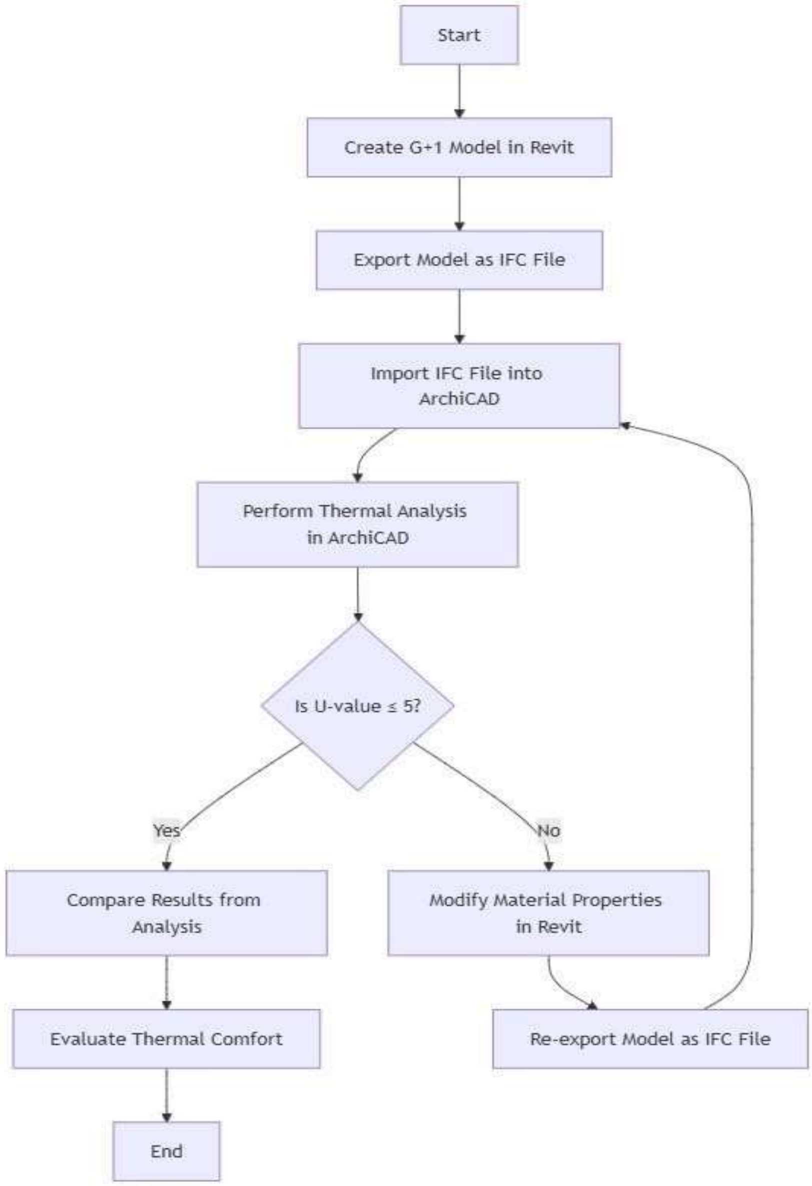

Fig: Methodology of the thermal performance evaluation

Modeling of a G+1 Residential duplex Building in Revit

1. Project Setup

Open Revit: Open Autodesk Revit and start a new project.

Set Units: Go to the "Manage" tab and configure project units as either metric or imperial.

2. Creating Levels

Add Levels: Use the "Level" tool in the "Architecture" tab to add levels at specified elevations, for example, Level 1 at 0 mm, Level 2 at 3000 mm and name them accordingly Adjust Properties: For each level, adjust properties such as elevation.

3. Working with Grids

Add Grids: Using the "Grid" tool, create a building layout by creating vertical and horizontal grid lines with the correct spacing, for example, 4200 mm.

4. Create Walls

Select Wall Type: Choose wall types from the "Architecture" tab (e.g., exterior walls at 300 mm thickness, interior walls at 200 mm).

Draw Walls: Outline the building's footprint using the rectangle tool.

Copy Walls: Replicate Level 1 walls on Level 2 with adjustments for room layouts.

5. Adding Doors and Windows

Insert Doors: Use the "Door" tool to place doors in suitable locations.

Add Windows: Use the "Window" tool to insert windows aligned with design requirements.

6. Adding Stairs

Add Stairs: Insert staircases going from Level 1 to Level 2, utilising the "Stair" tool and selecting appropriate stair types.

7. Add Roof

Roofing Design: Construct roofs above Level 2, using the "Roof by Footprint" tool or any other available roof tools, adjusting the materials and slopes as necessary.

8. Adding Curtain Walls

Add Curtain Walls If applicable, pick curtain wall types in the wall options and place them for aesthetic or natural lighting.

9. Finishing Touches

Apply Materials Apply materials to your walls, roof, and floors using the "Materials" tool for realistic finishes.

Light Fixtures Install light fixtures in proper intervals throughout your design for functional and aesthetic effects.

10. Rendering and Visualization

Set up views to view your model from different angles.

Render Model: Use Revit's rendering feature to generate high-quality images of your presentation design.

Steps provide a step-by-step guide on modelling a G+1 residential duplex in Revit, enabling one to go through this process with a structured approach to ensure that all architectural elements are comprehensively covered.

Figure 1: 3d model front view

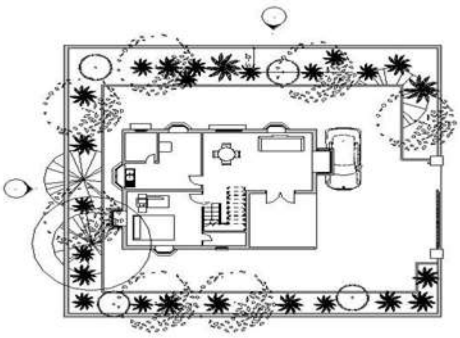

Figure 2: Plan of Ground Floor

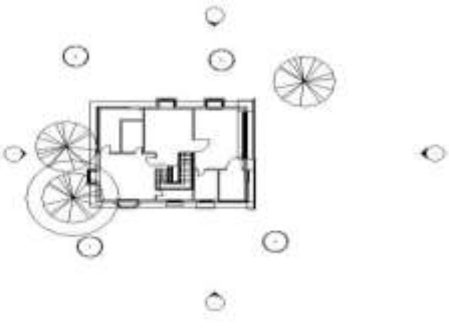

Figure 3: Plan of First Floor

Exporting the file from Revit to ArchiCAD through the IFC File

To export a Revit file of a G+1 residential duplex building into ArchiCAD through the IFC file format, apply these procedures:

Open Your Revit Model: Open Autodesk Revit and double-click to open the model of the G+1 residential duplex building that you intend to export.

1. Export to IFC:

Through the File menu, click.

Select Export, then IFC

In the export options, select IFC Design Transfer View for improved compatibility.

Save your IFC file to a location and click on Export. The time taken would depend on how complex your model is

2. Preparing ArchiCAD

Open ArchiCAD: After opening ArchiCAD, you will first be able to open a new project or one that you already have where you will import the Revit model.

3. Importing IFC File to ArchiCAD Import IFC File:

In ArchiCAD, open the File menu

Select Open and then open your exported IFC file.

Alternatively, you can also drag and drop the IFC file directly into the ArchiCAD workspace Adjust Import Settings: If required, adjust any import settings so elements are imported correctly. This may include selecting specific translators for better fidelity within the import process27.

4. Managing Imported Elements

Check Visibility of Layers: After import, you'll likely need to set some layer visibility so that you can clearly see all imported elements. Make a new layer combination that will be helpful for organizing and visibility management of your IFC elements.

Review Imported Model: Check imported model to ensure accuracy, and verify details that walls, windows, doors, and other elements transferred correctly. Some tweaking may be required since not all elements import perfectly because software varies

5. Final Adjustments and Editing

Edit Imported Elements: You can make edits to the imported elements whenever you want in ArchiCAD. But do take note that certain complex geometries or specific details need manual adjustment or even re-modelling in Archicad5.

Thermal Analysis Process in ArchiCAD

Although ArchiCAD and Revit are different BIM software, the overall process of performing thermal analysis with a BIM model can be applied to both. Here is a step-by-step simplified process for doing thermal analysis in ArchiCAD.

1. Model Preparation

Check for Completeness: Verify that the model contains all the necessary elements such as walls, windows, roofs, and interior spaces.

Material Properties: Input thermal properties on building materials, either by using ArchiCAD's library or with custom definitions.

Zone Definition: The building can be defined into different thermal zones. The organization of the building into thermal zones allows for targeted analysis.

2. Eco Designer Module

Basic Analysis: The preliminary assessments are done using the Eco Designer in ArchiCAD.

Location & Orientation: Input the geographical location and orientation of the building.

Energy Performance: Basic thermal simulation to estimate heating and cooling loads.

3. Export for Detailed Analysis (Recommended)

Export Options: export the BIM model to thermal simulation software such as IESVE or Energy Plus IFC Format: This will be IFC format, because of its property of compatibility with any other kinds of simulation tools.

4. Detailed Thermal Simulation (External Software)

Import BIM Model: load the exported IFC file into the selected simulation software

Advanced Settings: set detailed parameters including occupancy schedules and HVAC systems.

Weather Data: Obtain relevant weather data for accurate simulation runs.

Simulation Run: Performed the thermal simulation to simulate heat transfer through the building.

5. Analysis and Optimization

Results Analysis: Analyse simulation results to identify any heat gain/loss and thermal discomfort areas.

Visualization: Employ visualization tools, which include temperature gradient maps as well as energy consumption maps, for better comprehension.

Design Optimization: Use findings from analysis to modify corresponding design elements, like providing appropriate insulation, types of windows, etc.

Re-run Simulation: Verify the design changes using re-run simulation

6. Reporting and Communication

Reports: Produce an intricate report that documents thermal performance findings

Visualisation: Utilize graphical outputs from simulations to present results meaningfully to stakeholders

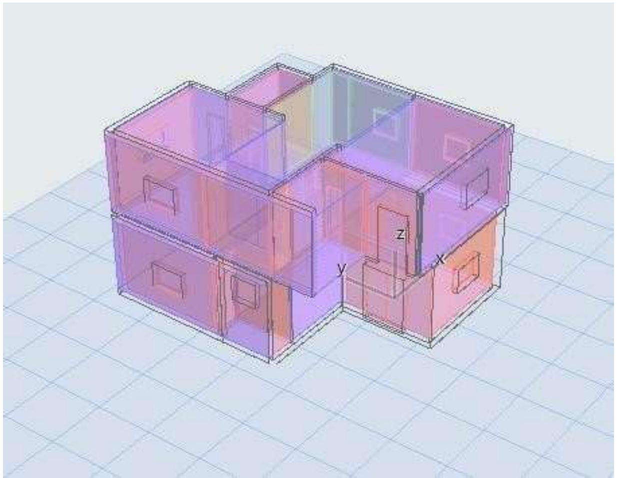

Figure 5: Model in Archi CAD

Thermal Blocks

Thermal Block	Zones Assigned	Operation Profile	Gross Floor Area m²	Volume m³
001 Bathroom	4	Residential	16.23	36.91
002 Bedroom	3	Residential	50.94	131.52
003 Kitchen	1	Kitchen (preparati...	12.30	31.67
004 Living room	2	Residential	49.59	131.65
005 Storage Room	1	Storeroom	5.05	11.50
Total:	**11**		**134.11**	**343.23**

Figure 6: No of zones assigned, gross floor area, and volume of each thermal block.

Results and Discussion

Energy Balance: Eco Designer typically presents an energy balance report that summarizes the building's annual heating and cooling loads. This indicates the amount of energy required to maintain comfortable temperatures within the building throughout the year.

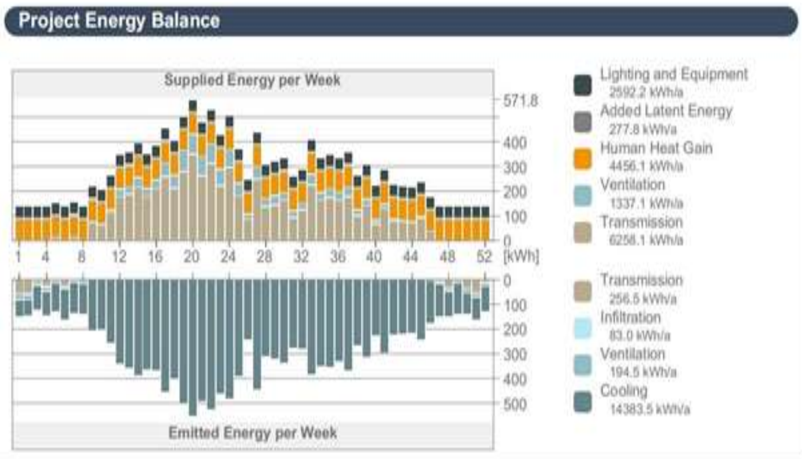

Figure 7: Project energy balance before changing the orientation and building components

Emitted Energy per Week

Category	Annual Energy (kWh/a)
Transmission	256.5 kWh/a
Infiltration	83.0 kWh/a
Ventilation	194.5 kWh/a
Cooling	14,383.5 kWh/a

Supplied energy per Week

Category	Annual Energy (kW h/a)
` Lighting and Equipment	2592.2 kWh/a
Added Latent Energy	277.8 kWh/a
Human Heat Gain	4456.1 kWh/a
Ventilation	1337.1 kWh/a
Transmission	6258.1 kWh/a

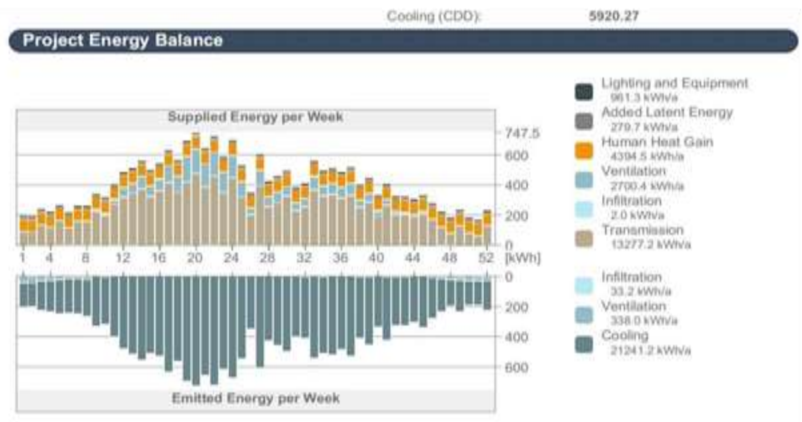

Figure 8: Project energy balance after changing the orientation and building components

Supplied Energy per Week

Category	**Annual Energy (kWh/a)**
Lighting and Equipment	961.3 kWh/a
Added Latent Energy	279.7 kWh/a
Human Heat Gain	4394.5 kWh/a
Ventilation	2700.4 kWh/a
Infiltration	2.0 kWh/a
Transmission	13,277.2 kWh/a

Emitted energy per week

Category	**Annual Energy (kWh/a)**
Infiltration	33.2 kWh/a
Ventilation	338.0 kWh/a
Cooling	21,241.2 kWh/a

Heating & Cooling Demands: Analyse the heating and cooling demands throughout the year. This will highlight peak periods when the building requires the most energy for heating or cooling

HVAC Design Data

Thermal Block	Heating Demand Yearly [kWh]	Heating Demand Hourly Peak [kW]	Cooling Demand Yearly [kWh]	Cooling Demand Hourly Peak [kW]	Internal Temperature Min. [°C]	Internal Temperature Max. [°C]
001 Bathroom	0	0.0 --	0	0.0 --	18.0 03:00 Jan. 11	42.6 12:00 May. 22
002 Bedroom	0	0.0 --	8254	3.7 13:00 May. 22	20.3 04:00 Jan. 11	32.4 06:00 May. 16
003 Kitchen	0	0.0 --	0	0.0 --	19.5 04:00 Jan. 15	38.0 14:00 May. 22
004 Living room	0	0.0 --	6129	3.3 10:00 May. 22	18.8 02:00 Jan. 14	35.8 06:00 May. 21
005 Storage Room	0	0.0 --	0	0.0 --	16.2 02:00 Jan. 14	40.6 10:00 May. 22
All Thermal Blocks:	**0**	**0.0** **--**	**14383**	**6.7** **11:00 May. 22**		

Figure 9: Heating and Cooling Demand before changing the orientation and building components

Term	**Description**
Thermal Block	Distinct areas within a building assessed for heating and cooling needs (e.g., Bathroom, Bedroom, Kitchen).
Heating Demand	Represents energy required for heating each thermal block:
- **Yearly [kWh]**	Total heating energy needed over a year, measured in kilowatt-hours (kWh).
- **Hourly Peak [kW]**	Maximum heating demand at any hour, measured in kilowatts (kW).
Cooling Demand	Indicates energy required for cooling each thermal block:
- **Yearly [kWh]**	Total cooling energy needed over a year, also measured in kilowatt-hours (kWh).
- **Hourly Peak [kW]**	Maximum cooling demand at any specific hour, measured in kilowatts (kW).
Internal Temperature	Temperature range within each thermal block, important for comfort levels:
- **Min. [°C]**	Minimum internal temperature recorded during the specified period.
- **Max. [°C]**	Maximum internal temperature recorded during that same period.

All Thermal Blocks	Summarizes total heating and cooling demands across all thermal blocks, providing an overall energy requirements view.

Breakdown of Data:

- **001 Bathroom**:
- Heating Demand: 0 kWh yearly, 0 kW peak.
- Cooling Demand: 0 kWh yearly, 0 kW peak.
- Internal Temp: Min. 18.0°C, Max. 42.6°C.
- **002 Bedroom**:
- Heating Demand: 0 kWh yearly, 0 kW peak.
- Cooling Demand: 8254 kWh yearly, 3.7 kW peak.
- Internal Temp: Min. 20.3°C, Max. 32.4°C.
- **003 Kitchen**:
- Heating Demand: 0 kWh yearly, 0 kW peak.
- Cooling Demand: 0 kWh yearly, 0 kW peak.
- Internal Temp: Min. 19.5°C, Max. 38.0°C.
- **004 Living Room**:
- Heating Demand: 0 kWh yearly, 0 kW peak.
- Cooling Demand: 6129 kWh yearly, 0 kW peak.
- Internal Temp: Min. 18.8°C, Max. 35.8°C.
- **005 Storage Room**:
- Heating Demand: 0 kWh yearly, 0 kW peak.
- Cooling Demand: 0 kWh yearly, 0 kW peak.
- Internal Temp: Min. 16.2°C, Max. 40.6°C.
- **Totals**:
- All Thermal Blocks:
- Heating: 0 kWh yearly, 0 kW peak.
- Cooling: 14383 kWh yearly, 11.0 kW peak.

HVAC Design Data

Thermal Block	Heating Demand Yearly [kWh]	Heating Demand Hourly Peak [kW]	Cooling Demand Yearly [kWh]	Cooling Demand Hourly Peak [kW]	Internal Temperature Min. [°C]	Internal Temperature Max. [°C]
001 Bed room	0	0.0 --	8342	4.3 10:00 May. 22	17.8 02:00 Jan. 14	36.6 06:00 May. 21
001 Bathroom	0	0.0 --	0	0.0 --	18.6 03:00 Jan. 11	41.4 12:00 May. 22
002 Kitchenette	0	0.0 --	0	0.0 --	17.5 02:00 Jan. 11	37.2 11:00 May. 22
003 Living Room	0	0.0 --	12898	6.5 10:00 May. 22	18.7 02:00 Jan. 11	34.5 06:00 May. 21
004 Storage Room	0	0.0 --	0	0.0 --	16.5 02:00 Jan. 14	42.4 12:00 May. 22
All Thermal Blocks:	**0**	**0.0 --**	**21241**	**10.8 10:00 May. 22**		

Figure 10: Heating and Cooling Demand after changing the orientation and building components

Term	Description
Thermal Block	Distinct areas or rooms in the building assessed for heating and cooling needs (e.g., Bed Room, Bathroom).
Heating Demand	Represents the energy required for heating each thermal block, divided into:
- Yearly [kWh]	Total heating energy needed over the entire year, measured in kilowatt-hours (kWh).
- Hourly Peak [kW]	Maximum heating demand at any given hour, measured in kilowatts (kW).
Cooling Demand	Indicates the energy required for cooling each thermal block, divided into:
- Yearly [kWh]	Total cooling energy needed over the entire year, also measured in kilowatt-hours (kWh).
- Hourly Peak [kW]	Maximum cooling demand at any specific hour, measured in kilowatts (kW).
Internal Temperature	Temperature range within each thermal block, important for assessing comfort levels:
- Min. [°C]	Minimum internal temperature recorded for the block during the specified period.
- Max. [°C]	The maximum internal temperature recorded for the block during that same period.
All Thermal Blocks	Summarizes total heating and cooling demands across all listed thermal blocks, providing an overall view of requirements.

Details:

1. **001 Bed Room** o Heating Demand:
   - Yearly: 0 kWh (no heating needed).
   - Peak: 0.0 kW (no peak heating demand).

o Cooling Demand:
   - Yearly: 8342 kWh (total cooling energy required over the year).
   - Peak: 4.3 kW (maximum cooling demand in a specific hour).

o Internal Temperature:
   - Min: 17.8°C (lowest recorded temperature).
   - Max: 36.6°C (highest recorded temperature).

2. **001 Bathroom** o Heating Demand:
   - Yearly: 0 kWh (no heating needed).
   - Peak: 0.0 kW (no peak heating demand).

   o Cooling Demand:
   - Yearly: 0 kWh (no cooling needed).
   - Peak: 0.0 kW (no peak cooling demand).

   o Internal Temperature:
   - Min: 18.6°C (lowest recorded temperature).
   - Max: 41.4°C (highest recorded temperature).

3. **002 Kitchenette** o Heating Demand:
    - Yearly: 0 kWh (no heating needed).
    - Peak: 0.0 kW (no peak heating demand).
  - Cooling Demand:
    - Yearly: 0 kWh (no cooling needed).
    - Peak: 0.0 kW (no peak cooling demand).
  - Internal Temperature:
    - Min: 17.5°C (lowest recorded temperature).
    - Max: 37.2°C (highest recorded temperature).
4. **003 Living Room** o Heating Demand:
    - Yearly: 0 kWh (no heating needed).
    - Peak: 0.0 kW (no peak heating demand).
  - Cooling Demand:
    - Yearly: 12898 kWh (substantial cooling energy required).
    - Peak: 6.5 kW (maximum cooling demand in a specific hour).
  - Internal Temperature:
    - Min: 18.7°C (lowest recorded temperature).
    - Max: 34.5°C (highest recorded temperature).

5. 004 Storage Room

  - Heating Demand:
    - Yearly: 0 kWh (no heating needed).
    - Peak: 0.0 kW (no peak heating demand).
  - Cooling Demand:
    - Yearly: 0 kWh (no cooling needed).
    - Peak: 0.0 kW (no peak cooling demand).
  - Internal Temperature:
    - Min: 16.5°C (lowest recorded temperature).
    - Max: 42.4°C (highest recorded temperature).

6. All Thermal Blocks o Heating Demand:
    - Yearly: 0 kWh (no heating needed for any block).
    - Peak: 0.0 kW (no peak heating demand for any block).
  - Cooling Demand:
    - Total Yearly: 21241 kWh (total cooling required across all blocks).
    - Peak: 10.8 kW (highest cooling demand in a specific hour).

Temperature Analysis:

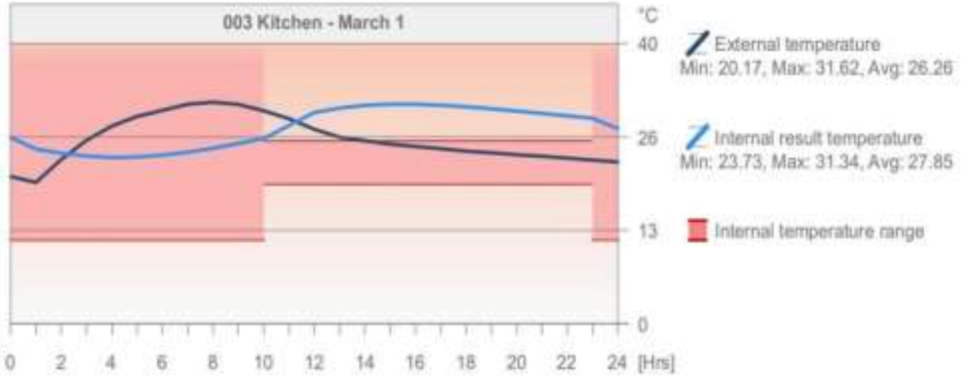

Figure 11: Temperature analysis before changing the orientation and materials

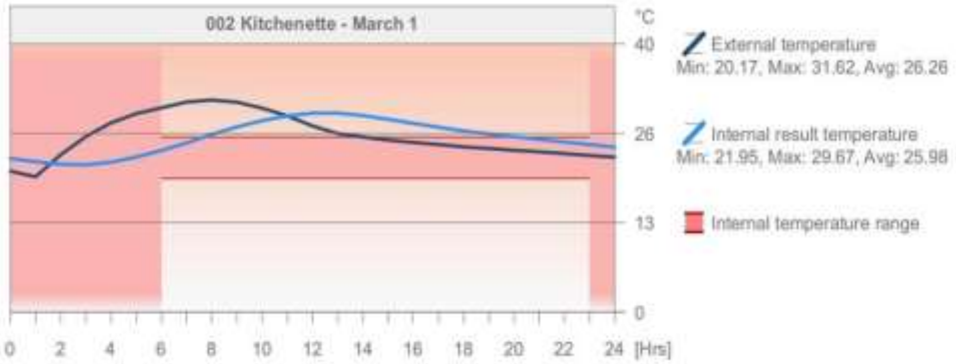

Figure 12: Temperature analysis after changing the orientation and material

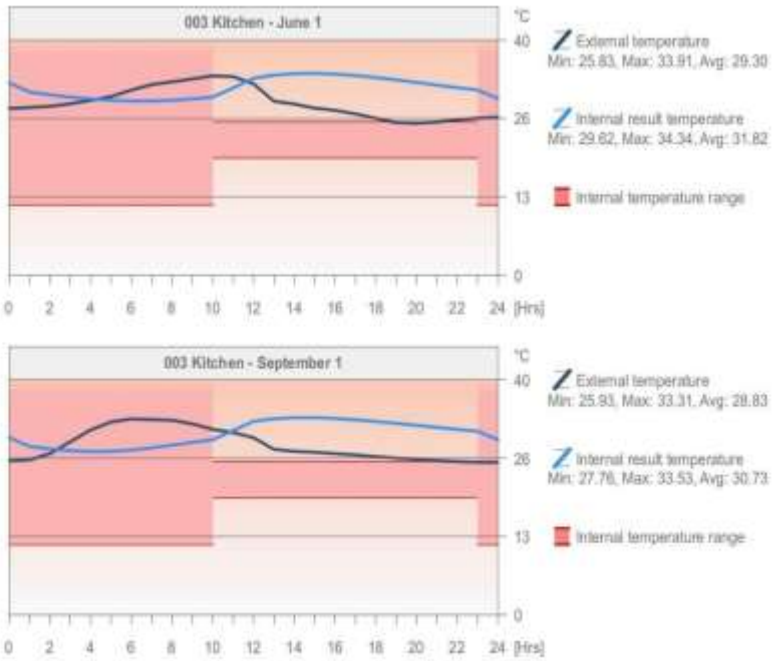

Figure 13: Temperature analysis before changing the orientation and materials

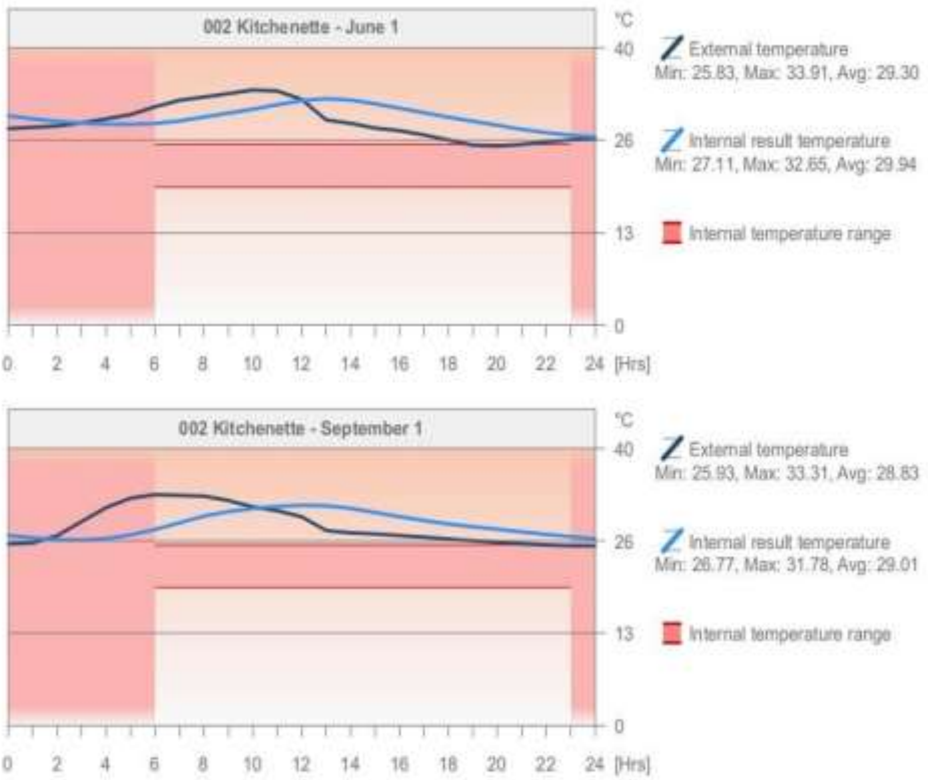

Figure 14: Temperature analysis after changing the orientation and materials

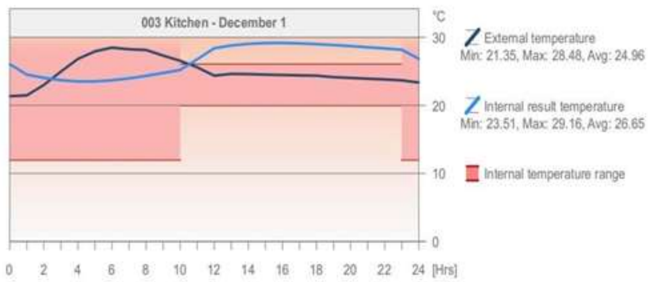

Figure 15: Temperature analysis before changing the orientation and materials

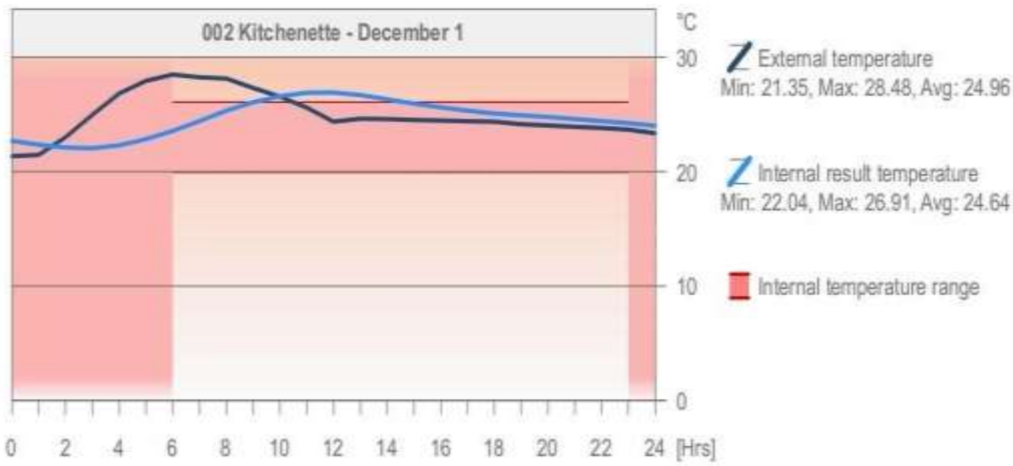

Figure 16: Temperature analysis after changing the orientation and material

Key Values of the Comparison

Key Values

General Project Data			Heat Transfer Coefficients	U value	[W/m²K]
Project Name:	Project Number		Building Shell Average:	4.54	
City Location:	London		Floors:	–	
Latitude:	17° 44' 53" N		External:	4.11 - 20.12	
Longitude:	83° 13' 7" E		Underground:	–	
Altitude:	0.00	m	Openings:	2.11 - 2.11	
Climate Data Source:	Strusoft server				
Evaluation Date:	14-11-2024 22:16		**Specific Annual Values**		
			Net Heating Energy:	0.00	kWh/m²a
Building Geometry Data			Net Cooling Energy:	115.16	kWh/m²a
Gross Floor Area:	134.11	m²	Total Net Energy:	115.16	kWh/m²a
Treated Floor Area:	124.90	m²	Energy Consumption:	136.82	kWh/m²a
External Envelope Area:	144.32	m²	Fuel Consumption:	136.82	kWh/m²a
Ventilated Volume:	343.23	m³	Primary Energy:	64.98	kWh/m²a
Glazing Ratio:	0	%	Fuel Cost:	–	GBP/m²a
			CO_2 Emission:	4.68	kg/m²a
Building Shell Performance Data					
Infiltration at 50Pa:	1.65	ACH	**Degree Days**		
			Heating (HDD):	37.63	
			Cooling (CDD):	5920.27	

Figure 17: Key Values of the project before changing the orientation and building materials

Key Values

General Project Data			Heat Transfer Coefficients	U value	[W/m²K]
Project Name:	Project Number		Building Shell Average:	4.03	
City Location:	London		Floors:	–	
Latitude:	17° 44' 53" N		External:	0.05 - 20.12	
Longitude:	83° 13' 7" E		Underground:	–	
Altitude:	0.00	m	Openings:	2.11 - 2.11	
Climate Data Source:	Strusoft server				
Evaluation Date:	14-11-2024 21:40		**Specific Annual Values**		
			Net Heating Energy:	0.00	kWh/m²a
Building Geometry Data			Net Cooling Energy:	169.37	kWh/m²a
Gross Floor Area:	134.78	m²	Total Net Energy:	169.37	kWh/m²a
Treated Floor Area:	125.41	m²	Energy Consumption:	177.04	kWh/m²a
External Envelope Area:	153.14	m²	Fuel Consumption:	177.04	kWh/m²a
Ventilated Volume:	344.63	m³	Primary Energy:	23.00	kWh/m²a
Glazing Ratio:	0	%	Fuel Cost:	–	BWP/m²a
			CO_2 Emission:	1.66	kg/m²a
Building Shell Performance Data					
Infiltration at 50Pa:	1.75	ACH	**Degree Days**		
			Heating (HDD):	37.63	
			Cooling (CDD):	5920.27	

Figure 18: Key Values of the project after changing the orientation and building materials

Conclusions:

The study on the thermal performance of a G+1 residential building in Visakhapatnam highlights strategic design modification and material selection for improved energy efficiency and enhanced thermal comfort in the indoor environment. Using Revit to create 3D models and perform thermal performance analysis, the building's behaviour at various orientations and material properties is determined. A comparison of U-values was made, and results showed that material property changes such as replacing the single-glazed glass with triple-glazed glass and changing flooring materials did improve significantly the building's insulation performance. Adjusting the orientation of the building further optimized the gains and losses of solar heat, thus further reducing the energy requirements in cooling and heating.

The results underpin the fact that with a high-performance material combination and proper orientation, heat transmission through the building envelope can be minimised, especially in the warmer and more humid climate of Visakhapatnam. Lower U-values resulted in improving thermal efficiency by reducing reliance on artificial heating or cooling systems. This indicates that passive design strategies may be aligned with the requirements for sustainable building by either lowering energy consumption or operational costs.

In conclusion, this research approves the notion that small but critical design interventions, such as optimal orientation and energy-efficient materials, can produce large improvements in thermal performance. This encourages to explore of integrated advance simulation tools like Revit in early design stages to test for and implement solutions while on their pathway to create energy-efficient residential buildings for a specific climatic condition. Not only does this help occupants enjoy greater thermal comfort but also supports wider environmental objectives through the effective reduction of residential developments' carbon footprint.

References:

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