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Climatic Effect on Building Facade, an approach to Sustainable Facade design of neighborhood row housing in Kathmandu Valley

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Abstract

Extreme weather events predicted as a result of air pollution have a significant impact on the materials, systems/components, and features used on building facades. The material surfaces of the facade will corrode due to changes in temperature and precipitation. Excessive amounts of rain, especially rain driven by the wind, will exacerbate surface erosion and facilitate moisture penetration and bio deterioration, resulting in a worsening of the building's hydrothermal performance. The rate of degradation of many materials used in building facade systems accelerates as ultraviolet (UV) radiation levels rise. Buildings presently account for more than 40 percent of global energy and one-third of global carbon emissions (Architecture 2030).The paper's major objective is to determine how climate and building facade interact, as well as to examine methods and approaches for building facade sustainability. Similarly Critical facade building materials, systems, components, and features that are vulnerable to accelerated deterioration due to extreme weather events are identified and classified. As a result of the impacts of climate and air pollution on different regions and activities, whether natural or social, it has become a serious concern.

Various aspects such as orientation, material type and durability are very important when designing a building facade, and they have a direct impact on the building's durability and efficiency. The sustainability approach to neighborhood row housing for living standards is the focus of this paper.

Keywords

Climate, building facade, sustainability, neighborhood row housing, building orientation, building materials

1. Introduction

One of the primary motivations for reducing energy use and, consequently, carbon emissions from the construction industry is bioclimatic or climate-responsive building design [1]. Although buildings in developing countries like Nepal are not as energy-intensive as those in developed countries, growing thermal comfort needs and changing lifestyles, as well as population expansion and rapid urbanization, will increase energy demand in the construction industry.

Climate change is accelerating fast, and human activities are the major cause, according to a growing body of scientific evidence [1]. The evident urgency of decreasing greenhouse gas emissions has now transcended other important social and economic imperatives, driving lawmakers and legislators as well.

As influencing developers, architects, and urban designers. Consumer behavior and purchase decisions are influenced by public knowledge, which is higher than it has ever been. Structures can be harmed by air pollution. It has become a major problem as a result of the effects of climate and air pollution on many locations and activities, whether natural or societal [2]. Because climate change has affected the buildings, the major focus of this research will be on the effects of climate change on building façades, as the building envelop is what protects the people who reside within. When choosing a building façade, take into account not only the site location, the energy crisis, and the cost, but also the climatic changes that may or have already occurred [3].

This research will concentrate on a long-term strategy for preserving living standards in neighborhood row housing. Because sustainability is such a vast topic, the study will focus on building sustainability in terms of thermal comfort, cost efficiency, and long-term durability.

Main objective of this research is to learn how climate and building facade interact, as well as to examine methods and procedures for building facade sustainability. Secondary objectives of the study is the identification and classification of critical facade building materials/ features that are sensitive to accelerated deterioration due to extreme weather events, simulation of weather conditions which affect the service life and performance of facade materials /features and to study the physical intervention in building facade by orienting the building in different directions.

2. Literature Review

2.1 Climate and Design

One of the primary motivations for reducing energy use and, consequently, carbon emissions from the construction industry is bioclimatic or climate-responsive. Despite the fact that buildings in developing countries like Nepal are not yet as energy-intensive as those in developed countries, growing thermal comfort expectations and changing lifestyles, as well as population expansion and rapid urbanization, will drive increased energy demand in the construction sector. Buildings with low energy consumption are only attainable if local climatic conditions are considered early in the design process.

Nepal has failed to adopt bioclimatic zoning or set any building energy saving standards. The National Building Code focuses on structural and earthquake-resistant design [4]. The lack of a climate categorization for the building construction industry has been recognized as a key weakness in Nepal's efforts to improve building energy efficiency. As a result, a study of Nepal's climate was performed with the goal of developing a bioclimatic zoning for Nepal. Climate data, which is the study's most significant input, must be properly picked.

2.1.1 Factors Affecting Climate

Climate is categorized by the factors known as climatic factors which directly or indirectly affect the climatic condition of a place. They are:

- Solar radiation
- Ambient temperature
- Air humidity
- Precipitation
- Wind
- Sky condition

2.1.2 Building Facade

A building's facade refers to one of building envelop, generally the front one. It is an important part of a building's overall design. It allows for the development of a building's identity and character.

Although facades are frequently linked with older and more famous structures, any structure may generate a recognizable exterior. The alteration of the facade of many listed buildings and structures in conservation zones may be restricted. This illustrates their significance not only to the structure, but also to the surrounding communities and ecosystems [4].

A building facade is significant because it provides an opportunity to emphasize design. Too many structures go for conventional designs that satisfy structural requirements but lack personality. This has a negative impact on the places we inhabit, as each structure lacks anything unique. A building facade serves as a link between the external and internal architecture of a structure, as well as being visually attractive. A building facade may unleash a plethora of options for structures thanks to new developments in materials, concepts, and design [5].

Building facades are becoming increasingly important as we expect more from the structures in which we live and work, whether it's in terms of energy efficiency or how well they sit in a given area. A building's façade, sometimes known as a curtain wall, has a significant influence on how air and light flow through it, as well as how it responds to external circumstances. Buildings facades are generally of three types i.e. the cladding, glazing and vertical/horizontal bands.

2.2 Climate responsive design methods for high performance facade

High-performance sustainable facades are outside enclosures that use the least amount of energy to generate a comfortable interior environment that promotes the health and productivity of the building's occupants [6]. This implies that sustainable facades are more than just barriers between the inside and outside of a building; they also help to minimize energy usage. During the design of high-performance building enclosures, climate-specific requirements must be addressed [7]. The strategies that work well in hot, dry climates differ from those that work best in temperate or hot, humid climates. The facade, more than any other system, has the greatest impact on a building's energy budget and occupant comfort. In order to provide occupants with a comfortable environment, a facade must provide views to the outside, resist wind loads, support its own dead-load weight, allow daylight into interior spaces, block unwanted solar heat gain, shield occupants from outside noise and temperature extremes, and resist air and water penetration, among other things [6]. The following are some of the most basic approaches for creating high-performance building facades:

- Orienting and developing the building's geometry and massing to adapt to solar position
- Controlling cooling loads and improving thermal comfort by providing sun shading
- To improve air quality and minimize cooling loads, natural ventilation is used.
- Optimizing external wall insulation and the utilization of natural illumination to reduce the amount of energy required for artificial lighting and mechanical cooling and heating.

Table 1: Facade design strategies for different climate types

Climate type	Design strategies for sustainable facades
Heating-dominated climates	• **Solar collection and passive heating:** collection of solar heat through the building envelope • **Heat storage:** storage of heat in the mass of the walls • **Heat conservation:** preservation of heat within the building through improved insulation • **Daylight:** use of natural light sources and increased glazed areas of the facade, use of high-performance glass, and use of light shelves to redirect light into interior spaces
Cooling-dominated climates	• **Solar control:** protection of the facade from direct solar radiation through self-shading methods (building form) or shading devices • **Reduction of external heat gains:** protection from solar heat gain by infiltration (by using well-insulated opaque facade elements) or conduction (by using shading devices) • **Cooling:** use of natural ventilation where environmental characteristics and building function permit • **Daylight:** use of natural light sources while minimizing solar heat gain through use of shading devices and light shelves
Mixed climates	• **Solar control:** protection of facade from direct solar radiation (shading) during warm seasons • **Solar collection and passive heating:** solar collection during cold seasons • **Daylight:** use of natural light sources and increased glazed areas of the facade with shading devices

The fundamental techniques for various climatic types are shown in Table 1. Solar radiation collection, passive heating, heat storage, better insulation to minimize heating demand, and the utilization of day lighting to reduce lighting demand all benefit heating-dominated climates [7]. Protection from the sun and direct solar radiation becomes increasingly necessary in cooling climes. Combination methods that balance sun exposure and daylight availability must be adopted in mixed climates [8].

2.3 Characteristics and properties of sustainable facades

- Allowing daylight into a building
- Preventing unwanted solar heat entering the building
- Storing heat within the mass of the wall
- Preventing air or moisture from passing through the facade
- Allowing natural ventilation to cool the building's interior.

2.4 Building sustainability

Sustainability is a wide word that refers to a building's overall capacity to offer a comfortable, healthy, and productive environment throughout time while minimizing negative environmental impacts. Sustainable buildings consider the three pillars of sustainability: planet, people, and profit, in addition to the environment [9]. Sustainable design aims to reduce, or completely avoid, the depletion of critical resources such as energy, water, land, and raw materials; prevent environmental degradation caused by facilities and infrastructure throughout their life cycle; and create liveable, comfortable, safe, and productive built environments.

Buildings consume resources (such as electricity, water, and raw materials), produce waste (from occupants, construction, and demolition), release potentially hazardous air pollutants, and fundamentally alter the function of land, including its ability to absorb and trap water into the earth. Building owners, designers, and builders all confront unique problems in meeting demand for accessible, safe, healthy, and productive new and refurbished facilities while avoiding negative consequences on society, the environment, and the economy [10].

2.5 Modern Architecture responding to climate

Climate and environmental factors have a significant role in building design. Ancient builders made the most of limited resources to attain optimum comfort, and environment was a key factor in traditional construction methods [10]. Heating and cooling in buildings has grown easier for modern structures as building technology have advanced, and there is less worry for temperature and environment in maintaining comfortable inside conditions. In the Kathmandu Valley, modern structures also follow the international standard style of construction, with minimal regard for the local climate [11]. In the previous two or three decades, building construction processes have evolved dramatically.

2.6 Strategies for climate responsive modern buildings

Seasonality, the direction of the sun (sun path and solar position), natural shade offered by the surrounding terrain, environmental elements (such as wind, rainfall, and humidity), and climatic data are all taken into account when designing energy-efficient dwellings (temperature, historical weather patterns, etc) [10].

Perform a Site Analysis

- Layout the Building on the Site
- Plan with the Sun in Mind
- Window Considerations
- Building for Geographic Area
- Minimize the Building Footprint
- Design for Natural Ventilation
- Relax the Occupants Comfort Standards
- Conduct Modelling and Analysis

2.7 Housing

Housing is a social unit that is organized around a neighborhood or community. In general, it is the design and construction of a residential unit that allows people to live in a pleasant, quiet, and healthy environment with social, cultural, and recreational amenities [12]. The following are important factors to consider while planning a residential unit [12]:

- Houses should be designed in different types and with pleasing elevation.
- They should be planned in harmony with the surroundings like lake, streams, greeneries etc
- Houses should be properly oriented to get advantages of sun, wind and topography.
- Density of population should be in accordance with the standards specified by the authority.
- Houses for different income group should be grouped together to build the spirit of neighborhood.

3. Research methodology

This study employed both qualitative and quantitative methodologies, as well as a mix of primary and secondary sources, to fulfill the main research objectives. The quantitative data analysis and outcomes are supported by qualitative data. Because qualitative and quantitative data kinds are used in the data analysis, the result achieved will be triangulated. Various building materials, case study, climate and building design data's are analyzed which is then followed by the simulation (Ecotect) where the intervention in façade material and the building orientation is done and analyzed for further evaluation.

4. Case Study

For the Kathmandu valley, a case study and analysis of a neighborhood row housing construction is used. Because the research is limited to the Kathmandu valley, this topic will begin with a brief discussion of the climatic conditions in the valley, followed by a description of the building, materials utilized, and simulations for various building scenarios.

Sun Rise Home is a private housing project (targeting high and upper middle class economic groups) in Lalitpur Sub Metropolitan City's ward no. 9's periphery region. Manjushree tole is located in Ward 21 of the KMC, in the historic center region. It is a significant Malla-period residential hamlet with various historical monuments and cultural treasures.

Parameter	SRH
Location	Balkumari – LSMC, ward no. 9 (peripheral area)
Project type	Private housing
Planning area	45 ropani (2.3 ha)
Development period	2002–
Development agency	Private sector

Parameter	SRH
Total developed area	45 ropani (2.3 ha) (1 × SRH)
Total number of urban blocks	9
Average urban block size	5 ropani (1 × SRH)
Total number of plots	164 units (1 × SRH)
Plot numbers per urban block	18
Population density	356 persons/ha (2.5 × GLP)
Urban block orientation	North-south (mainly)

Parameter	SRH
Layout on plot	Row housing type
Orientation	Mostly on a north-south axis
Access	Vehicular (private street)
Type	Mostly attached in row
Stories	2–3
Light & ventilation	Only two sides

Parameter	SRH
Area allocated for open space (%)	4
Area occupied by street (%)	15.0
Street width (m)[7]	5
Number of street junctions	7
Street width to building height ratio (approx.)	1:2

Source: Department of Housing and Urban Development (no date); Department of Urban Development and Building Construction (2003); Kathmandu Metropolitan City (2001); Oriental Construction and Development (no date).

Figure 1: Physical parameters for sunrise homes

The climatically inefficient residential units in Sunrise homes, which are generally two to three storeys high and situated on a north-south axis, have just one side window, leaving numerous places (dining room, living room, or stairway) without direct light and ventilation. Both the practice of upgrading historic buildings (adding a reinforced concrete floor on top of old mud and wood constructions, and haphazardly creating door and window openings on the load-bearing outer wall.

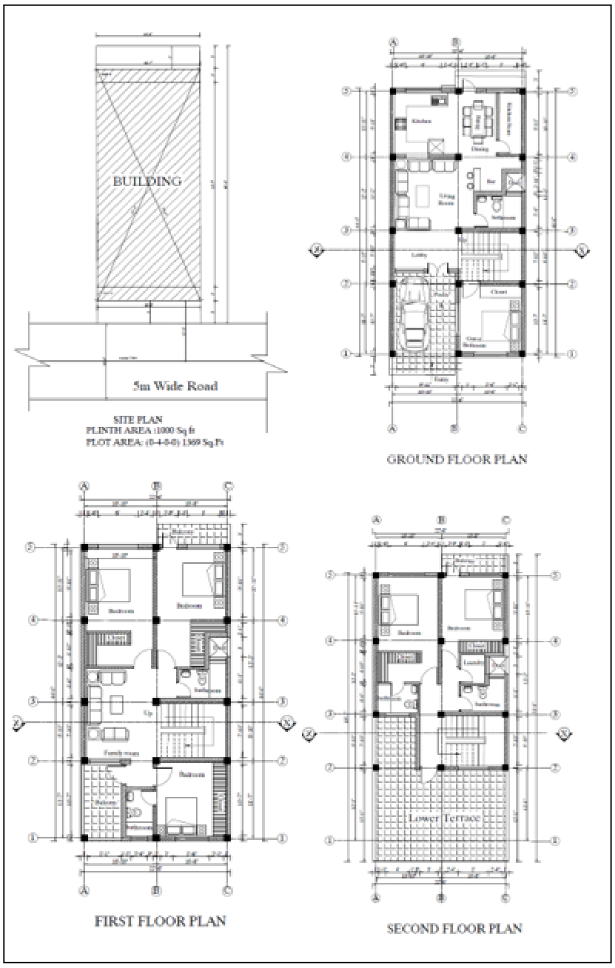

Figure 2: Architectural drawings

4.1 Thermal performance

The materials and technique used in most residential buildings are quite similar, regardless of whether they are erected informally or formally. They are often constructed with a complete brick wall (230 mm) or a partial brick wall (110 mm) with 10 to 12 mm plaster on both sides and only one side. The roofs are made of 100 mm reinforced concrete with a 50 mm floor finish and a 12 to 15 mm cement plaster finish. Thermal management is not achieved by the use of insulation or a false ceiling. Ordinary 5 mm glass windows with wooden or metal frames are used for the apertures. In Kathmandu, double glazing is not common.

According to Shrestha, the U-value for these walls is 1.903 W/m2°C, while the U-value for the roofs is 3.069 W/m2°C, both of which are greater above the minimum requirements for Kathmandu structures (Shrestha, 2009). The time lag for walls is 6 hours and for roofs is 3.7 hours, both of which are insufficient to maintain the building's thermal comfort. The U-value for windows with a single glass of 6mm thickness and a 10 percent wooden frame would be 5.3 W/m2°C [13].

Building Component	Materials	Thickness[mm]	U-value [W/m² °C]
External Walls	Brick	230	2.19
Internal walls	Brick	100	2.19
Roof	Concrete	100	2.80
Ground floor	Screed on brick solids	150	4.17
First floor	Concrete	100	2.80
Windows	Single-clear	25	5.38
Doors	Single-panel	35	2.00

Figure 3: U-values of building components (Susanne Bodach, 2016

4.2 Climate of Kathmandu

The Kathmandu Valley is situated at a height of roughly 1340 meters above sea level, between 27°36' and 27°50' north latitude and 85°7' to 85°37' east longitude.

The average monthly maximum temperature in the Kathmandu Valley is 29.30°C, with a monthly minimum of 0.90°C. The Valley's yearly mean temperature is about 16.50°C. The diurnal temperature range is 10.90°C on average. Relative humidity is high during the day, although it drops during the day, ranging from 36 to 100 percent and being highly dependent on ambient temperature, with the greatest humidity levels usually occurring around dawn (climate-data.org). The yearly rainfall averages approximately 1300 mm. During the months of March through September, severe downpours are common, owing to seasonal monsoon winds. The Valley's predominant wind pattern is westerly, with an average wind speed of 0.6 m/s (climate-data.org). The average number of hours of sunlight is 6.3, ranging from 3.3 to 8.4 hours (HMG, Department of Meteorology). Because to the monsoon rains, the month of July has the least number of hours of sunlight.

From October to May, the Kathmandu Valley receives an average of more than 6 hours of sunlight each day, which is ideal for passive solar heating during the cooler months. In the Valley, the average annual global sun radiation is about 1510 kWh/m2, with a daily average of 4.13 kWh/m2 (climate-data.org).

5. Results and Discussion

Simulation of the reference house is done with Ecotect where it is divided in two categories where analysis 1 is done by intervention in orientation of building i.e. the building façade is rotated in each direction creating four scenarios to analyze the maximum efficiency of the building.

Similarly in analysis 2 the intervention is building materials for façade is changed with three scenarios where scenario 1 is with brick plaster, scenario 2 is with stone cladding and scenario 3 is with timber cladding.

5.1 Analysis 1

This analysis is based on the orientation of the building façade where intervention in orientation of the building is done. Four scenarios are taken, in scenario 1 i.e. base case scenario the building is oriented towards south then in scenario 2 the building is oriented towards east followed by scenario 3 towards north and scenario 4 towards west.

Max Heating: 21.5 KW At 06:00 On 3rd January Max Cooling: 17.7 KW At 10:00 On 14th June Total Heating 70.1 Kwh Per M2 Total Cooling: 34.7 Kwh Per M2 Total Load: 104.8 Kwh Per M2

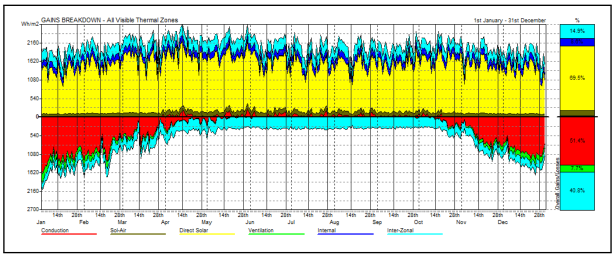

Figure 4: monthly heating cooling loads

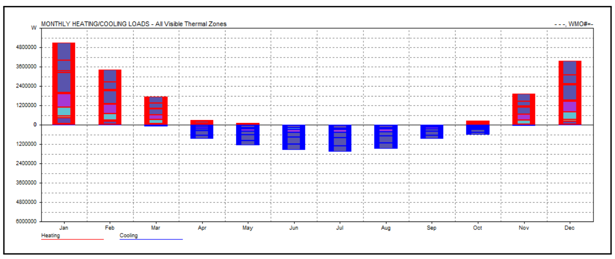

Figure 5: heat gain/ heat loss

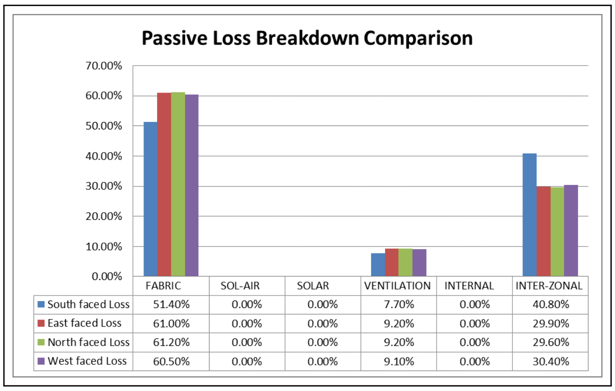

Figure 6: Passive loss breakdown comparison

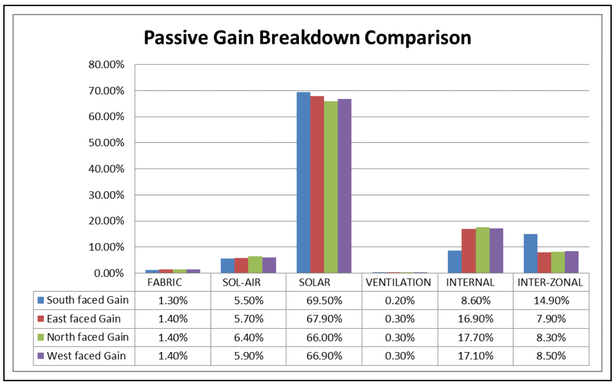

Figure 7: Passive gain breakdown comparison

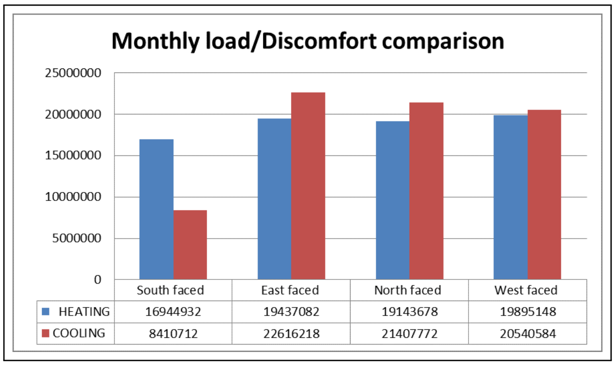

Figure 8: Monthly load

The primary calculation and analysis of the reference scenario shows that the optimum orientation of the building should be South 5° towards East. The longer axis of the building should be east-west and the longer face should face south.

So from the comparison table we can see that the maximum amount of heating load is required when the building is oriented towards west as the south face will not have any openings and solar energy entering the building will be from east and west. At peak hours i.e. 11 am to 4pm the building will not receive direct solar heat. Similarly in south orientation less heating and cooling load is required.

5.2 Analysis 2

In this analysis the façade materials is intervened with different building materials. Where 1. Brick plaster (Reference scenario), 2. Stone cladding, 3. Timber cladding is used.

Table 1. Values of thermal conductivity and density for construction materials Source, (**Iyengar, 2015**)

Material	Heat Transfer Coefficient *k* W/(mk)	Density (kg/m³)
Stone	1.7	2300
Solid concrete	1.13	2000
Raw clay brick	0.51	700
Masonry brick	0.7-0.8	500
Cork sheets	0.05	300
Polyester sheets	0.04	20
Wood	0.13	600

Conductive heat transfer **q** is expressed with Fourier's Law's as:
q = (k/s) A dT = heat transfer (W, Btu/h)
q/A = (k/s) dT = heat transfer per unit area (W/m², Btu/(h ft²))
k = Thermal Conductivity of material (W/mK or W/m C, Btu/(hr ft °F))
s = material thickness (m, ft)
A = heat transfer area (m², ft²)

Figure 9: Materials heat coefficient coefficient (k)

- Max Heating: 10045 W at 05:00 on 4th January
- Max Cooling: 12522 W at 12:00 on 15th July

Scenario 3 wood cladding

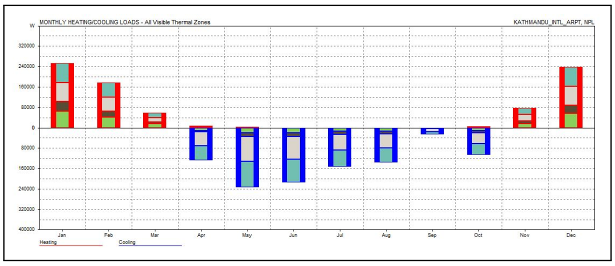

Figure 10: Monthly Heating Cooling Loads

- Max Heating: 9487 W at 05:00 on 4th January
- • Max Cooling: 11798 at 12:00 on 15th July

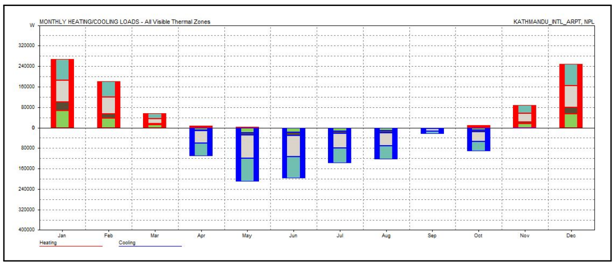

Figure 11: Monthly Heating Cooling Loads

Monthly heating/ cooling load	Reference Scenario (w)	Scenario 2 (w)	Scenario 3 (w)
Max. heating load	10020 W at 05:00 on 4th January	10045 W at 05:00 on 4th January	9487 W at 05:00 on 4th January
Max cooling load	12407 W at 12:00 on 15th July	12522 W at 12:00 on 15th July	11798 W at 12:00 on 15th July

Figure 12: Scenarios comparison chart

Lower the U value less the heating and cooling load is found. Methods to reduce the amount of consumed energy depend on factors that affect the thermal design of buildings i.e. thermal performance of building materials and thermal insulation. Relationship between their thermal properties and the thermal cycle Heat flows into and out of the material are aligned with the thermal cycle of the occupied space.

The ability of a material to absorb and release heat through thermal cycles is based on its thermal capacity, conductivity, density, and thickness.

6. Conclusion

All facades act as a barrier between the outside and the inside of the structure, providing thermally, visually, and acoustically comfortable regions for the building's occupants. Facades that are both sustainable and high-performance must be able to provide maximum comfort while utilizing the least amount of energy. Designers must examine a variety of factors, including temperature and climate-based design methods, thermal performance, day lighting, solar shading, glare, moisture movement, materials, and their environmental effect, to attain this high level of performance.

Finally, buildings with façades that are adapted to their orientation are more climate-friendly (hence as a result of which they are more likely to be energy and carbon efficient). Buildings may have primary façades that welcome sunlight and secondary façades that block it out, providing the building directionality in how it interacts with its surroundings. Despite its widespread recognition, it is surprisingly infrequent in current practice. Measures should be put in place to deal with the additional light and heat (together with the fluctuations) that will result from adding more glass to a façade. If you want to spend a lot of time in the sun, this is equivalent to putting on sunscreen.

This article discussed high-performance façade design approaches, the relationship between building simulations and the design process, and how performance predictions may aid in the discovery of solutions to reduce energy consumption and improve building performance. The report's initial portion focused on climate-based design methodologies, including outlining core design approaches for different climate types as well as the traits and characteristics of sustainable, high-performing facades. The methods for conducting building performance evaluations were then thoroughly examined, with a particular focus on building facade design. Quantifiable predictions that must be integrated in the design phase include energy modeling and analysis, heat transfer analysis, combined heat and moisture analysis, daylight analysis, and thermal comfort analysis. The issues that were found and studied may be used as a tool for evaluating existing buildings or as part of a design strategy for new projects.

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