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THERMAL ADAPTIVE ARCHITECTURE: INTERPLAY BETWEEN ARCHITECTURE AND CLIMATE

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ABSTRACT

The concept of architecture as a form of shelter, integral to both classical and contemporary discourse emphasizes the interplay between building structures and their climatic contexts. Vitruvius early observations underscore the importance of understanding how buildings act as barriers and responsive filters to their environments thereby shaping human activities. This paper explores the multi-faceted roles of buildings-functional, social, symbolic, artistic and their interconnections with thermal performance. While the adaptability of buildings to thermal conditions is well recognized, the impact of fluctuating economic factors such as energy prices, and the unpredictability of space usage add layers of complexity to thermal performance assessments. The research highlights the gap between theoretical knowledge and practical application in achieving optimal thermal conditions. By examining the integration of precise thermal techniques into building design this study aims to bridge these gaps and propose strategies for designing climate-sensitive architecture. The focus is on achieving comfortable and healthy living environments while ensuring cost-effective resource use. This approach advocates for a refined understanding of thermal response and its application in the design-build-occupy process ultimately contributing to more efficient and adaptive building practices.

Key Words: *Architecture, Climate, Thermal Comfort, Specific Heat, Adaptability.*

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Driven by a passion for discovery and a commitment to excellence she continues to push the boundaries of knowledge in Theory of Design and Structure system. Through her teaching, research, and service, she strives to inspire the next generation and contribute meaningfully to academic discourse.

INTRODUCTION

The need for shelter inherently stems from the fundamental goals that a building is intended to achieve. These objectives require a specific pattern of activities which occur within an environment shaped by the building's physical systems. The building's hardware comprising its structure, services and interior contents constantly influences the thermal environment which may need to vary spatially and temporally to accommodate different activities and provide thermal comfort or aesthetic experiences. Determining an appropriate thermal environment and assessing its effectiveness involves a thorough understanding of the activities conducted within the building. This includes not only considering the characteristics of the occupants such as age, gender, clothing and habits related to eating, resting, and cultural practices but also understanding their energy needs, potential issues related to attention, fatigue, boredom and their typical experiences with indoor and outdoor thermal conditions. On parallel lines, the external climate of a building is seen as a medium which surrounds it, penetrates it through openings and by heat transfer through non-permeable membranes, and is continuous with the internal environment which surrounds the occupants of the building. So, the climate has an obvious and direct effect on the thermal environment within the building as well as thermal performance of buildings. Traditional or vernacular architecture could be qualitatively judged on the basis of traditional knowledge and practical experience gathered over a number of generations. This was possible because the character and use of buildings did not change over a long period of time. However, it was not possible to quantify the performance of the building to any reasonable degree. Nowadays, buildings have been subjected to a variety of usages, and the lifestyles of occupants have undergone tremendous changes [1]. Consequently, there is often no past reference to fall back on, from the point of view of predicting the thermal performance of a design, even qualitatively. The estimation of thermal performance of buildings therefore assumes prime importance. The lack of such quantification is one of the reasons that solar passive architecture is not so popular among architects. Clients would like to know how much energy may be saved or the temperature reduced to justify any additional expense or design change. Architects too need to know the relative performance of buildings in order to choose a suitable alternative.

THERMAL PERFORMANCE OF BUILDINGS

The thermal performance of a building is determined by several key factors. They are (i) design variables (e.g. geometrical dimensions, wall-types, glazing-types, orientation, etc.); (ii) material properties (e.g. density, specific heat, thermal conductivity, transmissivity, etc.); (iii) weather data (e.g. solar radiation, ambient temperature, wind speed, humidity, etc.); and (iv) occupants' living habits (e.g. internal gains, air exchanges, etc.) (Figure 1)

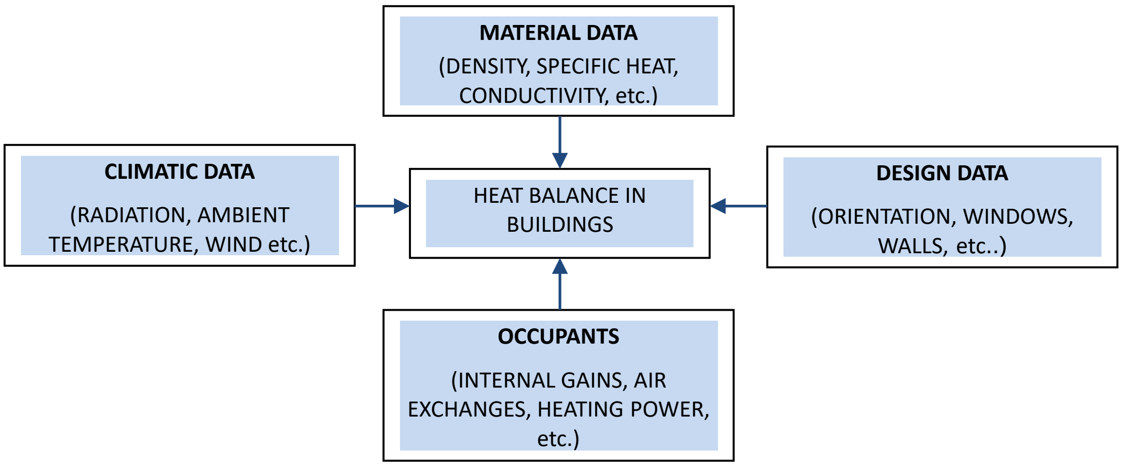

Figure 1: Building's thermal simulation flow paths [2]

TYPES OF HEAT LOADS IN BUILDINGS

Heat gain or loss of a building is caused due to external, internal and ventilation load. Each of these is briefly described below —

External load: The external load is the net effect of the outdoor environment on indoor conditions. Heat is conducted through building components from higher to lower temperature regions, as a result of solar irradiation and temperature differences between indoor and outdoor air. In addition, direct solar gains through transparent openings contribute to the external load.

Internal load: Internal load refers to the heat gain generated inside the building. This includes heat gain due to occupants, artificial lighting and equipment operating in the space. The heat gain from occupants refers to the heat released by radiation, convection and evaporation from the skin and respiration. Furthermore, the heat released by artificial lighting and equipment (mechanical and electrical) too contribute to internal load.

Ventilation load: Air infiltrates from outside into the interior spaces of the building through various openings (i.e. windows and doors) and cracks. Besides, a building is designed to admit a certain amount of fresh outdoor air to maintain indoor air quality. Air ventilation imposes heating/ cooling and humidifying/ dehumidifying load because of the difference between the indoor and outdoor temperatures and humidity.

The sum of these loads determines the rate of heat flow required to heat or cool down a conditioned building by using mechanical appliances like air-conditioners and heaters. In case of non-conditioned building the total load manifests itself in altering the indoor room temperature.

DESIGN VARIABLES TO INCREASE THE THERMAL PERFORMANCE OF BUILDINGS

In order to reduce heating and cooling loads, there is need to focus on design parameters i.e. shape and size, the 'body' and the 'skin' of the building and issues of internal organisation. It provides a basis for articulating the building on the site in order to provide an energy-efficient and comfortable internal environment.

Shape of Buildings

For any given enclosed volume there are numerous ways in which the actual dimensions of height, length and breadth can vary, resulting in difference in total surface areas. Thus two buildings, both having the same volume and built of the same materials, may have quite different surface areas and hence different rates of fabric heat loss. When considering the factors which will result in a minimum heat loss/ gain care must be taken to relate Q (the rate of heat loss from building, per degree centigrade) to the size of the building. Failure to do so merely results in stating that for similar conditions a large building has a greater heat loss than a small one. An analogy can be made with a two-seater car and a 70-seater bus. For the same length of journey the bus will consume far more fuel than the car, but a far better comparison of their performance is obtained when the amount a fuel consumed is related to the number of passengers which each vehicle can carry. A similar situation arises with the heat loss/ gain for a building; the value of Q per degree centigrade has to be related to the capacity of the building, i.e. volume [3].

The ratio $\frac{Surface\ Area}{Volume}$ is now seen to be an important factor and the relationship between them will be considered. This ratio is dependent both upon the dimensions for height, length and breadth, and also upon the actual size of the building. The latter point is illustrated by considering a cube of side x.

Table - 1: Relationship between surface area / volume ratio and size of cube

Dimensions=x	Surface area = $6x^2$	Volume = x^3	Ratio 'surface area/volume'=6/x
1	6	1	6.00
5	150	125	1.20
10	600	1000	0.60
20	2400	8000	0.33

From Table - 1 it is seen how quickly the volume increases relative to the surface area as the dimensions of the cube increase and also the way in which the ratio $\frac{Surface\ Area}{Volume}$ changes with the size of cube.

The ratio of the individual sides of the enclosed space is also important; this is demonstrated by the following example. Consider three solids with different heights but same volume. (a) All sides equal, (b) and (c) Two sides equal.

Table - 2: Relationship between surface area / volume ratio and building shape

Solid Shape type	Solid shape dimensions			Surface area	Volume	Ratio 'surface area/volume'
	L	B	H			
a	4.0	4	4	96.0	64	1.50
b	7.1	3	3	103.2	64	1.61
c	16.0	2	2	136.0	64	2.13

As it is clear from Table - 2, in each case the volume was the same but the surface area was different, thus giving different values for the 'surface area / volume' ratio. It will be noted that the lowest value for this ratio occurs with the cube.

As H increases, 'surface area / volume' ratio decreases; this is due to the volume being dependent on H^3 whereas the surface area depends on H^2.

However, in order to compare the 'surface area / volume' ratio of different shapes of buildings, the volume of the buildings must be the same. It has been shown that the best 'surface area / volume' ratio occurs with a cube. It will be noted that the height increases rapidly with changes in volume when the building is small, but when the building is large the rate of increase of height with increase in volume is much less. In addition, it will be observed that the less compact the building is, i.e. departing from a 'thermal cube', the smaller the ideal height becomes. But, when the U-values for the various surfaces are taken into account, the 'surface area / volume' ratio in itself does not give sufficient information with regard to the fabric heat loss. The aim is to optimise the building shape so that the fabric heat loss will be least [4].

The Building Body

An important consideration is how quickly a building responds to heat inputs (internal and external), which are related to the thermal conductivity of its materials, the thermal mass or heat capacity and related to these, the admittances of the elements of the construction. The admittance, Y of a constructional element, put simply, is the amount of energy entering the surface of the element for each degree of temperature change just outside the surface and, as such, has the same units as the U-value (W/m^2 K). The admittance of a material depends on its thickness, conductivity, density, specific heat and the frequency at which heat is put into it [5]. Table 3 gives properties of some constructions.

Table - 3: Admittance and density of selected construction elements [6]

Sl. No.	Item	Admittance (W/m^2 K)	Density (kg/m^3)
1.	220mm solid brickwork, un plastered	4.6	1700
2.	335mm solid brickwork, un plastered	4.7	1700
3.	220mm solid brickwork with 16mm lightweight plaster	3.4	1700 for brickwork, 600 for plaster
4.	200mm solid cast concrete	5.4	2100
5.	75mm lightweight concrete block with 15mm dense plaster on both sides	1.2	600 for concrete, 600 for plaster

As can be seen from the Table - 3, dense constructions have higher admittances, which is to say they absorb more energy for a given change in temperature. If a building absorbs a great deal of heat and only experiences a small temperature rise it is said, in no very precise manner, to be thermally heavyweight. Such buildings tend to have high admittances and a great deal of thermal mass, usually in the form of exposed masonry. Lightweight buildings, on the other hand, may have thin-skinned walls, false ceilings with lightweight panels, metal partitions and so forth. The CIBSE has tried to be more precise and has defined a heavyweight building as one whose ratio of admittance value to U-value is greater than 6; British standard 8207, on the other hand, uses a ratio of 10. The concept matters more than the number. The particular importance of these issues is in providing comfortable conditions in the summer without the use of air conditioning. This is not simply a problem for office buildings. Normally, the heat flow into a building from the outside is approximately cyclical. On a daily basis, the Sun rises, the air temperature increases and heat is transferred directly via windows and indirectly via the building structure. As the Sun sets the building starts to cool, and the following day the cycle continues. In the winter, the external gains are insufficient and so the heating system supplies heat each day during the period of occupancy. At night, the temperature is allowed to drop to conserve energy. Again, the following day the cycle continues [7].

The thermal mass of the building evens out the variations. In the summer, by delaying the transfer of heat into a building, the time the peak temperature is reached can be altered. By using high-admittance elements the building fabric can store more of the heat that reaches the internal and external surfaces, thus reducing the peak temperatures. This 'balancing' effect can apply both during the day and at night, because if cool night air is brought into contact with high-admittance surfaces their temperatures will drop, i.e. there will be cool thermal storage. The next day, when warmer day-time air flows over the same elements, they will be cooled thus improving comfort conditions for the occupants. Architecturally, the key requirement is to incorporate high-admittance materials in the building and expose them in an appropriate manner.

Heavy weight buildings have an important role to play where air-conditioning might otherwise be needed. However, study of a number of buildings has shown that —

- If loads are low, there is limit to the need for thermal mass, and
- There can be a limit to its usefulness.

To make efficient use of mass, one must be able to ventilate at night to lower the temperature, otherwise the heat absorbed tends to accumulate and discomfort results.

If loadings are low and air movement is good, comfort can be achieved with lightweight buildings. If a building is always in use-for example, sheltered housing schemes-heavyweight buildings are often appropriate, but if occupancy is intermittent a lightweight building can have a positive advantage. For example, in winter, the heat stored in a heavyweight building during the day may be released at night when there is no need for it.

The Building Skin

Development of building envelope or 'skin' needs to be durable, economical, aesthetically pleasing, weather tight, structurally sound and secure. Psychologically, views out are very important. Environmentally, the questions that need to be addressed are: how they respond to solar radiation (both for the sun's heat and light), how ventilation is made possible, how heat gain or loss is minimised and how noise is controlled. The envelope will, to a large extent, determine how the internal environment is affected by the external one.

Solar Radiation

If we first consider the opaque elements, the amount of radiation absorbed at the surface depends in part on the colour of the surface. Lighter colours, of course, absorb less and reflect more of the incident radiation. Turning to translucent materials each one has a different characteristic. The percentage of solar radiation transmitted by a window varies with wavelength as it decreases with increase in wavelength.

The amount of radiation that enters and exits a room can be controlled to a certain extent by altering the components of the glass, by using several layers of glazing, by applying special coatings and filling the spaces between the panes with various gases, or by evacuating them. The heat gain or loss from any building element is related to its U-value. U-values for different glazing types along with transmission and acoustic characteristics are shown in Table – 4 below.

Table - 4: Characters of glazing systems [6]

Type	U-value (W/m^2 K)	Light transmittance	Solar radiant heat transmittance		Mean sound insulation
			Direct	Total	(dB)
Single (4mm clear float glass)	5.4	0.89	0.82	0.86	28
Double glazing (6mm clear float inner, 12mm airspace, 6mm clear float outer)	2.8	0.76	0.61	0.72	30
Double with low emissivity coating (6mm Pilkington K inner, 12mm airspace, 6mm clear float outer)	1.9	0.73	0.54	0.69	30
Double with low emissivity coating and cavity (6mm Pilkington K inner, 12mm airspace with argon, 6mm clear float outer)	1.6	0.73	0.54	0.69	30

The Table – 4 shows that there is some loss of light and solar radiant heat as the U-value improves. However, in most applications this is not a significant disadvantage compared with the benefits obtained. It also shows that direct solar transmittance is not the same as direct light transmittance, and this suggests possibilities for glass development. In the summer, for example, an ideal glass would transmit light (to reduce the need for artificial lighting) but no other part of the solar spectrum (to keep the space cooler). In the winter both light and heat are likely to be advantageous. Similarly, in the winter, a very low U-value saves energy. If in the summer, the internal temperature is above the external, as it often occurs in lightweight, non-air-conditioned buildings, a high U-value would help get rid of the heat. Glasses whose characteristics can be altered have enormous potential. Energy loss through a window depends particularly on internal and external temperatures and is independent of orientation. Energy gain, on the other hand, obviously depends on direction because of the sun. Shading is normally needed to control overheating in the summer and in some designs in the spring and autumn. Shading devices need to be considered as systems rather than isolated elements and shading control at the building envelope must be related to the activities in the building, its mass and its ventilation system [8]. A disadvantage of external, fixed shading is that it results in some permanent loss of passive solar gain when needed. It is, nevertheless, too easy to say 'avoid external shading' and it is much better to examine the functional requirements. Structural overhangs are one form of shading that also offers the possibility of rain-shielding. In this situation the required light levels were low. A combination of overhang and hopper window means that very simple night ventilation can be provided without major risk from rain entering, if someone forgets to close the windows; the night ventilation works well with the high thermal mass. Movable external devices tend to be costly and because of exposure to the weather require significant maintenance. They should be used only after careful consideration. Movable shading devices such as blinds placed between glazing layers let more heat into a space than external shades but are more reliable. They are also more effective than internal blinds (but more costly). Very approximately, if single glazing allows in 1.0 unit of solar energy, single glazing with internal blinds will allow 0.67 unit. Double glazing will allow 0.88 unit and double glazing with internal blinds, 0.33unit.

Ventilation

Ventilation of buildings has varied from uncontrolled infiltration at cracks around windows, doors, junctions, floorboards and so forth for, say, homes, to purpose-made openings to provide air to air handling units in sealed air-conditioned offices. In most domestic situations it was assumed (usually correctly) that enough air would enter the rooms to meet the needs of oxygen, odour and pollutant removal, condensation control and in the summer, possible removal of heat. Indeed, generally too much air gained entry during the winter and this led to excessive heat loss. For several years, partly as a result of increased interest in energy conservation, there has been a growing interest in ventilation, summarised by the slogan 'Build tight, ventilate right.' If the right amount of air is provided, if heating systems distribute heat as needed throughout the building, and if moisture is dealt with at the source, for example through extract fans in kitchens and bathrooms, there is a high probability that condensation will be controlled and energy consumption kept reasonably low [9].

But what is the way to provide the 'right' amount of air? As a starting point, the building needs to be tightly sealed so that entry and exit points for air are controllable, or at least well defined. A tightly sealed construction requires careful design and good workmanship. Flexible sealants are required at junctions, say, between window frame and walls and at interfaces of steel frames and masonry; and when detailing external joints, allowance must be made for thermal expansion, deterioration, distortion and weathering. Openings for ventilation will vary according to the application, and windows have normally been the main means of providing natural ventilation in both winter and summer.

CONCLUSION

There exists a pressing need to improve the performance and quality of buildings. Because of the energy crisis, the relationship between the formal aspect of architecture and those related to energy has become very crucial and, in many cases, the later aspects lead the project development and define its visible form. At the same time, we need to broaden the scope of energy conserving buildings from special projects for motivated clients to everyday buildings. Institutional complexes as energy saving places have their value in generating new ideas, but we need to focus our attention on the common commercial building and the ordinary house that is being built and used every day. Appropriate knowledge and technology is available for creating energy efficient and green buildings but behavioural, organisational and financial barriers would need to be overcome for achieving desired results. Adopting a holistic and integrated approach towards improved thermal performance of buildings, there is need to promote awareness through education and motivation of professionals involved in building industry to integrate various techniques that can improve thermal performance, into the fabric of the building. Efficiency gains in buildings are likely to provide the greatest energy reduction globally. It is estimated that demand reduction measures could almost halve the expected growth in global electricity demand and carbon di-oxide emissions, from building energy use by 29 percent at no net cost by 2020.

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