A SIMULATION STUDY OF THERMAL COMFORT IN EARTH FORMED SPACES

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DECLARATION

I declare that this dissertation represents my own work, except where due acknowledgement is made, and that it has not been previously included in a thesis, dissertation or report submitted to this University or to any other institution for a degree, diploma or other qualification.

Signed:..

D.M.N.I. Gunadasa

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A SIMULATION STUDY OF THERMAL COMFORT IN EARTH FORMED SPACES

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A SIMULATION STUDY OF THERMAL COMFORT IN EARTH FORMED SPACES

ABSTRACT

This is a continuation of the B.Sc. dissertation of the writer, which concludes that rocks can moderate the level of thermal comfort inside the spaces they form. It is likely that over other material, rocks have potential to create thermally comfortable spaces in the context of Sri Lanka.

This Dissertation has expanded the range of study from rocks to earth architecture. This begins with the identification of the thermal sensation as an integral part of spatial experience and therefore as a feature of the spatial art. Integration of earth is seen as the possible mode to create and orchestrate thermal moods in Architecture.

This deals more with the identification of the underling principles behind the thermal behaviour of earth material and the use of them as tools of Architecture. The study is based on computer simulation of the thermal behaviour of earth formed spaces, which enables an otherwise impossible multiplicity of flexibilities, options, control over variables and accuracy of testing and comparison.

The study identifies the need to integrate boulders and heaps of material, instead of walls and roofs, and discusses the need to rethink of spatial articulation beyond the conventions.

INTRODUCTION

A Simulation Study of Thermal Comfort in Earth Formed Spaces

A SIMULATION STUDY OF THERMAL COMFORT IN EARTH FORMED SPACES

INTRODUCTION

1.1 Thermal sensation is an Integral part of spatial experience

Architecture embeds mindsets in spaces. The Architectural space may project unto you a sense of loneliness, a sense of relief, or a sense of an unknown sorrow by creation of a setting that craves out bygone pains buried in bygone memories. Alternatively, it may create a setting that makes you forget all your pains and generate relief and mindfulness. Or, perhaps, do both at the same time that creates a nostalgic bitter-sweet moment. Thereby, Architecture becomes a concretization of frames of mind. It freezes moods into volumes and forms of space and makes the spatial experience something beyond the mere perception of space. Experience of space becomes experiencing a work of art.

Music is the art of those heard, painting – those viewed and Architecture is the art of those lived! Like in all arts, in Architecture too the carnal satisfaction of leads to the intellectual joy. However, the spatial experience is not a proliferation of stimuli of one sense but consist all those heard, viewed, felt and understood. The sense of space that generates spatial experience is multi faceted.

Space being experienced with all senses, the thermal sensation comes to be an integral part of it. In the visits, we have made to rock formed places such as Polonthalawa Farmhouse and Vessagiriya Caves, it is felt that despite the awe-inspiring grace and calmness of rocks, the thing that enchants us to the place is the felt little chill of atmosphere. Together with other sensory experiences, the thermal sensation takes part in bringing out frames of mind of serenity.

1.2 Scope of the study

However, it is said, virtually, that it is impossible to achieve a comfortable thermal environment in our climate with passive means. This brings the debate that how one can think of thermal orchestrations when it is impossible to achieve at least the comfort range in tropical climate.

It is seen that this thermal discomfort of our environment is due to the nature of material and concepts of development of the modern day. There is no argument that there was one time where the streets are shaded with trees and people were comfortable in the wattle built houses. The earth, as a building material, seems to have played a vital role to create thermally comfortable spaces. It is important to study the possibility to achieve the same but in terms of modern technology and needs. However, the vista of this study is beyond the study of wattle built walls but rests upon the integration and articulation of rocks and heaps of earth as themselves.

1.3 Justification to integration of earth to Architecture

In tropical buildings, the thermal sensation seems to be almost taken too loosely as if it is assumed that the only thing to achieve in the aspect of thermal experience is the standard thermal comfort level and nothing else that we do not see orchestrations of thermal sensations in buildings.

Much is thought about the visual sensation of a space in their act of creation but the submerged use of other sensory stimuli is weakening. As a result, instead of being an art of weavers that weaves together several sensory images to stage a dramatic scenario of space, Architecture has become unilateral and 'monochrome'.

This may be because there is no spur to visualise space in terms of olfactory and tactile senses. Nevertheless, the thermal sensation is a direct outcome of form and material and can be visualised in terms of Architecture. Therefore, the need to investigate the ability to use thermal sensation as a gizmo of mood creation is felt as imperative.

1.4 Previous findings - earth as a moderator of thermal sensation

The history of Architecture and Social Studies essay of B.Sc. (B.E.) of the writer is concluded with the statement that rocks and earth do moderate the level of thermal comfort inside the spaces they form. They moderate the average temperature (average of the temperature measured for 24 hrs) inside the space in relation to that of the outside and they effect the heat flow due to time lag effect.

Behaviour of earth material differs from that of conventional insulators. In case of rocks and earth material, Thermal Diffusivity and Heat Capacity of the material become the governing factors of heat flow. Thermal Conductivity is less important. Theoretically, the thickness of a rock shell required to bring the level of thermal comfort to an appropriate value in Sri Lanka is approximately 0.5m.

There is nothing more to prove on the fact that earth and rock can moderate the level of thermal comfort felt inside the spaces they form. What is to be found out is the integration of it in Architecture.

1.5 Towards a study of Earth Architecture

The important aspect here is that earth formed spaces can orchestrate thermal sensation due to the flexibility of the thickness and possibility to use as bulks, which the standard brick walls or standard concrete slabs by no way can do.

It is no wonder that the integration of earth material to Architecture, due to their physical properties, has to be in the form of boulders and mounts. This will affect all key constituents of Architecture – the form, the space and the details. What the articulation of earth going to challenge are not only the thermal properties of spaces but also the very roots of the conventions of spatial articulation. The spatial ambience, the ways of encapsulating the space, the detailing of it, all will be radically challenged. It is an invitation to break through these mind-forged manacles and rethink of the form of space and the spatial articulation not in terms of walls, floors and roofs but in terms of space itself.

On the other hand, the feeling of space and the meaning of space will be stronger due to the articulation of earth. Though it can be argued that Architecture has the potential to affect ones psyche, whether those contemporary buildings with alien forms and material can do it, is a problem. When we talk about whispering to ones inner self by the means of forms and spaces, those forms and spaces should some how be meaningful to his intellect.

Rocks and earth are elements closely related to human life from the beginning of human civilization. Their effect on formation of human cognition – in the formation of the concept of home (rock caves), beliefs, religion and feelings of awe and respect is enormous. Earth is the true womb of man. Therefore looking at a rock, one can perceive things beyond its physical existence – rocks and boulders of earth have instinctive meanings. There is the possibility to use them as strong Architectural proliferators that evoke instinctive references once laid deep in human mind.

Therefore, a challenging architectural problem is observed in integrating earth to Architecture. However, this study is not going to touch on the broader aspect of the human instincts embedded in earth forms but narrow it down to the thermal sensation of the earth formed spaces and use of it as a tool of mood creation. When it comes to the practical application of the integration of identified principles, the problem of articulation of rocks and boulders too is to be discussed.

1.6 Method of study

Mechanical properties of earth and behaviour of earth material is identified with a survey of literature on the subject. The existing kind of earth Architecture that is evolved with the development of human civilization is studied. Thereby, in both the aspects the resultant nature of earth Architecture is rendered.

Thermal performance of earth material and principles behind the phenomena are revealed with simulation studies. The integration of the identified principles to the identified nature of earth Architecture is discussed and thereby concepts are derived for the practice of thermal comfort conscious earth formed Architecture.

The possibility to use the concepts to manifest moods of space and orchestrations of thermal sensation is discussed. The thinking process to be fallowed by the designers of 'earth' is discussed.

CHAPTER ONE

Background Knowledge for the Study

CHAPTER ONE

(The background knowledge for the study)

The living spaces of tropical countries are experienced by tropical people themselves as thermally uncomfortable. The evolution of tropical man happened in tropical climate itself. How it be possible for the being who born from tropical environment to find its climate painful. Is it something wrong in the evolution of man itself that it makes him suffer forever from his climate? Evolution has created the eel slim, slippery and flexible to perform wonderfully its task of creeping through and the dragonfly so lightweight, so strong and so versatile to perform wonderfully the task of flying. Has it gone wrong in its most perfect, ultimate and supreme creation. Has climate changed drastically within past few thousands of years to which we are still adapting?

The simple answer is that this is nothing else but due to the nature of built environment of tropical man. When we get into the natural landscape and living places of tropical man – an environment fully shaded with foliage, wet with retained water in the bed of fallen leaves and places of living formed in rocks and from earth – even today we do not see a thermal discomfort at all.

The reality is that we are being carried away with the western cement mortar, concrete and steel and it is this resultant alien culture of built form that makes us suffer. The answer, though it should be in modern terms, already lies in forests, rocks and boulders of earth. Therefore, the integration of earth – Earth Architecture – stands to be the direct solution.

The form of Architecture of Earth fundamentally alter from that of conventional Architecture that it places the research area and goals of study in a doubtful and vague position. Without tracing the kind of Architecture and its basic nature, it is difficult to go into a study of its thermal behaviour, because the phenomena of thermal resistance fundamentally rest upon the form. The identification of critical aspects will thereby be uncertain and therefore it is Imperative to render the form of Architecture at first. Within those aspects that determine the form of earth Architecture, invariably the properties of earth material is the most determinative.

To trace the kind of Architecture that will be rendered at the integration of earth to the concept of thermal sense of Architecture, it is necessary to identify the properties of earth material in both the aspects of its mechanical and thermal behaviour. This requires a general understanding of the underline concepts of properties of material and the way those properties effect in the manifestation of form and space. Before getting into the specific study of the properties of earth material and its effects on thermal comfort levels, a general knowledge of the properties of material and their thermal behaviour is necessary.

2.1 Mechanical properties of material in general

Properties of materials have given form to our built environment! Properties of material have formed our spaces! It is nothing but properties of material that has brought in the concepts of the wall, the roof, and the slab. Moreover, the properties of material have formed our way of perseverance of space in terms of above concepts!

Type of Architecture generated by material such as polycarbonate and FRPs will naturally be of thin walls rising to the skies embodying large volumes of spaces. They will facilitate free forms of curves and parabolas that are almost floating. Materials like PTFE (polytetrafluoroethylene) may generate a kind of Architecture that is suspending and cobweb like. Materials like steel facilitate a kind of Architecture, which is of dominating structures supported by cables embodying large volumes of space with long span limbs. With the possibility of easy moulding, steel facilitates fabrication of large number of repetitive elements that it brings a kind of Architecture of rhythm and rhyme in the form of repetition of elements in space frames, trusses and girders.

To visualize the kind of architecture that evolves in the matrix of a material, it is important to understand the physical properties of it. Listed below are some of the basic aspects to be looked at in the examination of a building material.

- **Strength**
- Tensile strength

Elasticity

Plasticity

- Compressive strength
- **Density**
- **Toughness**

Ductility

Brittleness

- **Hardness**

- **Strength**

Strength is the prime property of a building material. Limit of height that can be reached and the limit of free span possible with a certain material are predefined in its strengths. Strength is two typed – tensile strength and compressive strength.

- Tensile strength

This refers to the amount of tensile force that can be bared by a uniform perpendicular cross section of a material. Materials are said to be deformed due to the application of external forces and that quality is measured as elasticity

Elasticity

Elasticity refers to the amount of elongation of a material due to the forces. Materials with a higher elasticity elongate more under a unit force. . Due to the force, material may deform but at the release of the force, the material may recover its form. If not, it is said that the material has undergone plastic deformation.

Steel and Teflon are some materials with higher tensile strengths that it is possible to create long span structures with them. Where as glass and concrete with no reinforcements will easily fracture under tensile stresses that they bring in a kind of Architecture, which is of non-load bearing panels resting their weight upon skeletons and leads to a skeleton Architecture with less enforced definition of space. Materials with a higher tensile strength may be formed into cables and threads that the potential Architecture of them may be suspending and floating.

Plasticity

Plasticity also refers to the deformation of a material due to external forces but at the release of the force, the material will not recover its original form. Clay is the most plastic material. Due the possibility of forming and perpetual correction of mistakes might have generated a celestial fire of free forms and unlimited deco but the unavailability of such a plastic material have fettered its application. The ability of moulding and extruding due to the plasticity most of the time appear in materials at high temperatures have given form to our building elements but not to the form of Architecture.

- Compressive strength

Compressive strength is simply the opposite of the tensile strength. While tensile strength talks about the tensile force acting on a unit cross section of material perpendicular to the section, the compressive strength refers to the compressive force acting on a unit cross section perpendicular to it. Materials with a higher compressive strength will not fracture or fail due to higher compressive loads.

In a world where most of the building materials have only a compressive strength, such as in the Middle Ages where most of the construction was done with masonry and concrete, architectural forms are always bulky. Forms that can tolerate loads without developing tensile stresses in them such as arches and buttresses dominate. The enormous weight and heaviness of forms projects a sense of valour and proud ness to the space.

'Arches, vaults and domes have been used for centuries to roof houses when wood was scarce or not available. The curved structures are some of the most sophisticated and important architectural feats in history. Domes, vaults and arches work by compression. As gravity presses down upon the structures, uniform loads keep them firmly in place.'

Basu A.(2003)

- Density

Density means the amount of mass in a cubic unit of material. Density is the ultimate governing factor of the form and scale. The limit of reach, both horizontal and vertical is predominantly defined by the self-weight of material in relation to its strength.

The integration of lightweight material to construction have elevated the possible reach of height that it facilitates the construction of slender towers and have explored another horizon of form and spatial articulation in Architecture. Architectural out come of a dense material will always be a bulk with wholes. Bulk is the form and wholes are spaces.

- Toughness

Toughness refers to the amount of energy absorbed by a material before fracture. This is something very different to the concept of strength. While strength deals with force, toughness deals with energy. A strong material will not always be a tough one.

Toughness is something like courage. Though you are not strong enough to withstand, you do not easily give up. Binder Gum is a tough material. Cap of a binder gum bottle, if dried with glue in groves, however great the force you apply, you cannot open. Nevertheless, keep your twisting force steady for a minute or two, you see it weakening and opening as if by a miracle.

Materials such as glass are not tough and therefore tend to break easily. Those material, therefore, are impossible to be formed in the site by hammering and bending and therefore leads to a culture of plain and factory made type of architecture.

Ductility

Tough materials are usually ductile, ductility refers to the capability to hammer and form without breaking. Cupper is ductile than steel.

Brittleness

Brittleness is the opposite of ductility and refers to the quality of breaking easily without deforming. Glass and ceramics are brittle.

- Hardness

Hardness is defined as resistance to indentation or resistance to scratching. It is a measure of wear resistance. Hard materials are the ones that are difficult to cut. Before using of metals as building material the ability to cut and form in both timber and stones have generated a tradition of Architecture in Sri Lanka and in India, which is full of decorations and cravings which the integration of metal and masonry have decayed today.

To identify the physical properties of a material is to be able to describe it with the above norms. The identification of mechanical properties leads to the identification of the form of Architecture.

2.2 Orders of Magnitude

Form of Architecture or the form of any creature or creation, what may its underline concepts be, depends on its scale. For instance an ant, though it has very slim legs and limbs, can lift three times of its own weight. Now does this mean, if we enlarge it to the size of an elephant, it is capable of lifting three elephants? It simply cannot at least bare its own body weight!

When we enlarge an ant ten times its length, due to the increase of length, with and height, its actual volume and the weight increases from thousand times (10^3) but the surface area of its foot prints increases only from hundred times (10^2) due to the increase of foot area in length and with. Therefore, the pressure on the footprint has risen from ten times and still the leg being made out of same material, it is not strong enough to bare such a pressure that it collapses. This is the principle behind the ant having extremely slim legs where as elephants and big dinosaurs have proportionately large legs.

"Legs of a large animal are relatively weak in proportion to the legs of a small animal. Steel and concrete by themselves are stronger than bone and living tissue, but in terms of scales of magnitude, the stalk of grass is proportionately far stronger."

(Eugene T. 1999)

This implies that it is impossible to enlarge the Petronas towers twice its size. Its form is pre defined by its magnitude of scale. With the strength limits of materials, the form of a building is predominantly determined by its magnitude.

Identification of mechanical properties and order of scale will lead to the revealing of the form of Architecture of earth. But our goal being not just integration of earth to Architecture but integration for the moderation of thermal sensation, the form of Architecture generated may once again alter. To comprehend this form of Architecture an understanding of thermal comfort, climate and thermal properties of material is necessary.

2.3 Thermal comfort and its parameters

In the absence of active means of cooling and heating, the level of thermal comfort is a manifestation of climate, material and form. Therefore, to for-see the nature of Architecture, it is equally important to know what is thermal comfort, what are thermal properties of material and how they perform in the particular climatic condition.

Thermal sensation is not a direct outcome of the temperature of atmosphere but how it is felt and interpreted by our selves. On the other hand, we are not receptive to the temperature of atmosphere but to the temperature of our own skin and the skin temperature differs from that of atmosphere.

- **Mean Radiant Temperature and Air Temperature**

Temperature of a considered point in a space is a resultant of the Mean Radiant Temperature (MRT) and the Air Temperature (AT). MRT refers to the temperature due to the presence of thermal radiation from sources of thermal energy. Any element with a higher temperature in relation to its environment acts as a source of thermal Radiation. The term air temperature refers to the temperature of air, which will be almost the same in a considered space.

- **Humidity**

Perspiration facilitates heat loss. Evaporation of a liquid takes with it thermal energy as latent heat and therefore the evaporation of sweat brings the skin temperature down. How the atmosphere helps evaporation becomes a parameter of thermal comfort. When the air is saturated with water vapour, no evaporation of sweat takes place and do not facilitate heat loss. When the air is less saturated, sweat is easily evaporated and we feel the situation to be comfortable. Therefore the level of humidity is a function of thermal comfort.

- **Wind**

We live in a ball of humid and ht air created by ourselves. Due to the continuous evaporation of sweat and heat transfer, the air around our skin is always more hot and humid. The presence of wind breaks this tissue of air and helps fast heat loss. There by the wind speed also becomes a parameter of thermal sensation. Level of clothing traps the tissue of hot air and prevents it blow out by the wind.

- **Other parameters of thermal comfort**

Thermal sensation is an opinion rather than a measure of physical parameters. It talks about how you feel and therefore depends on tastes and habits of individual. Thermal comfort is ale\ways bias. The admired level of thermal comfort by those who live in peninsulas will fundamentally differ from the level of comfort preferred by those who live in tropics.

Thermal sensation, finally, is a function of the amount of heat generation by your self. More the heat generation of the body, more will be the need to remove it and more will be the amount of swear to be evaporated. Heat generation of the body is a function of both the physical and mental excitement and activity level. Therefore, thermal comfort is a function of the activity and the movements we are going to house in the spaces. It is a function of the level of excitement and animation we create in the space. Therefore, to some extent, the required level of thermal comfort is determined by Architecture itself.

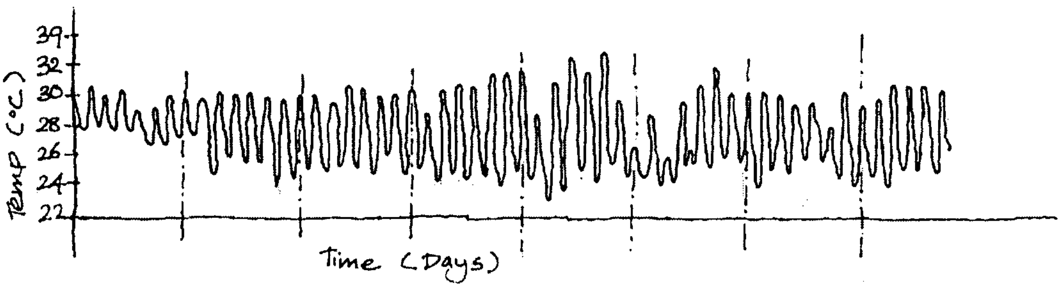
"There are six parameters that largely influence thermal comfort: Air Temperature (AT), Mean Radiant Temperature (MRT), Air Velocity (AV), Relative Humidity (RH), Clothing (Co), and Metabolic Activity Rate of Person (met.)"

Emmanuel R (1993)

2.4 Climate

The form of tropical Architecture is an outcome of climate. Climate generates the culture of built form. The sun that stands right above the head, rain and the wind that drives drops of water almost horizontally has given form to the openings of vernacular house. High levels of humidity and the dew point reached every day in the morning have given form to the roofs and eves.

Climate is an ultimate determinative factor of both the form and material. More over climate determines the thermal behaviour of materials also that it becomes important aspect of the study.



Tab. 1.1 Temperature variation of Colombo from September to October 1998

The critical feature of the temperature variation is its perpetual nearly sinusoidal variation round the clock. Temperature of outdoor environment rises with the rising sun until 03.00 p.m. and there by marks its climax. The fall of temperature occur at that point continues until the done of next day. The same system is perpetuated with little change due to the seasonal variations and due to the rains.

This variation significantly affects the thermal behaviour of large masses of material from that of thin layers. Time taken by masses of material to arrive at a steady flow of heat is proportionately greater to the temperature variation of the environment that the steady state never occurs. The material undergoes an ever-lasting transient heat flow. The advantage here is that the material gains the ability to store heat in itself and emit out at night. This makes the thermal behaviour of boulders fundamentally differ from conventional insulators.

2.5 Thermal properties of materials in general

Thermal properties of media govern the heat transfer between two elements. Under the light of Architecture, thermal properties are the parameters of building material that moderates heat flow between two spaces. Thermal properties at the fundamental level are Thermal Conductivity and Heat Capacity.

Heat Capacity

Heat capacity refers to the amount of thermal energy that is stored in a material. In definition, Heat Capacity mean the amount of thermal energy required to increase the temperature of a unit mass of a material by one unit. Building materials with a high Heat Capacity is capable of storing thermal energy in them without allowing it passing through.

Thermal Conductivity

Thermal conductivity refers to the amount of thermal energy transferred through a unit cross section and a unit length of a material perpendicular to the cross section, at unit temperature deference and at the steady state of heat flow.

Those materials with higher values of thermal conductivity are good conductors that efficiently transfer heat and those materials with lower thermal conductivity are good insulators.

The term steady state at the above definition is an important aspect that limits even the Architectural application of the concept of Thermal Conductivity. When a temperature difference is applied, the first reaction of a material is to absorb energy, the amount of thermal energy received at the other end of the material will not be equal to the amount of energy that is taken in from the heated side. Some amount of time is taken for the material to be saturated with energy and provide a continuous flow of energy. Steady state refers to this state where the heat flow is steady and no heat absorption by the material happens.

If the temperature variation of the environment due to the solar movement is faster than the time taken by the material to come to steady state, the material is at a perpetual transient heat flow and its behaviour cannot be described with thermal conductivity alone.

Thermal Diffusivity

In case of transient heat flows, thermal diffusivity is the parameter that governs the heat flow. It takes into account both the tendency of material to absorb heat and to transmit it. Thermal Diffusivity represents how fast heat diffuses through a material. It is defined as the ratio of the Heat Conducted through the material to the Heat Stored per unit volume.

This concludes the study of basics and the background knowledge of the materials, scales, thermal properties, effect of climate and thermal sensation. This leads to the specific understanding of mechanical and thermal properties of earth material, and effect of climate on their thermal behaviour and leads to the rendering of the nature of earth Architecture.

CHAPTER TWO

Earth Formed Architecture

CHAPTER TWO

(Earth formed Architecture)

The birth of earth Architecture is said to be running to the birth of human being. Today we come across modern architects who endeavour to practice earth Architecture due to the salient nature of earth material. The verity and diversity of earth structures built up to date bare in them a treasure house of knowledge of earth Architecture. The study, therefore, begins looking into the existing earth Architecture and identifying its nature, verity, virtues and drawbacks.

"The diversity of earth architecture is the result of an immense range of natural, historic, cultural, and socio-economic environments. Variety and universality are not enough to indicate the significance of earth architecture. Raw earth has been associated with the architecture of the poor as well as the rich, the popular as well as the eclectic, the simple as well as the monumental, the ancient as well as the modern, and even of the contemporary."

Basu A (2003)

3.1 Importance of Earth Architecture today

The form of earth Architecture is not mere manifestation of verity but an outcome of culture, traditions and environment. The core factors that determine the nature of earth Architecture are broad. The applications of earth Architecture are wider. Due to the uniqueness of the properties of earth material, it has a multiplicity of virtues over those other materials.

From the beginning of human civilization up to the date, people have lived in earth-based structures. The number of people that live in earth structures today, we hardly have ever imagined!

"It is estimated that currently one third to one half of the world's population, almost 3 billion people on six continents, lives or works in buildings constructed of earth defined as the softer, fragmental material composing part of the surface of the earth."

www.eartharchitecture.com (2003)

"There is hardly an inhabited continent, and perhaps not even a country, which has no heritage of buildings in unbaked earth, whether ancient or modern, in all its richness and diversity. Forms of indigenous earthen structures and materials have been developed throughout the world. Today it is estimated that 40-50% of the world's population live in earthen dwellings."

Basu A (2003)

In addition to the thermal comfort problem, earth architecture addresses two more fundamental problems of the human civilization – the problem of housing for the poor and problem of dense urban development.

"Earth is one of the few materials that enable people to build directly for themselves, using material that is literally at their feet. New Zealand, like Australia, the U.S.A. and many other countries, is seeing a large revival in interest. Up to half of the world's population live in earth dwellings and come from a wide social and political spectrum. Earth-building has the potential to help empower people by putting them back in charge of their own housing needs. It is a powerful notion that you can actually go and dig up some ground and convert it into a good sound structure."

North G (2003)

Underground architecture is one of the fundamental forms of earth architecture and its nature and virtues, mainly in the aspect of resolving the problems of urbanization, can be summed up to the followings.

"Underground space development is one possible way to help solve urban problems such as congestion, lack of open space, and an aging infrastructure... The use of underground space, provides a noise-free or vibration-free environment, reduces energy costs by reducing heat loss and increasing the potential for earth cooling, provides for safety and security, dampens daily temperature fluctuations, reduces life-cycle and maintenance costs, offers protection from natural disasters, environmental extremes, difficult living conditions, or a stressful climate, preserves areas of beauty or areas of historical significance so as not to visually impact them by buildings or other structures, or isolates an area where better control of air moisture or temperature is required. Disadvantages include increased construction costs, limited or no natural light, limited access and air circulation, limited visibility, negative psychological reactions, and site restrictions. Questions frequently asked about the use of underground space often concern drainage, waterproofing, windows, lighting, and ventilation."

Underground Architecture (2003)

While directly contributing to the thermal comfort level of formed spaces, Earth Architecture indirectly contribute to the thermal comfort of our environment by preserving the trees and landscape. Earth Architecture is perhaps the most sustainable form of building. Even a highly dense construction of earth buildings will not appear to be a mass of concrete but earth itself on which plants grow and creatures inhabit.

"Earth Architecture is essential to the world's forests in its potential to reduce the use of wood in building construction. In most instances, earthen structures reduce the amount of wood needed for construction by half, and if the structure is constructed of adobe barrel vaults or domes, wood use is further reduced to a minimum... It is also one of the most sustainable, in that it involves a plentiful resource and generates no pollution."

Basu A (2003)

"To me, the greatest builders are those little creatures in the sea that make seashells. Their shells, their homes, have the best texture, the best colors, the best forms. They are waterproof, yet they are created only from water. If we as humans understand and realize our own potential, we should be able to do just that. We should be able to mold the earth into its best and most beautiful form without the need to cut trees and destroy the environment. It is shameful that we call ourselves made in the image of God, and yet we have to destroy everything to build our little houses."

Khalili N (2003)

Even though the earth material stands as the solution for the urban development, sustainability and thermal comfort problem, it does not appear to be popular in the urban situation. The main reason may be the misconceptions of the structural strength and the quality of construction of earth.

"The use of these materials greatly reduces the dependency on scarce resources such as wood and cement. Materials from the earth posses excellent thermal properties, and are non-toxic, so they can greatly reduce energy consumption and pollution. Furthermore, despite common misconceptions, earth architecture can be built to meet the highest standards of structural safety. "

Basu A (2003)

The immense potential, the Architecture of earth has to resolve the existing problems of built environment and urbanization is clear. However, this study looks only into one of those aspects.

3.2 Need to identify the core generators of earth Architecture

To identify the universal nature of Earth Architecture, mere looking through the existing works of earth structures will not help. What is required to be brought to the surface is the row nature of possible earth forms. With the integration of many other generators such as culture and traditions, the form of earth Architecture will diversify.

However, in all cases the underling nature of earth material will remain the core originator of form and will act upon identity and uniqueness of earth Architecture within the manifested diversity and verity. The touch of the differences of ethnicities, cultures and climates on the form of earth Architecture are to be eliminated and the critical aspects worthwhile for the study are to be singled out.

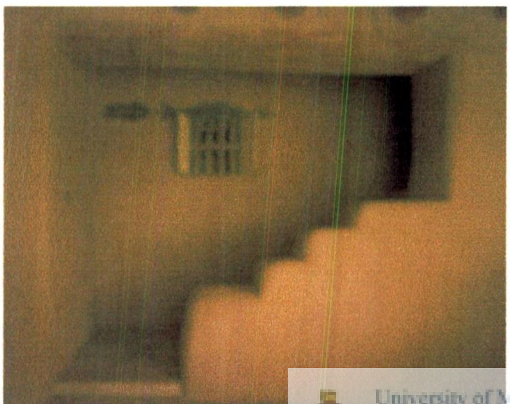
3.3 Form of earth Architecture defined by Mechanical Properties

The form of man is defined by the properties of living tissue and bones. Instead, if the man were to be created with steel and glass, its form and scale would drastically be altered. The living organisms are not formed like plates or boxes. It is not because such forms cannot survive but because what material of construction facilitates are curves and ovals, and not sharp edges. No mammal species that grow much bigger than the elephant exists in the world not because the world cannot provide food but simply because the material do not support beyond that scale. The form and the scale of man, the form and the scale of the termite and the form and the scale of the bee hive; all is determined by material of construction.

The form of space created with earth and the magnitude of it are determined in the properties of earth itself. Therefore, the identification of the basic properties of earth materials comes first in the determination of the nature of earth formed Architecture.

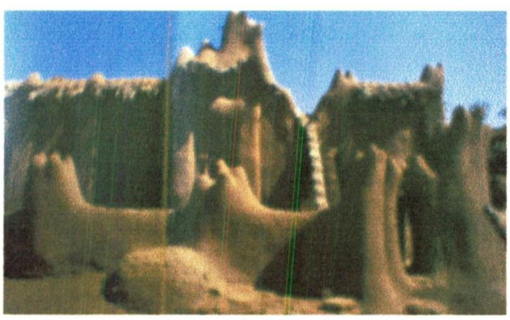
Earth materials, based on mechanical properties, can easily be classified into three groups as rocks, soils and sands. The sands being consistent of masses of tiny solid particles with no chemical bonds, do not act as one mass that it is impossible to be considered in the direct integration into Architecture. Therefore, the subject is confined to soils and rocks. Mechanical properties of soil and rock differ as if they are altogether non-related that it is necessary to discuss them separately. However, thermal properties of them do not differ considerably.

Soils, here after referred as earth, have no tensile strength at all, even when compared with concrete and cement mortar, unless it is wet. Due to this, it is impossible to form sharp edges and rectangular forms, which needs some amount of tensile strength to hold its form by itself. Therefore what ever the basic form modelled be, if it is to be in earth, it needs to be with curved edges. This may be seen as setting out a limitation for detailing but actually, for the creator it opens out a new horizon of imagination and a guideline of form making; for detailing are not to be imposed on forms but evolved from material itself.



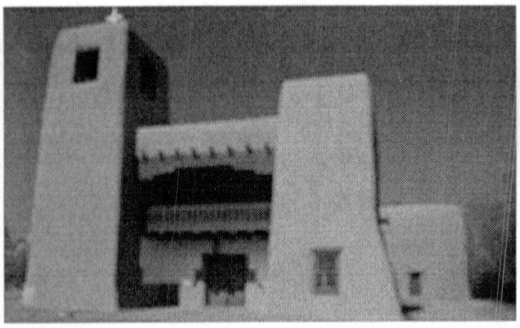
3.1 Curved edges in an earth house

Due to the same reason, spheres and horizontal cylinders are not to be invited. Whatever the form it may be, at the base the form has to embrace the floor. The form invariably comes to be born of the place and not something placed on. Lack of tensile strength confines the form of earth Architecture to two main forms – the heap and the puncture or the mountain and the valley. There may be heaps in punctures and punctures in heaps but even walls are impossible unless the material is reinforced.



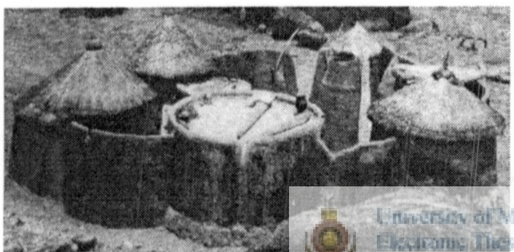
3.2 Mosque of Nando – heap forms and embracement of earth

Earth can be reinforced but strong bonds between earth material and reinforcements will not occur due to the poor toughness of earth. Therefore, it is impossible to think of an earth formed beam or a slab. There being no tensile strength, it is meaningless to think about the plasticity and the elasticity of earth. However, when in the presence of moisture, earth shows a very high level of ductility and in the dried form, it is brittle.



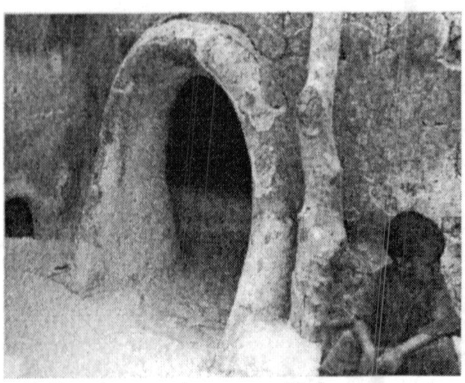
3.3 Cristo Rey Church – Non-decorative faces of earth

Ductility inspires forming that earth Architecture may not restrict its forms to the limitations of straight lines as many other building materials. Instead of, it facilitates free forms of curves and hyperbolas. Brittleness on the hand discourages cutting and craving and makes earth Architecture plane and non-deco in the aspect of forms. It adds a high level of uniformity.



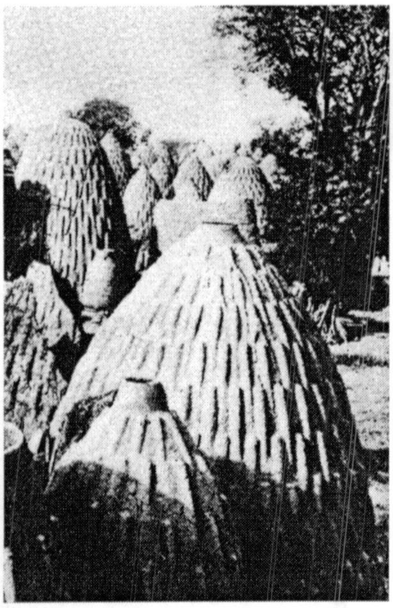
3.4 Nabdam Compounds, Northern Ghana - The free and circular forms

The integrated effect of less tensile strength, less toughness and high brittleness is a kind of smooth Architecture, although it may be rough textured, with soft edges and no protrusions, limbs and cantilevers; an Architecture that do not float; and rises from the earth as if it is rooted to the place and celebrates the embracement of the floor. Without reinforcements, constructions thinner than one meter are not practical. Therefore, unlike glass or PVC panel partitions, it always emphasises on spatial distance.

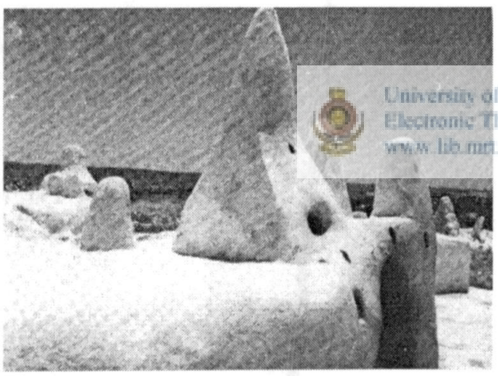


3.5 entrance to an earth house Northern Ghana – the arched opening

The compressive strength of earth is high although it may be not so in compared with that of concrete. Therefore, shapes that bare loads without developing tensile stresses such as arches, domes, parabolas ad


3.6 Massa 'bomb' houses, Northern Cameroon – the form of the dome

eggshells may give form to the earth Architecture. This leads also to the bubble spaces formed under ground. The bubbles invariably needs to be eggshells and spheres or cylindrical wells or otherwise will collapse due to the development of tensile forces. The form of openings and the form of spans replicate ellipses and circles and those rectangular ones looses the perfection of its form by making the edges round and becoming nearly ellipses and circles once again. The size of openings and the spans are determined by the proportions of strength to density and magnitude.


3.7 Koubba, Algerian Oases – Large legged building

Density of earth is high in proportion to the strength that the forms that are generated to house humans will be 'elephants'. Therefore, earth structures are 'large legged'. The base of the structure needs to be proportionately larger to the crown. With earth, it is possible to form many a kind of structure to the scale of the length of a palm. However, when it comes to the scale that is to house a human body, it is virtually impossible to create a right vertical wall without reinforcements. The wall always needs to be larger at the foot. This brings an air of bulkiness that it enriches Architecture with a sense of fullness and weight.

"Earth is one of very few readily available building materials that can give beautiful, thick, massive, sturdy walls at reasonable material and low environmental cost. No other building material has earth's availability and intrinsic properties. Its beneficial attributes include not only the ambience peculiar to earth buildings, but also the non-toxic nature of the material, the solidity, thickness and massiveness of the walls, thermal and acoustic performance, the subtle variation of the natural earth colours (if these are left exposed), and the aesthetics peculiar to earth building techniques."

North G (2003)

In contradiction, rocks can bear tensile stresses as well that it is capable of acting as individual elements rather than a mass of particles. Compressive strengths of rocks are higher in compared to the earth material that the magnitude of scale of rocks is higher.

Due to the higher density, the erected structures will naturally be heavy looking. This is the factor in fact, that brought the pride and grace to the Architecture of Anuradapura, Rome and Egypt. The ancient builders have withstood the brittleness and hardness of rocks that their works in rock seems to be of wood. However, rocks inherently are hard and brittle and therefore do not facilitate cutting and forming. In the Architecture of the day, earth buildings are not for the emperors and kings with massive labour forces, but for common man and those poor, integration of rocks has to be in its row form. Virtually, here rocks cannot be cut and formed. Rocks become elements to be integrated rather than a material for construction.

The integrated effect of thermal and mechanical properties of earth will fundamentally decide the basic nature of earth architecture. The form of earth Architecture rendered at this stage and for this purpose is a proliferation of the mechanical properties of earth and the underline theme of generating thermal comfort.

3.4 Thermal properties of earth buildings

The nature of earth Architecture is identified. What is to be discussed now is how it is going to be moderated when it comes to the aspect of creating thermally comfortable spaces. What requires here is to theoretically look into the thermal performance of earth buildings and identify the governing parameters. The testing method and analyse of each parameter is to be discussed in next chapters.

Form appears to be a governing parameter of the thermal sensation. The relationship of encapsulated space to the internal surface area and the relationship of it to the external surface area determine speed of the heat flow. When the surface area of interior increases the amount of heat radiated into the space too increases proportionately. In the same way, when the surface area of the exterior increases, the portion of exporter to solar radiation increases and therefore more heat is absorbed into the material. The form that minimises the surface areas to the extreme is the sphere. Those forms that come closer to the sphere have proportionately smaller surface areas and those complicated forms contain large portions of surface area.

The form of earth Architecture, generated for the purpose of thermal comfort will therefore likely to be of near spherical forms. This goes hand in hand with the rise of curved edges and elliptical and circular forms due to the mechanical properties of earth.

The portion of surface area, as it is defined by the proportion of the housed volume to the surface, depends on the magnitude of scale. The surface area decreases proportionately when the size is increased. For instance, if we enlarge a 1mX1mX1m box as twice as its length, its volume increases from eight times due to the increase of length, width and height. However, its surface areas increase only from four times due to the increase of lengths and widths that the proportion is decreased from two times. What this implies it that larger the space, lesser will be the heat gain.

This leads to the encapsulation of large spaces and sub division to form smaller ones instead of forming small segregated units of buildings. The outcome is a kind of integrated hive of spaces.

The thermal flywheel effect or the time lag effect of earth material is the fundamental factor that makes its thermal behaviour different to the conventional thermal insulators. The earth material has the ability to store thermal energy within the material itself at peak times where the temperature of the environment is high. A large portion of this thermal energy is radiated back at the times where the temperature of the environment is low. These effects are discussed in detail in the B.Sc. dissertation of the writer.

"Heat gain and loss is slow with heavy materials such as earth giving a 'thermal flywheel' effect. This is used to good advantage to maintain year-round comfort while reducing the need for supplementary heating and cooling. Owners of earth houses often spontaneously comment on their coolness in summer and their warmth in winter."

North G (2003)

The important factor here is that to perform as a thermal flywheel, the thickness of the earth material needs to be higher. This goes hand in hand with the possible form of earth structures and therefore for both the mechanical and thermal behaviour, the structures need to be heavy and thick.

Thickness governs the temperature difference between two spaces by increasing the resistance to the heat flow. Due to the time lag effect, the heat flow is more than directly proportional to the thickness.

It is seen that the thickness of earth material as the main moderator of thermal sensation. In case where the other parameters are constant, heat flow between two spaces is predominantly controlled by the thickness of the boundaries and the size of openings. Thickness of the earth elements are not pre-defined as in the case of masonry walls that it becomes an important variable.

The effect of earth elements used as roofs appears as to be more effective than walls. How elements facing sky, north, east etc. contribute to the thermal performance of a space is to be studied. Due to the time lag effect of the earth material, their thermal behaviour has to be studied round the clock because the result of the higher temperatures environment at daytime may cause its effect in the enclosed space at night.

CHAPTER THREE

Method of Study

CHAPTER THREE

(Method of study)

4.1 Aspects to be studied (description of sites)

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The magnitude of the space may be a governing factor that determines the level of thermal comfort. When the magnitude of a space increases, its proportion of surface to the volume too increases resulting limitations to the heat flow. If this factor is identified as a critical principle behind the heat flow of the earth buildings, then the aspects of form and the nature of openings that effect the surface to volume proportions has to be taken into account.

4.2 Data collection method

It is already shown that the heat propagation through earth material under the tropical climate is perpetually transient. This factor makes the heat transfer mechanism of them unique and very different to that of conventional insulators. Therefore, the study is to be based on the thermal diffusivity calculations than thermal conductivity. The mathematics of thermal diffusivity are far too complex to be discussed in a study of Architecture that here the study is based on software that eliminates the need to go into calculation.

There is no argument that this kind of a study is impossible to be carried out in real world. There is no way to change earth walls and roofs that are few meters thick, as it is wished by us. Even if it were, it would have become a time consuming and extravagant exercise. Changes of periods, climatic conditions and location will change the outside conditions up to a level, which veils the subtle changers of temperature. To make constant those other parameters that affects the level of resultant thermal comfort level, expensive and extreme precautions are required.

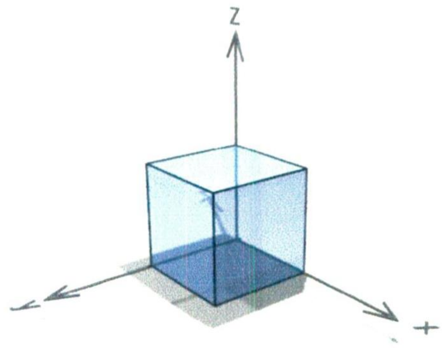
When these factors are considered, there is no doubt that the method of study has to be based on computer simulation. In case of simulation software, the possibility to change the materials and thicknesses of elements are possible with ease and there are no doubts of the environmental conditions. What are to be made constant are made constant with reliability.

When the required spaces and environmental settings are virtually created in the software, the computer will generate the necessary data. Temperature variation four every three hour within the 24 hours of the day, are calculated. The predicted Mean Vote (PMV) and the Air Temperature of the room are the basic parameters of the results.

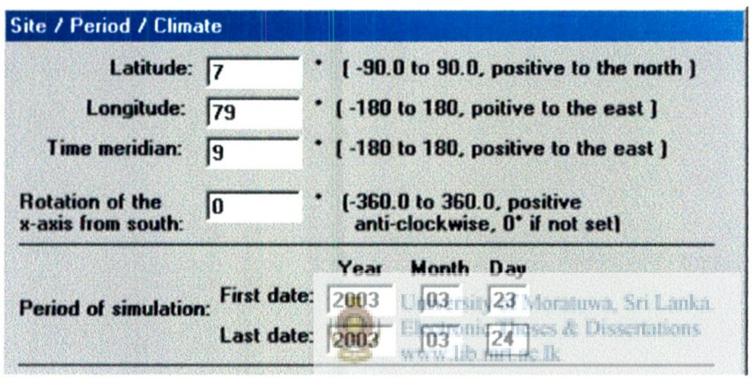
4.3 Variables of the study

The main variable of the study is the positioning of material and their thermal properties. Thickness of the earth material is taken as a variable to be studied. The effect of the magnitude of the spaces too being a parameter to be studied, is also taken as a variable. All climatic conditions, environmental conditions and the location are constant in all the case studies.

4.4 Analysis method



4.1 3D model in a Cartesian coordinate system



Tab. 4.1 Location and the orientation of the models

Opaque Materials

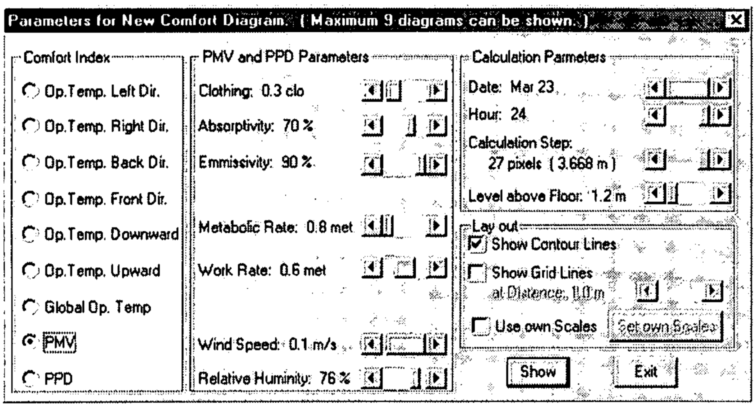
Type	Name	Conduct. (W/m.K)	Sp. Heat (Wh/kg.K)	Density (kg/m3)
1	Concrete	1.7	.24	2300
2	Reinf. concrete	1.28	.26	2100
3	Cement mortar	.93	.29	1800
4	Brick	.5	.2	1300
5	Gypsum	.22	.23	900
6	Mineral wool	.04	.24	50
7	Air Space at 21 C	.024	.280	1.201
8	Sand	.4	.24	1700
9	Earth	1.4	.22	1300

OK Cancel Help
Add Change Delete

Tab. 4.2 Properties of assigned materials

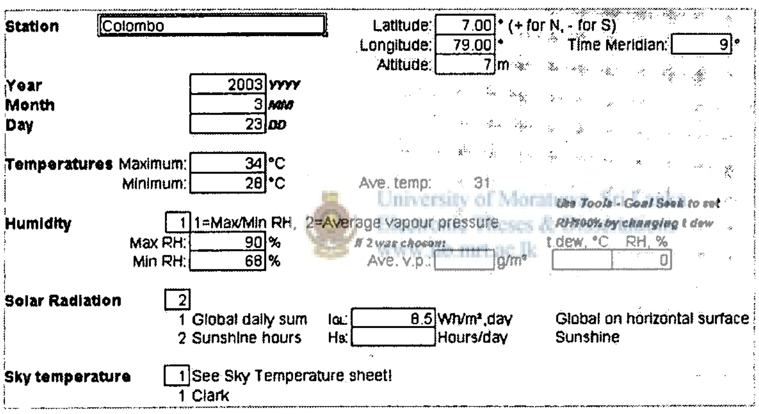
The simulation study is done based on DEROB-LTH, which is an acronym for Dynamic Energy Response of Buildings LTH, is a MS Windows based flexible simulation tool for thermal model design. DEROB-LTH was originally developed at the Numerical Simulation Laboratory of the School of Architecture of the University of Texas at Austin.

In the simulation, a 3D model of the spaces to be tested is done. Geometrical model of the building is assumed to be placed in a positive oriented Cartesian building coordinate system. The model contains data of its location, the orientation and the period of testing. It includes thermal properties of the materials of the model.



Tab. 4.3 Assumed internal thermal conditions

The calculations are influenced by climatic factors such as outdoor temperature, solar radiation and the sky temperature. Loads from direct and diffuse solar radiation, reflected long-wave solar radiation from the ground and shading devices are included in the heat balance equations. DEROB-LTH calculates solar loads for each surface in the model based on direct and diffuse solar radiation stored in a climate data file.



Tab. 4.4 Climatic data

Properties for the indoor climate of the building can be calculated based on the simulated results.

The results are generated in the form of plans with colour indicating the distribution of the level of thermal comfort in the space. The study of the maps allows the identification of the level of thermal radiation of the surfaces and its effect on the resultant MRT of the space. More over it displays the relative temperature change of an element during the course of the day. The maps display the temperature distribution within a space but do not allow the comparison of two of them.

The basic phenomena that can be directly compared are the resultant air temperature. The air temperature measured for every three hour of the day is plotted in graphs and compared. The comparison leads to the identification of the relative variation patterns and the level of comfort achieved relatively.

4.4.1 Study the thermal behaviour of a conventional insulator

The study of the behaviour of earth is comparative. The level of the moderation of thermal comfort and the thermal behaviour of the formed spaces are to be understood in relation to the conventional buildings and material.

The identification how good or bad the use of earth is to be judged in comparison to the conventional ones. When a conventional element in a building is replaced with earth, would it result better thermal conditions is the direct and simple way to judge the importance of earth material. When the performance of concrete is understood, it leads to the understanding of how different the behaviour of earth material is. Identification of the difference of the thermal behaviour and performance leads to the identification of the uniqueness of earth material.

Therefore, as a reference, it requires studying the thermal performance of conventional material. A model is to be created with application of conventional material and simulated for its thermal performance. The elements of the same model, then, can be replaced with earth and it leads to the comparison of the integration of earth and its effectiveness.

4.4.2 Thermal performance of thin earth walls

On the evidence that the thermal behaviour of earth is different to the conventional thermal insulators, there is the need to compare the difference of the thermal performance of earth to the conventional building material.

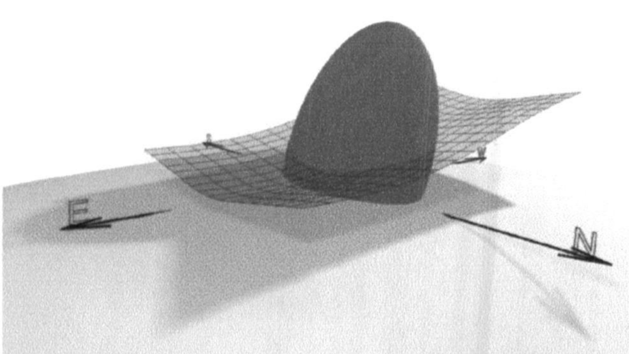
It is impossible and unfair to compare a 225mm thick masonry wall with a 2m thick earth element and say earth is more effective. However, it is not correct to compare earth element with same thickness of masonry wall. 225mm is the limit of the masonry wall. It is far more expensive to create masonry walls with thicknesses of our wish. However, in case of earth, the average thin element practical is 500mm and to create larger ones, it costs only a little bit more labour and nothing else.

Therefore, if earth is to be compared with conventional masonry for thermal performance, the comparison needs to be between 225mm masonry construction and 500mm thick earth construction. The walls of the reference case have to be replaced with earth walls and tested.

It is expected to identify the difference of the occurrence of thermal peaks and temperature variation patterns in order to understand the principles behind thermal performance of earth material.

4.4.3 Effectiveness of integrating earth to west

It is a geometrical truth that east and west facing walls receive more solar radiation than the others does. From the two, the west-facing wall seems to be more critical. The highest temperatures of the atmosphere occur in the evening, to which the west walls face. From morning to the noon, the temperature of the environment does not reach its maximum that the rise of temperature of the east walls is less.



4.2 Graphical representation of the temperature variation around a single rock element (The mesh heights represent level of temperature)

In the previous studies this phenomena is observed in case of Vessagiriya rock formations. In case of a single rock boulder, when the average comfort levels are measured at points east to the boulder and west to it, the results indicated a clear difference.

Therefore, it is shown that, among walls, the west-facing wall is the one that mostly contributes to the rise of internal temperature. What is to be identified is – to what extent and of what quantity does the earth material effect. Therefore, it requires studying the effectiveness of the west wall quantitatively. The conventional masonry wall of the reference case is replaced with earth material and tested for changes of thermal comfort levels.

4.4.4 Effectiveness of earth roof

While the contribution of the west wall is the most effective among walls, it is once again a geometrical truth that it is the roof, which receives the highest intensity of solar radiation and therefore, is the most predominant element in the aspect of thermal comfort.

What is to be found out is, how effective the earth roof, to what extent does it effect. There is the need of some kind of a quantification of the contribution of roof to the resultant thermal comfort level.

The roof of the conventional building is to be replaced with earth and tested. The results can be compared with the results of the conventional building as well as with the other cases where the effectiveness of other elements tested. The comparative analysis leads to the identification of the value of the roof in comparison to the other.

4.4.5 Thermal performance of a predominantly earth building

The maximum potential of earth material to moderate the comfort levels generate thermal comfort in the spaces it forms is to be identified. This identification once again can also be comparative.

Only if the maximum level of comfort achievable is within the accepted levels, it is possible to think about a tradition of Architecture that uses no energy to make the interior thermally comfortable. This case therefore is going to be more critical and is actually the basic challenge of this dissertation.

If it is seen that it is impossible to achieve the standard levels of thermal comfort with the integration of earth, then the study has to yield in front of the saying that with energy passive means, it is impossible to create thermally comfortable living spaces within the tropical climate of Sri Lanka. In which case, the suggestion of thermal orchestrations of spaces and thermal moods of spaces too become meaningless.

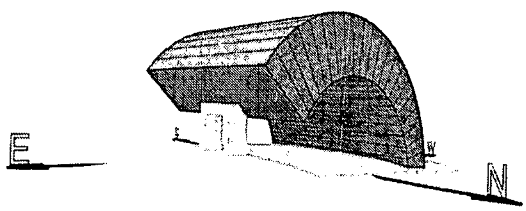
The elements of the reference case are to be replaced with 10m thick earth. The east-facing wall is considered as a thin earth wall with a thickness of 0.5m. The space is to be tested for its thermal comfort levels round the clock.

4.4.6 Effectiveness of earth enclosure

In the previous cases tested, the number of earth surfaces present in the encapsulation of the space is varied. While the number of earth surfaces is increasing, the level of thermal comfort too is increasing. It is likely that more than the orientation of the earth elements, the earth enclosure is important.

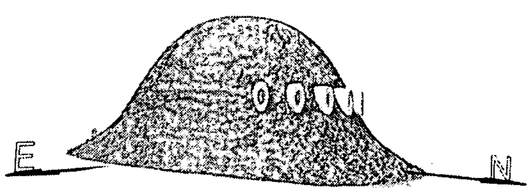
To test this, the roof of the predominantly earth building is replaced with ordinary material and tested for the level of comfort. Secondly, instead of the roof, two sidewalls facing north and south, theoretically less effective orientations are replaced with masonry walls and tested.

If this shows a poor level of thermal comfort in relation to the case where the roof is out of concrete, it is an indication of the importance of the earth enclosure over the orientation of the elements. However, none earth area in this case is doubled that if the difference is not much it means the earth enclosure is equally important. If the comfort levels are poor in relation to the case of concrete roof, what it simply means is that the orientation of earth elements is the important factor.



4.3 An illustration of Form of Architecture governed by Orientation

This study is critical in the aspect of the form of Architecture the integration of earth going to create. If the orientation is much more important, what we can suggest is a kind of Architecture which is of more open kind and consisting of few earth elements carefully placed in the correct



4.4 An illustration of Form of Architecture governed by Enclosure orientations. If the enclosure is more important, it invites a kind of introverted closed tradition of Architecture with fewer openings.

4.4.7 The effect of thickness

The study of the effect of the thickness is important. The thickness mainly is the parameter that determines the nature of Architecture the earth going to create. If the thickness require is less it will be just replacement of masonry works with earth. If the required thickness is considerable, then the integration of earth in the form of boulders has to be considered. If the thickness require is very high, the kind of Architectural space will be of holes created in heaps, mountains and into the earth.

The walls of the reference case are replaced with earth material of thicknesses 0.5, 1.0, 1.5, 2.0, 3.0m and to be tested for the level of thermal comfort inside the space they form.

4.4.8 The effect of the magnitude

The increase of the magnitude of spaces increases its surface to volume ratio. The identification of the effect of which to the resultant thermal comfort level is important. If the factor found to be determinative, then it heralds the need of a kind of Architecture of beehives with a complexity of three dimensionally integrated spaces that minimises the surface to volume ratio.

Secondly, if this factor is found to be important, what it directly suggests is the importance of the form. The form then will govern the level of thermal comfort that it will bring out the need of a study how forms contribute to the level of comfort. It will bring out the need of a study of form in both mathematically revealing the relationships of surface to volume and practically based on the resultant thermal comfort levels in the formed spaces.

If the study suggests that the relationship of magnitude to the level of thermal comfort is negligible, that means there is no considerable relationship of form to the level of comfort in earth Architecture. The form or the scale does not determine the level of thermal comfort that they do not become generators of Architecture in the aspect of creating comfortable thermal environment.

2mX2mX2m space is to be modelled in the software and tested for the level of comfort. The scale of the space to be increased several times without changing the other parameters such as thickness and the time and tested for the level of comfort. The results are to be plotted in a graph and the kind of relationship of magnitude to the resultant level of thermal comfort is to be identified.

4.4.9 Aspects that are not studied

The study indicated that there is only a marginal relationship of surface-volume ratio to the level of thermal comfort inside the spaces formed. This is an indication that there is no relationship of form of space to the level of thermal comfort. Therefore, there is no need to study different forms of spaces such as flat spread ones and thin tall ones, spherical ones and cubical ones and the level of thermal comfort they generate.

There is no need of a study of the forms of openings either. The scale of openings is not separately studied. The openings are considered as non-earth area and the importance of the minimization of which is shown.

The effect of material and thermal properties of them is not studied considering the engineering nature of that study. The variation of the thermal properties of different soils is marginal and in the context of Sri Lanka, the top soil, which is to be used for earth building do not vary considerably from place to place when their thermal properties are concern.

CHAPTER FOUR

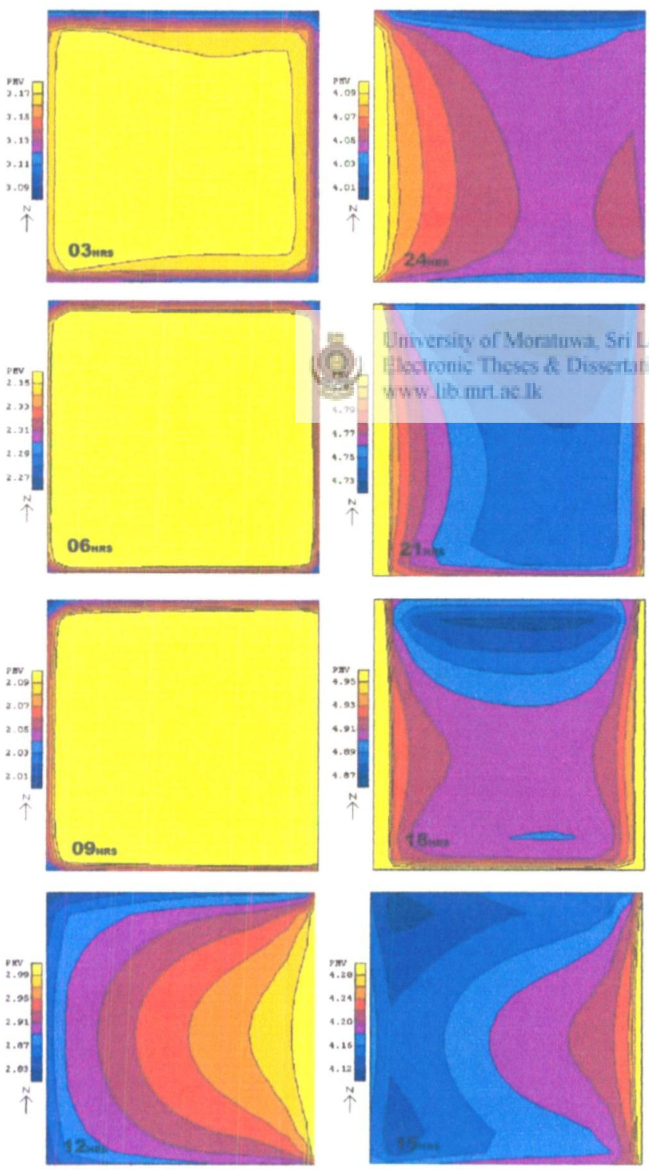
Case Studies

CHAPTER FOUR
(Case studies)

The spaces modelled in DEROB-LTH are tested. The air temperatures of the spaces recorded every three hours of the day are plotted in a graph for the convenience of the comparative study before going into the individual detailed study of each case.

5.1 Study of the thermal behaviour of a conventional building

REFERANCE CASE



Tab. 5.1

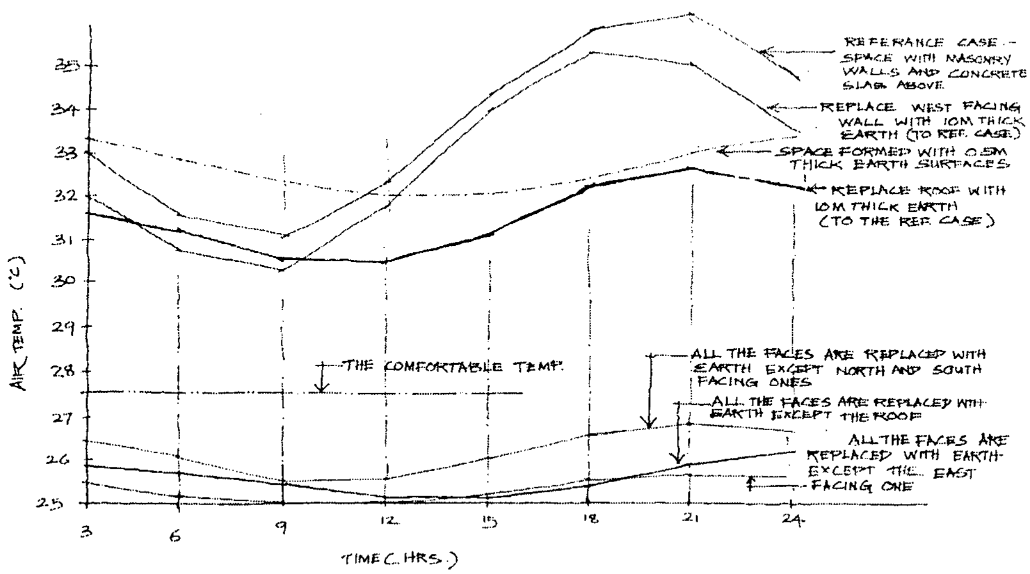
This is the reference case of a standard masonry and concrete structure. The results show that the situation is not comfortable. The temperature does not go below 31^{0}C and this indicates that it never comes to a comfortable limit. The inhabitants are to suffer from thermal discomfort forever.

The graphs shown here display the distribution of the comfort levels inside the space at given times.

The rise of temperature at 9.00 at the east end displays the rise of temperature of the east wall due to the rising sun. The radiant heat from that wall has contributed to the increase of temperature in the entire space except at the brim of other walls.

At 12.00, the difference of temperatures in the space is clearly seen. Eastern wall is at a higher temperature and its radiant effect is felt all over the space. The transverse of this begins to occur at 15.00. At 18.00, the radiant effect of the west-wall is predominant and in the evening at 21.00, it is clearly seen that the element that contribute to the heat is the west-wall. The highest PMV values and highest air temperature are indicated at this time and the effect is continued to be felt until 24.00.

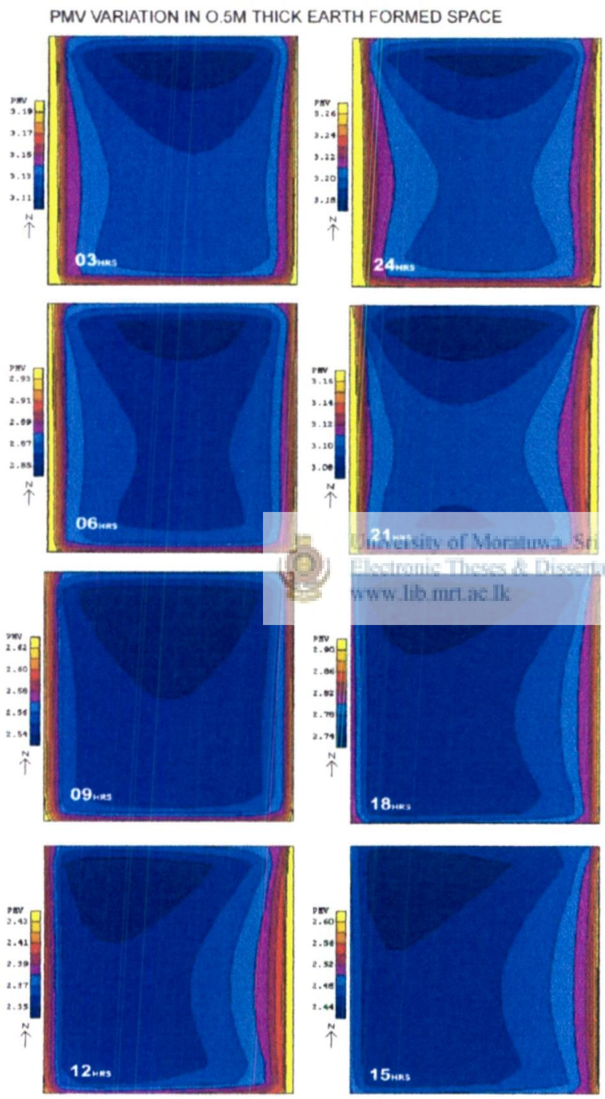
From 3.00 to 6.00 it is clearly seen that the edges of space closer to the walls are comfortable and cooler. This indicates that at this time all walls are contributing to the cooling of the space. What is hot at this time is the air itself.



Tab 5.2 temperature variation for 24 hrs of cases studied

This reveals the contribution of the west elevation to the generation of worst thermal comfort conditions over other elements. It also displayed the contribution of masonry walls in absorbing the temperature of air.

5.2 Thermal performance of thin earth walls



Tab. 5.3

In this case, the entire building is replaced with 0.5m thick earth construction. The comparison of the resultant graph with that of the reference clearly shoes the difference of the behaviour of earth material to the conventional ones.

Mainly it has flattened the amplitude of the variation of temperature. The range of the resultant curve is between 32^0C and 33.5^0C where as the standard one varies between 30^0C and 36^0C. This disables the possibility of achieving the comfort level at east one time of the day where the outside conditions are actually comfortable. But the important factor to notice is that it has eliminated the worst part of the temperature. While the maximum temperature of the reference case reaches 36^0C, the earth formed space keeps its maximum at 32.5^0C.

Two more things are there that require the careful consideration. The first is that the average temperature of the space has drastically come down in the case of earth material. In the reference case the average temperature is 34^{0}C while in the case of earth building, it is around 32.5^{0}C. The reduction of average temperature from 1.5^{0}C can be regarded as a considerable moderation. Secondly, in the reference case the minimum and the maximum occurs at 9.00 and 21.00 hrs respectively, where as in the case of earth structure they occur at 12.30 and 24.00 respectively. This indicates a shift of the temperature curve from that of the environment. The important factor is, in earth spaces the most comfortable conditions occur where it becomes worst at out side.

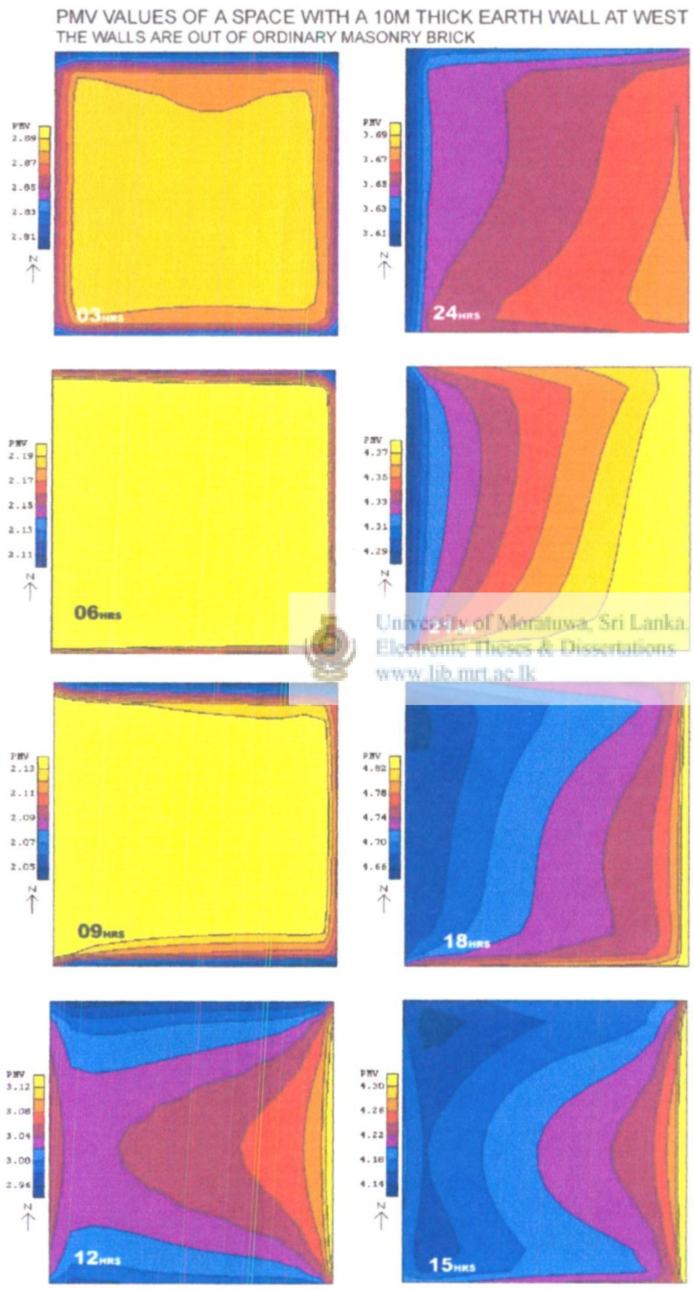
There are no yellow and red zones seen in any graph. This is a clear contradiction to the reference case. What this indicates is that the earth material tends to radiate heat into the space relatively less.

5.3 Effectiveness of integrating earth to the west

In this case, with the identification of the importance of the west wall, an earth wall is inserted to the west side of the same building. The inserted wall has a thickness of 10m. The graph shows a clear reduction of air temperature. The reduction is approximately 0.5^{0}C. The maximum temperature of 36^{0}C that was there has been reduced to 35^{0}C.

The thermal behaviour of the earth element is interesting to be studied. From 12.00, the west wall faces the radiant heat of the sun. It is at 18, the last rays of the sun reaches the west wall. Interestingly, at this time the wall seems to be the coolest element. During the entire period of time where the solar radiation reaches the earth element, its temperature contradictorily goes down.

This is a clear indication of the time lag or the thermal flywheel effect of earth elements. Entire thermal radiation that reaches the exterior surface of the space is tolerated by the earth material itself. Thermal energy is stored in the material.



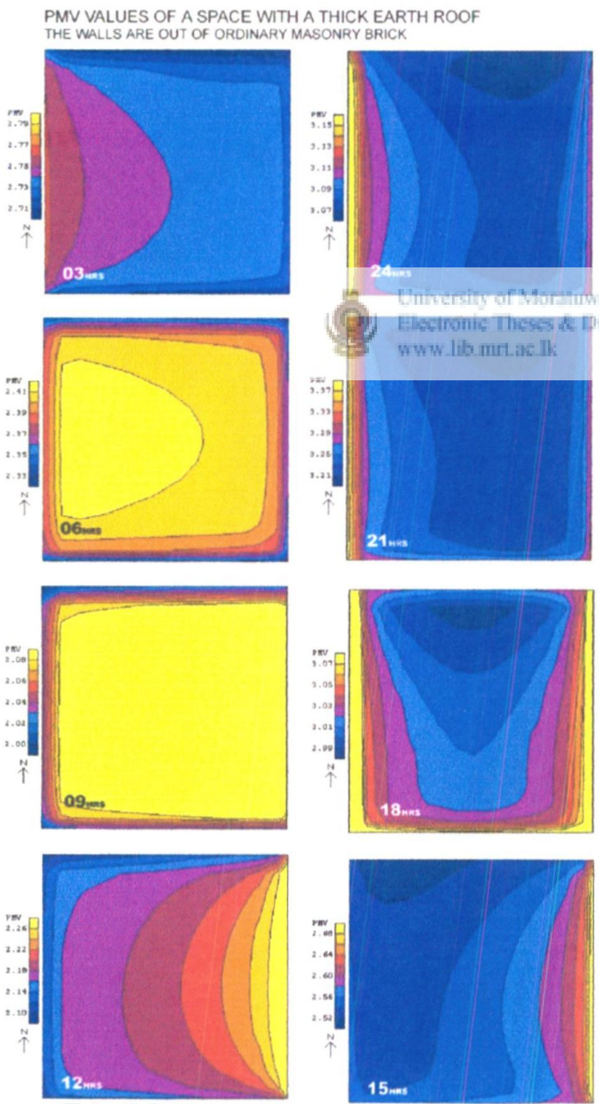
Tab. 5.4

After cooling over the entire night, it is seen at the 6.00 the west wall to be the hottest element. The difference of phase of the temperature variation curve of the interior surface of the earth element to that of the environment is 180^0 that the right opposite happens.

Except from 6.00 to 12.00, the earth element clearly acts as the heat sink of the space. The blue curves shown at 15.00, 18.00, 21.00 and 24.00 clearly seen to be originated from the west wall. The contribution of the wall to increase temperature is quiet less than its contribution to the reduction. This is a clear indication of the comparative effectiveness of earth elements over the conventional walls.

This shows that the integration of an earth element has a great potential to moderate the felt comfort level inside the space. The earth stores thermal energy and radiates a great amount of it back to the outside environment itself. There are no radial discomfort zones shown round the earth element that indicates its contribution to the increase of the temperature inside.

5.4 Effectiveness of earth roof



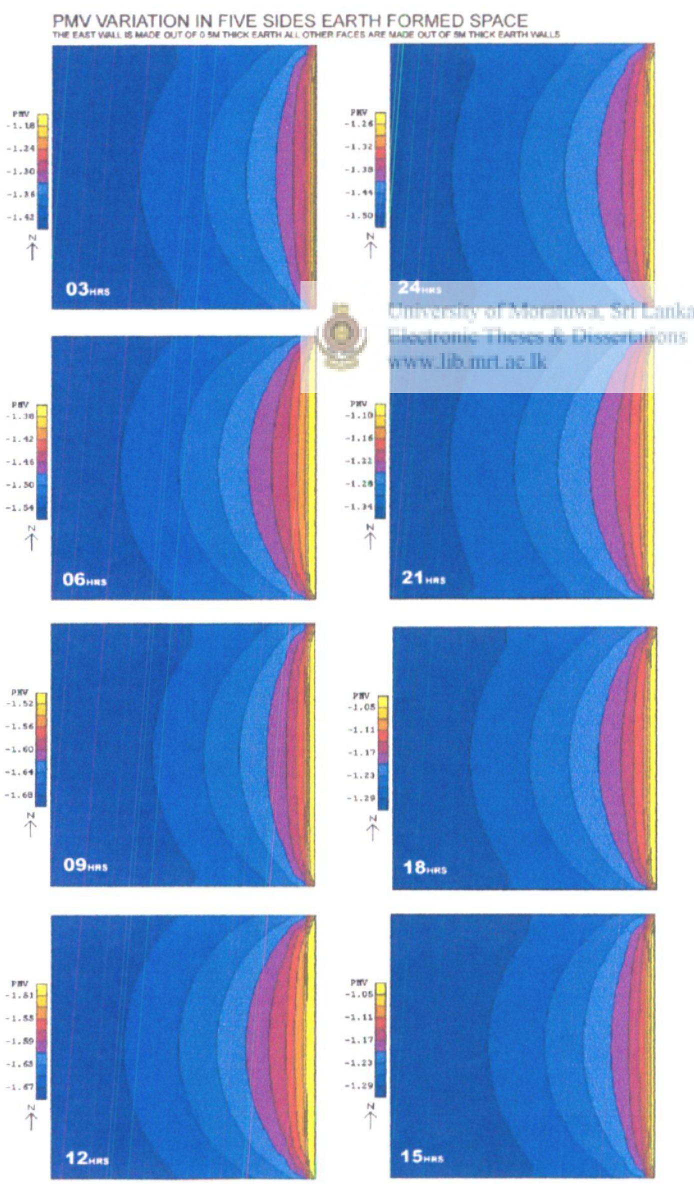
Tab. 5.5

Instead of an earth wall, an earth roof of 10m thickness is inserted to the reference case. This is to compare with the case two where the effect of an earth formed wall is considered. The results show a drastic reduction of temperature. The average temperature has become 31.2^{0}C, which was about 33^{0}C in the case of an earth wall. The curve tries to be equal to that of the previous earth walls case where the temperature variation is minimal.

This reveals that the roof becomes an effective element in moderation of thermal comfort levels in relation to a wall. The integration of a thick earth material layer on top of a space is going to result a more effective changes of comfort levels inside.

The effect of the drastic changes of the temperature of standard masonry walls dominate the graphs that the effect of the roof cannot be identified with simply studying them. A careful comparative study is required in relation to the reference case.

The effect of the temperature variation of the walls is more prominent in the space with an earth roof. The sensitivity of the interior thermal comfort level to the temperature of the walls is predominant. The internal temperature is receptive to the drama of the environmental temperature variation.



Tab. 5.6

5.5 Thermal performance of a predominantly earth building

This is a typical cave structure where the space is defined with massive earth elements with a thickness of 10m instead of one side.

dramatic reduction of the average temperature. The average temperature falls within 25.2^{0}C, which is an optimum comfort level for a tropical man. The temperature to not exceed 25^{0}C and seems to be constant all the time in relation to the reference case.

The most important thing to notice in the graphs is the darker area to the west and the lighter area to the east, which is present in all the graphs with slight variations but without altering. The east stands as a heat source forever and the west wall have become the perpetual heat sink.

The thermal sense of the space do not change that in this case it is easy for an Architect to imagine space in terms of it s thermal sensation because how one persevere the space in terms of thermal sensation is as solid as earth itself and do not going to alter.

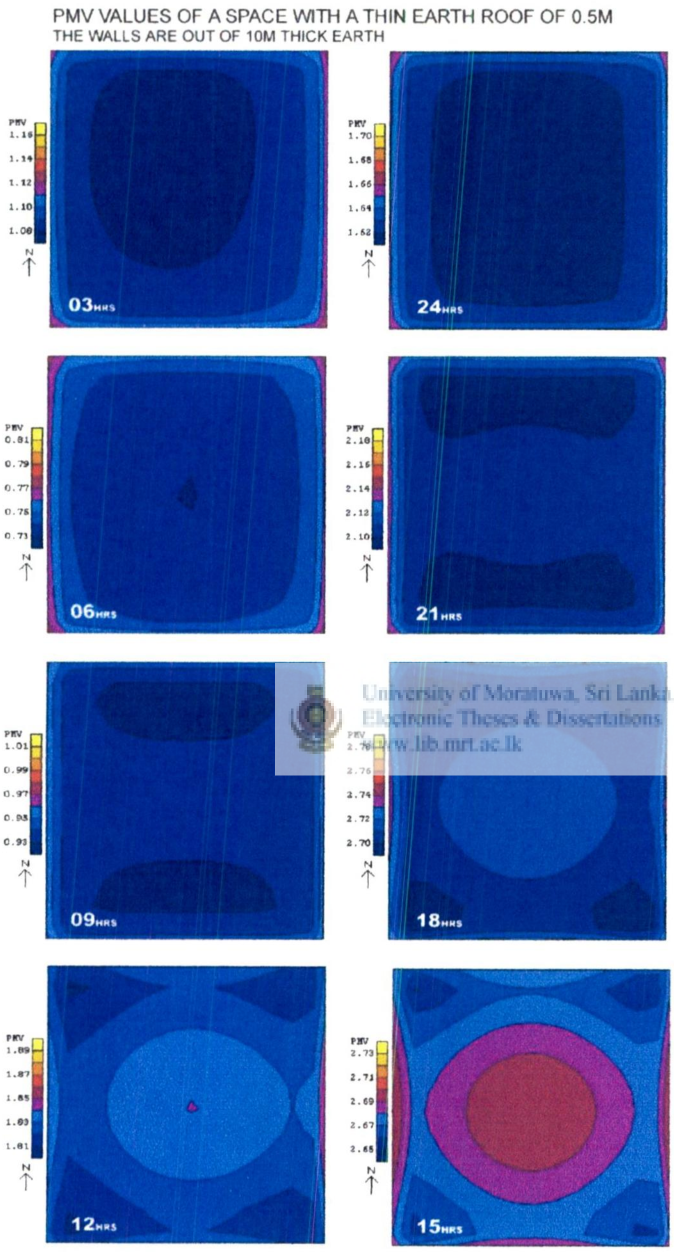
5.6 Effectiveness of earth enclosure

In this case, a space created as an indentation or a well into a heap of earth is considered where the top is covered with a thin earth element of 0.5m. The space is made with 10m thick elements of earth

The results show that even in this case the level of temperature is considerably low. It clearly shows that there is only a bare difference to the case above but in that, the situation is slightly better.

At 15.00, the red spot at the centre suggests the contribution of the thin earth roof to the heat generation. At this time all the earth walls of north and south seems to act as heat sinks that they absorbs the internal heat. This thermal spot is present only from 12.00 to 18.00 it is clearly seen that the opposite takes place at 24.00. The temperature of the centre is lower whereas at the edges of the walls, the temperature is high. The cool spot may partly be the result of the low air temperature but the contribution of the thin earth roof is clear.

may partly be the result of the low air temperature but the contribution of the thin earth roof is clear.



Tab. 5.7

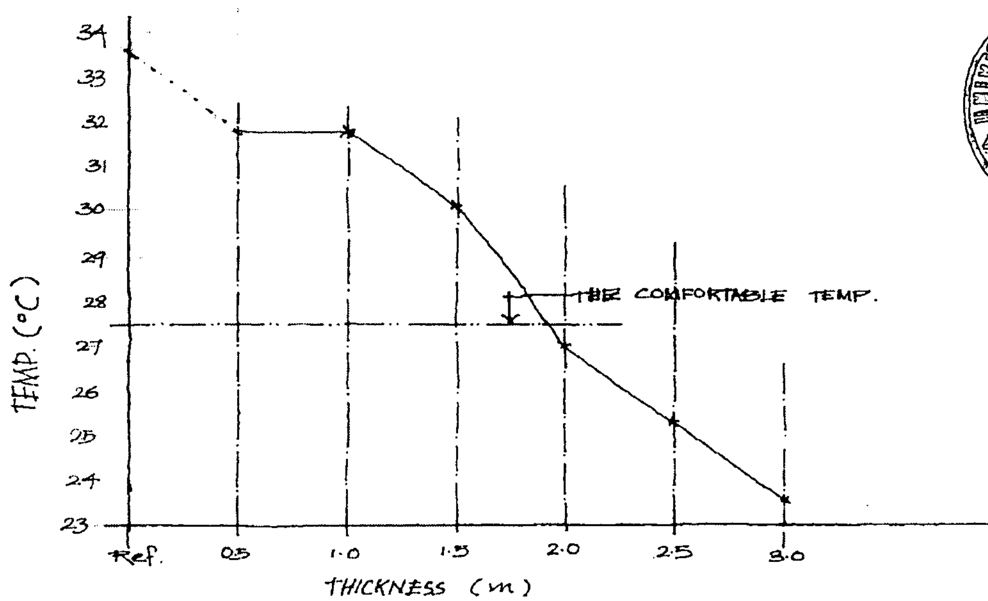
Though the roof is the predominant source of heat, what this shows is that even without a roof cover it is possible to create comfortable earth buildings. Those limitations of creating earth roofs due to the intrinsic properties of earth material, does not limit the use of it.

The case is compared with another study of a model of the same space with north and south facing walls replaced with masonry. The temperature variation is plotted and compared with that of the roof less. Standing well above, the graph suggests that the roofless situation is far better. Therefore, it is clear that although the north and south facing walls are considered less effective in relation to the roof, the governing factor is not the effectiveness of individual element but the enclosure. The effect of losing two sidewalls of $2500m^2$ each

When we look through all the cases above it can be identified that higher the number of earth surfaces present, the level of thermal comfort is also high. What this strongly suggests is that the important thing is the enclosure – the percentage of earth surfaces in the envelope of the building. More the enclosure of earth is, more will be the level of thermal comfort. The effectiveness of individual elements has a less regard.

5.7 The effect of thickness

A space of 50mX50mX50m is created and the thicknesses of the walls are changed from 0.5m to 3m. The thicknesses beyond 3m are not tested due to the identification that the level of comfort achieved with 3m thickness is fully satisfactory that there is no theoretical need to go beyond. The spaces are tested on 23rd march at 15.00 hrs. the time and the date are selected at the times where worst conditions are expected to occur. As a reference, an ordinary masonry constructed space with 225mm thick plastered brick walls and a 100mm thick concrete slab is tested at the same conditions.



Tab. 5.8 The variation of resultant internal air temperature with the increase of thickness

Air temperature levels are plotted in a graph for comparison. The range of temperature variation is between 23^{0}C to 33^{0}C. That is a range more than 10^{0}C. the worst conditions have occurred in the case of masonry construction where it shows an air temperature of 33.6^{0}C. In the case of thin earth walls with a thickness of 0.5m, it is 31.9^{0}C, which is a 3^{0}C drop. However, at 1m thickness, the results do not show a difference and indicates an equal level of temperature to the case of 0.5m thickness. A continuous temperature drop is visible clearly from 1m thickness to the 3m thickness.

The graph can be hypothetically completed with the theoretical understanding that at 0m thickness, the temperature should be equal to the temperature of the environment and at the infinite thickness, the temperature should reach 0 Kelvin.

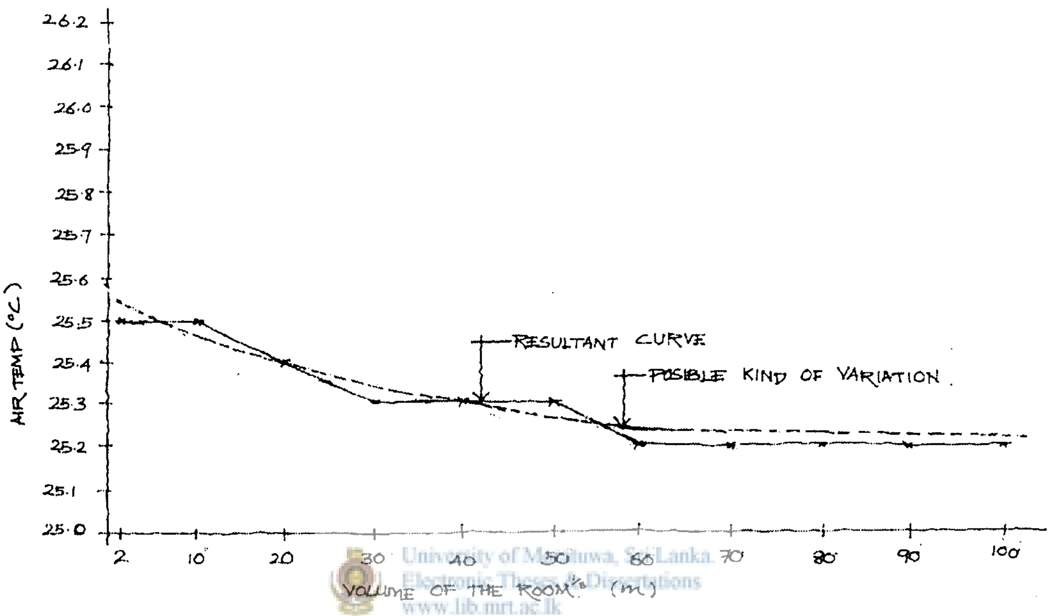
The study strongly suggests the importance of the thickness of the used earth elements and the effectiveness of the thickness on the resultant temperature levels inside the spaces. The thickness is the governing parameter and therefore the factor to be strongly considered in the integration of earth to Architecture.

5.8 The effect of the magnitude

Spaces of cubic shape are created with different volumes. the volume changes from 8m^3 to 1,000,000 m^3 resulting a variation in the volume to surface ratio of 2 to 100. The range tested is so vast. The thicknesses of the walls are kept at constant value of 3m. The cases are tested on 23rd march at 15hrs. The change of the surface to enclosed volume is the variable of the study.

The results show a continuous drop of the temperature with the increase of the magnitude of the space, resulting a relative decrease in the surface area. The level of air temperature resulted in the case of 8m^3 space is

25.5^{0}C and in the case of 100 m^3 it is 25.2^{0}C. For a range of the variable from 2 to 100, the resultant temperature drop is only 0.3^{0}C. It is very clear that there is a relationship of the magnitude to the resultant temperature level inside due to the gradual drop of the temperature level with the increase of the magnitude.



Tab 5.9 Variation of the resultant air temperature with the variation of the volume of the room

However, it is wonderful to find out that the parameter has no considerable effect at all. For a variation of the size of the volume nearly by 100,000 times, the effect is only a deduction of 0.3^{0}C. What this indicates is that the matter what we are going to create with earth is a small toilet or is it the worlds largest theatre, does not have a considerable effect on the resultant level of temperature.

This contradicts with the idea that earth Architecture will be of integrated hives of spaces that minimises the surface area. What this shows is, there is freedom to scatter spaces into individual units as small as little toilets, without much trouble on thermal comfort.

5.9 Concluding remarks

The results indicate the importance of exploiting the possibility of using earth elements as bulks, heaps and boulders instead of thin walls. The effectiveness of huge earth elements is such that it clearly displays the faultiness of the idea that it is impossible to achieve thermal comfort in Sri Lanka without using energy.

The identified effectiveness of the earth roof is a major challenge to explore because instead of integration of rocks, there is barely a minimum ways to construct an earth roof due to the brittleness of earth material.

The integration of an earth roof to a conventional masonry construction and integration of an earth formed west wall to a conventional concrete building have created a relative difference in the resultant levels of thermal comfort. However, when it is compared to the difference occur due to the increase of the number of earth surfaces, it is understood that what is governing is the number of earth surfaces present. Therefore it is seen that the over the importance of the orientation of earth material, the earth enclosure or the amount of earth elements present becoming more important.

Moreover, it is seen that the magnitude of the spaces have almost no effect to the level of thermal comfort. Whether an earth-formed space is larger or small does not determine the level of air temperature inside.

Thin earth walls too have moderated the level of resultant air temperature, but the effect only has made the situation slightly better. Integration or replacement of conventional material with earth within the range of conventional concepts of spatial articulation and spatial encapsulation, the situation is going to be only slightly better. The effectiveness of the thickness of earth material is to be identified as a major parameter of the temperature levels resultant inside the spaces. A little change of the thickness makes a greater difference of the resultant level of thermal comfort.

This clearly indicates the need to go beyond the conventions of walls and roofs and rethink of space with new dimensions of principles of spatial definition. More over it is clear that the kind of Architecture is of more enclosed kind and the shape of the building and the scale of the building has little to do with the resultant level of thermal comfort and therefore does not stand as generators of thermal comfort conscious earth Architecture.

CONCLUSION

The principles, concepts and Application

CONCLUSION

6.1 Principles for thermal comfort conscious earth Architecture

The research is incomplete and have missed its soul purpose if not suggest applications of the identified phenomena. In the case of integrating earth to Architecture, the suggestion of application needs to be different from the conventional, because here it deals much on the creation and the creativity of the individual designer. For instance, in case of urban design, it is possible to indicate patterns of streets and ways to shade them. However, in case of earth Architecture such suggestion will 'freeze the clay on designers' hand'. The act of creation is fragile. Much thought and care needs to be given to the impingement of criteria and methods or else, instead of facilitating creativity and evolution, it may force the designer to select within few given prototype solutions. To preserve the abstract nature of the principles is important whereas the concretization of them leads to prototype repetition of pre-conceived solutions. The intervention of the writer should not choke the art of Architecture.

Therefore, the identified principles of the thermal behaviour of earth material are to be brought forward with its aspects of mechanism, result, consequences and Architectural value. What kind of Architecture the application of such principle would generate is the important aspect to understand.

6.1.1 Less effectiveness of thin walls

The thinnest wall that can be practically built with earth material to last is thicker than 0.5m and the simulation study have clearly shown that the use of such walls cannot contribute much to the reduction of felt temperature inside the space even at the extreme situations where entire space is encapsulated with the material. Even the walls as thick as 1.5m have brought the temperature down to 30^0C at the peak times. However, in comparison with the conventional masonry walls, the performance of earth walls has clearly shown better results.

6.1.2 Use of massive elements

Therefore, the first principle that can be identified in the use of earth to create thermally comfortable places is the importance of the presence of massive elements. To make spaces with invariably good thermal conditions, it is necessary to go beyond the thin wall. The elements that define the space need to be as massive as 3m thick.

The use of huge walls appears to have many fundamental practical problems. Mainly the space that is taken by the material will be greater in relation to the space enclosed that in case of the situations where the value of space is high, the use of the suggested principle is a challenge.

6.1.3 Use of earth roofs

It is clearly shown that the roof is the element that mostly contributes to the temperature inside. Therefore, in earth Architecture, importance of the earth roof is to be identified.

The creation of an earth roof is challenging due to the physical properties of earth material. Lack of tensile strength has confined its use to arches, domes and vertical construction unless alternative precautions are taken. The possibility to use rocks that can tolerate tensile stresses is vital in this situation.

The spreading of a building horizontally increases the susceptible roof area. Kinds of 3D spatial articulations can be expected which facilitates making of spaces one above the other but in extra ordinary ways in both form and composition that exploits the possibilities of earth material.

6.1.4 Use of earth walls at west

Next to the roof, it is identified that the most effective element that contribute to the level of thermal comfort as the west facing wall. Optimal earth-cover of the west facing elements, therefore, has to be encouraged. Mostly, in the case of integrating existing earth elements, the orientation of the resultant space has to be decided with attention to this principle.

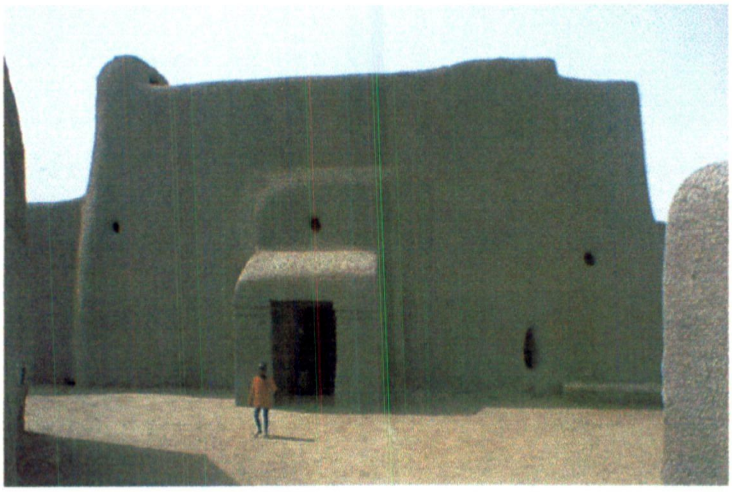
The second most effective element is the east facing one. North and south facing walls have comparatively less effectiveness. However, for the better thermal performance, the earth cover is to be maximised regardless of the direction.

6.1.5 Less effectiveness of surface to volume proportion

This refers to the magnitude of the created spaces. It is seen that larger the space, the resultant temperature inside the space tends to go down due to the decrease of surface area in proportion to the housed space.

The effect of this parameter is so minute that the difference between a space of $8m^3$ and $1,000,000m^3$ was only 0.6^0C. It is understood and in many cases of conventional insulators proven that this proportion is one of the most critical governing factors of heat flow. But in case of earth Architecture, the variation of the magnitude have meant almost nothing to the internal resultant temperature.

6.1.6 Increase the earth enclosure of space



6.1 An earth house in Mali.
Small openings help prevent the entry of dust, heat and glaring sunlight

It is shown that the enclosure of earth is one of the governing factors of the level of thermal comfort inside the spaces formed. This suggests not only the increase of the amount of earth surfaces but also the minimization of the size of openings.

The nature and the form of the openings will differ from the conventional. With the arising of the problems of receiving enough lighting and ventilation, there is the need to rethink the nature of Architecture and the form of space with form and position of openings. Therefore, the importance of earth enclosure will fundamentally affect the nature of the resultant kind of Architecture.

6.2 Challenge behind integration of earth to Architecture

The form of climate sensitive earth Architecture can be imagined with the above. It mainly consists of volumes enclosed with large elements of earth. It retains the fundamental nature of earth Architecture – the sense of weight, embracement of earth, smooth forms etc. - rendered at the first chapter.

Whether such a kind of building with huge walls and thick roofs is possible in urban and sub urban situations is the main issue here. Though it is less expensive in terms of costs for material, it is extravagant in terms of cost of space. When it comes to the encapsulation of large volumes of integrated spaces, the magnitude of the required elements of earth is increased. As it is explained with the example of large legged animals, the need of huge bases is intensified with this.

6.2.1 Required change in design approach

It is with convention we see and with convention, we criticise. Without convention, we may not have a vision, a base of perception. The convention illumines the land of imagination. Convention forms concepts – the base of thought.

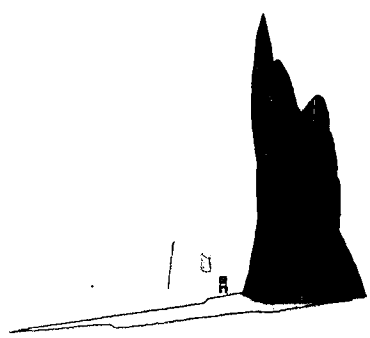
The convention, at the same time, stands itself as the barrier of imagination and perception of space with magnanimity and broad scope. The convention narrows the vision of the designer and keeps him in an unknown and unseen fetter of thought. The convention windows the vision of the designer, makes him see one clear path but at the same time, prevents him see many other paths, which otherwise he would have taken.

The conventions of space are the floor, the wall and the roof. We design in terms of them. That is, we unconsciously restrict our freedom of imagination to the limits of them. It is an unknown bond, formed within the designer himself to go not beyond the pre-conceived concepts of wall and roof. Wall gives a guideline for the designer, but at the same time, the concept of wall skirts the radical creativity.

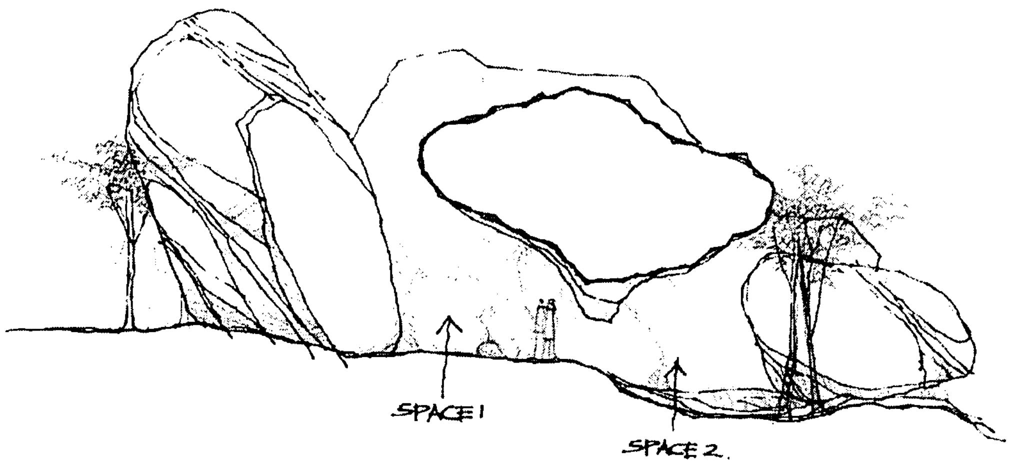
We perceive space in terms of the concepts of walls and roof. Anything that encloses space is proliferated in terms of walls and roofs. The walls of imagination are the walls of perception too. Our concepts determine what we see. The space we see is not the reality, but the way the reality is proliferated by ourselves. The conventions of space restrict broad perception.

This aspect of space is important in the earth Architecture of thermal comfort because the need to explore the limits of conventions, here, is imperative. Here we discuss the need to integrate huge elements of earth and rock to define space. The problems of space the earth elements take are due to our conceptual proliferation of them in terms of walls, windows and roofs. The problem itself is a creation of our convention. It is nothing else but due to the restriction of thought and the enslavement of imagination. The restrictions to think in terms of radical ways of spatial definition and radical ways of spatial articulation developed within the realm of urbanity, earth and thermal comfort is the root of all the problems.

It is a deep-rooted prejudice that it requires a wall to define the boundary of two spaces. When we look into the naturally formed places of living, it is seen that no ware the spaces are defined with walls. Instead of definition, the boundaries are suggested. The boundary, the limit and the edge are the meanings of spatial art and the wall is only one way of projecting that meaning. The wall, as far as the poetry of space is concerned, stands as a far more direct and precise statement, where as the suggestions of a boundary always appear to be more artistic - science states where as poetry suggests.



6.2 Presence of a rock boulder in a desert



6.3 A rock formation at Vessagiriya

Figure shows a rock formed cave in Vessagiriya. The protrusion in the top breaks the room into two. The boundary of the two spaces is only a small niche hanging down.

In a barren, the presence of a single boulder itself has the potential to generate the sense of a space. Its boundaries are not defined but the presence of them is felt round the boulder as a sense of its territory. Taller the boulder, the height of the felt space is greater and at the same time, the expansion of the felt boundaries too is high. The room, the space, is something proliferated by ourselves.

When the space we see is something we project into the reality, the flexibility and freedom the designer of earth Architecture can enjoy is increased. The ability to suggest spatial meanings by facilitating the spatial cognition or the spatial interpretation of people instead of putting them down as concrete physical elements is the key tool. An earth Architect that drives his imagination without sticking into fossil assumptions and rooted conventions of space, and let his creativity thrive on basics of space, shall arrive at extra-ordinary designs that well addresses the very root of the problem.

The suggested difference of design method lies in the act of thinking with absolutes instead of conventions. For an instance, in case of solar penetration into the building, while another one goes to select shading device from the conventional set, the earth architect need to take into him the absolutes of the behaviour of the sun. He will, instinctively, be with the sun and within himself, be the sun and thereby facilitate the evolution of a design in the realm of his imagination to address the problem.

The resultant kind of Architecture of earth, in this case can be so flexible and vivid. However, three basic principles are seen to have potential to dominate the entire culture of earth.

6.2.2 Dual functioning earth elements

The duality of earth elements that defines the boundaries of space will come to be a key constituent. The term duality refers to acting as two things though it is one. For an instance, an earth element, which is the roof of an earth building, can be a recreational park on top. An earth element that defines the boundary of a space can be a high way, which is half elevated.

6.2.3 Using earth as earth itself

To allow earth to stay as earth itself may be another principle. This refers to underground and earth submerged architecture. The use of underground buildings actually retains urban space instead of housing them. By going under, earth becomes the inevitable roof of the created space and on that roof, there may be high ways, car parks or loans and meadows. In an earth submerged building, the boundaries of the space has an infinite thickness and it takes no profitable space.

6.3 Thermal moods of space created with earth

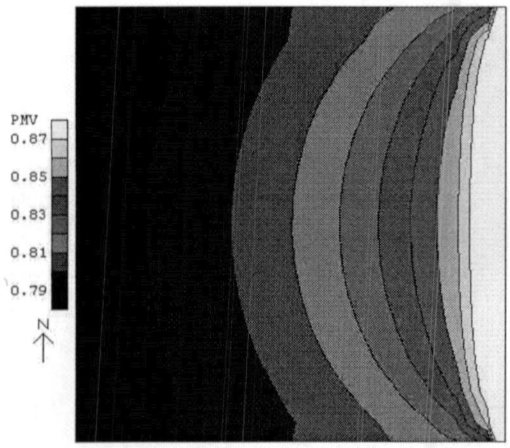
When the standard level of thermal comfort is achieved, the adjustment of it to create a sense of space seems to be possible. However, it is clearly shown that the temperature and the level of thermal comfort inside a space do not stay constant. The level of thermal comfort changes from month to the other and during the course of the day itself. The other difficulty faced here is the human adaptation. That is, after being in a space for a while, we adapt our selves to its thermal level that we stop perceive the space to be hot or cool. Therefore, the subtle use of thermal sensation to create spatial modes is difficult.

However, what can be tuned with the adjustment of parameters is the relative thermal sensation. That is the sense that one space is cooler than the other and the sense that the centre of the space is cooler in relation to its edges.

The adjustment of the thickness of earth material and the ratio of enclosure fundamentally alter the thermal sense of two spaces. The terrible outside thermal comfort level is a virtue in hand of the designer that generates a thirst of thermal comfort in people who enter the building.

The progression of the sense of coolness is an instinctive driver that makes the one who enter move forward. The desire to seek better thermal settings is a sub-conscious motivator that becomes a tool in the hands of the designer, with which he makes the turmoil of movement within the piece of Architecture.

The earth material can be used to enforce the thermal sense of the centre, the entrance and the end of a space. In chapter 2, it is clearly shown that the integration of a reasonable earth element makes an aura of coolness round it. Due to the same reason, the absence of an earth element in a totally earth formed space, gathers a sense of heat round it. In coherence with other sensory perception, the relatively heated area suggests the entrance, the interface of inside and the outside whereas the cool suggests the deep end, the climax, of the space.



Tab. 6.1 Thermal comfort variation at 18 hrs in an earth formed space. The east wall is formed thinner.

Instead of a uniform thermal sense, the integration of earth always tends to result a thermal progression in spaces, which when merged together with the other senses of space, can be used to make strong the instinctive meanings of space.

6.4 Salient splendour of the art of thermal comfort conscious earth Architecture

Many are the aspect to explore in the fields of thermal behaviour of earth, earth Architecture, thermal moods of space and the creative process of design. Only when the research gap of them all is filled, the full bloom of this study happens. One out come of this study is bringing forth the need of research on them.

This dissertation is an attempt to show that the use of thermal sensation as an integral part of creating spatial moods is an art. The practice of which, under the tropical sun, can be thought in no way but with integration of earth. Earth as an integrated element in built environment is so special. Its performance as a thermal barrier is so different. Therefore, in using earth, there arises the need to think different and think special. The deep-rooted bedrocks of convention need to be explored.

Being an art, the splendour and the divinity of the act of creation is to be preserved and facilitated that prototype solutions are not suggested. Earth Architecture has a history - history as long as the human civilization – upon which the designer has to build his individual base of thought. This dissertation has spread at the feet of the creator the principles behind the thermal performance of earth and the nature of earth as a material. The principles are abstract – based on which, the designer can perform alone.

Only a glimpse of suggestion is made on the nature of earth Architecture created for this particular purpose. It is of integrated bulks instead of walls and roofs. The possible doubt is how one can manifest such a difference of forms and spaces in the imagination without guidance.

The answer is - look upon the Earth! Look at the bat. Look at the lizard, look at the banyan, look at the pumpkin, and look at the earth warm. Each is a creation - a so spatial creation. Look at the thoughts behind the creation of each. Behind the flexibility, the ribs, the slipperiness, the form and the scale of the earth warm, lay the qualities of the material of living tissue, the desire for survival and the imperative need of regeneration. Look at how these concepts are woven together with the concepts of sustainability and interdependency on the environment. The creation of the creature is a proliferation of those concepts and, so is the earth Architecture.

The clear realization of the principles and the phenomena leads the creative mind to imagine in terms of them. The main objective of the conclusion is to lead towards understanding the thermal performance of earth in such a way that it forms the base of thought on which one can develop his own way of imagination.

To draw the relationship of form and thermal sensation is the key constituent here. The cessation of rooted conventions of thinking makes the ground of imagination broader. Then, where the depths of thought where imagination thrives is enriched with realization of the basic principles, the weaving of the concepts of earth and the concept of thermal sensation into the socio-cultural and economic fabric begins to takes place.

Creation is divine. Creation is unconscious. It happens in an unfathomed depth of mind. We can enrich the depths of mind with identified principles and remove the weeds of pre-conceived thoughts. We can enforce creation by being passionate. We have control over the act of creation. However, the human creator cannot create – but let it happen within himself. Creation is unknown.

The verity of spatial needs, the verity of thermal moods can generate an outburst of a verity of forms and concepts in earth Architecture. Where the background information is compiled, the only mundane requirement is the clarification of principles and identification of application of them - the Illumination to the land of imagination.

BIBLIOGRAPHY

BIBLIOGRAPHY

Basu A., (2003). ***An Overview of Earth Architecture.*** http//.www.eartharchitecture.com. (2003). http//.www.carpetarea.com.

Billington N., (1952). ***Thermal Properties of Buildings.*** London: Cleaner Hume.

Carmody J., (1993) ***Underground Space Design.*** New York:Van Nostrand Reinhold.

Diamant R.M.E., (1986). ***Thermal and Acoustic Insulation.*** London: Butterworths.

Easton D., (1996). ***Rammed Earth House.*** Chelsea: Green Publishing.

Emanuel M.R., (1993). ***Making the Commons Liveable***: Climate Conscious Urban Activity Patterns for Equatorial Tropics. A Thesis Submitted to the Graduate Faculty of Louisiana State University.
(1999). ***Effects of Roof Insulation on Indoor Thermal Environment.*** Moratuwa: University of Moratuwa.

Eugene T., (1999). ***Evolutionary Architecture.*** Canada: John Wiley and sons, inc.

Fanger P.O., (1970). ***Thermal Comfort: Analysis and Application in Environmental Engineering.*** Newyork: McGrawhill.

Givonid B., (1969). ***Man Climate and Architecture.*** Essex: Elsevier

Horrison P.W., (1993). ***Thermal Insulation Properties of Fabrics.*** Manchester: Textile Institute.

Keable J., (1996). ***Rammed Earth Structures.*** London: Intermediate Technologies.

Khalili N., (2003). http//.www.calearth.org.

Koenigsberger O.H., (1965) ***Roofs in the Warm Humid Tropics.*** London: Lund Humpries.

Koenigsberger O.H., (1973). ***Manual of Tropical Housing and Building.*** Madras: Orient Longman Ltd.

Mason R., (1978). ***Petrology of the Metamorphic Rocks***. Great Britain: Unwin Brothers Ltd.

Matthews H., (1978). ***Investigating the Earth.*** Boston: Hougton Mifflin Company.

Maxwell F., (1982). ***Tropical Architecture in Dry and Humid Zones.*** Malabar Krieger.

Nelkon M. & parker P., (1982). ***Advanced Level Physics.*** New Delhi: Arnold Heinemann Publishers Pvt.Ltd.

North G., (2003). http//.www.carpetarea.com.

Norton J., (1986). ***Building With Earth.*** IT Publications.

Oliver P., (1971). ***Shelter in Africa***. Great Britain: Barrie and Jenkins, Ltd.

Preason D., (1994). ***Earth to Spirit: in Search of Natural Architecture.*** London:Gaia Books.

Romero O., (1994). ***Adobe: Building and Living with Earth***. Italy: Garzanti, Milan.

Schaupp W., (1967). ***External Walls: Cladding, Thermal Insulation and Damp Proofing.*** London: Crosby Lockwood.

Somerton W.H., (1992). ***Thermal Properties and Temperature-related Behaviour of Rock/ Fluid Systerms.*** Amasterdam: Elsevier.

Sperling R., (1971). ***Roofs for Warm Climates.*** London: Building Research Station Publications.

Suini B.S., (1970). ***Architecture in tropical Australia.*** London: Lund Ituphries.

Sundberg J., (1988). ***Thermal Properties of Soils and Rocks.*** Sweedn: Giotechnical Institute.

Watson D., (1983). ***Climatic Design: Energy Efficient Building Principles and Practices.*** New York: McGrawhill.

Yunus A.C., (2002). ***Heat Transfer - a Practical Approach.*** New York: McGraw-Hill Companies, Inc.

Wells M., (2003). http//.www.malcomewells.com.