LAYERS OF ENCLOSURE-BETWEEN THE EPIDERMIS AND EXOSPHERE

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ABSTRACT: The human body is screened from the external environment by layers of enclosure starting from the epidermis (outermost layer of the skin) to the exosphere (uppermost layer of the atmosphere). They affect human comfort level by acting as filters. Previous work in this area identifies three layers namely; the skin layer, the clothe layer and the building envelope. This paper argues the inclusion of the neighbourhood layer and global region layer as valid filters that determine comfort levels .Various illustrations of the concept of these layers acting as filters are given and an overall description of optimal conditions for each layer in different climates is attempted. This work lays the foundation for future work of developing a cornucopian matrix for human comfort determinants.

Keywords - Building Envelope, Comfort Level, Epidermis, Exosphere, Micro-climate.

1. INTRODUCTION

This paper was inspired after I shifted the initial thoughts for my PhD research from passive cooling of tropical skyscrapers to investigation of possibilities for a symbiosis between tropical skyscrapers and neighborhoods (Eco-symbiosis between photosynthetic skyscrapers and Eco-neighbourhoods).I was concerned about which layer of enclosure should be given the most attention in providing the right environmental filters for thermal comfort, so the target becomes how to fully recognize what layers might exist between the human body and the farthermost part of the planet and what each layer can offer in providing comfort. Previous work in this area commonly recognizes three layers namely: skin, clothe and building envelope but this work introduces two new layers; neighbourhood layer and global envelope. Since this is an initial investigation –a bit afar from the core of my architectural research I recognize there might be some drawbacks especially on the technical input.

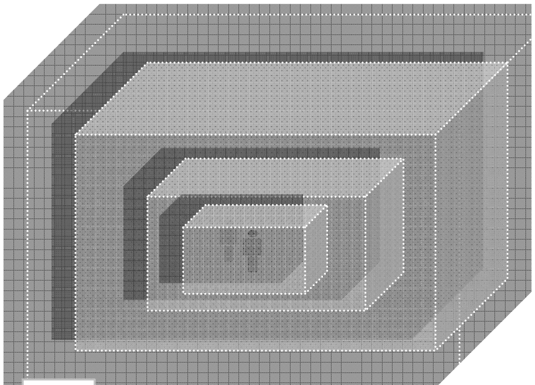


Fig 1

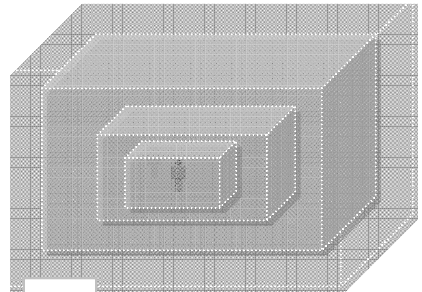


Fig 2

Layers of enclosure

2. THERMAL COMFORT

Thermal comfort relates to the condition of mind which expresses satisfaction with the thermal environment. Victor Olgyay (1963) defines the comfort zone as the point at which man can spend the minimum energy adjusting to his environment .Comfort conditions is defined to be between the temperatures of 21.1^{0}C (winter) and 26.7^{0}C (summer) and between humidity of 20% to 80% (Givoni 1976) **.**In terms of bodily sensations, thermal comfort is a sensation of hot, warm, slightly warmer, neutral, slightly cooler, cool and cold. From the physiological point of view, thermal comfort occurs when there is a thermal equilibrium in the absence of regulatory sweating in the heat exchange between the human body and the environment. It is affected by about six variables which can be subdivided into environmentally controlled and individually controlled variables. Environmental determinants or variables include: - air temperature, air speed, humidity and mean radiant temperature. Individual variables include: activity/metabolic generation and thermal insulation of clothes. Individual differences, recent thermal history and swiftness of acclimatization may also contribute.

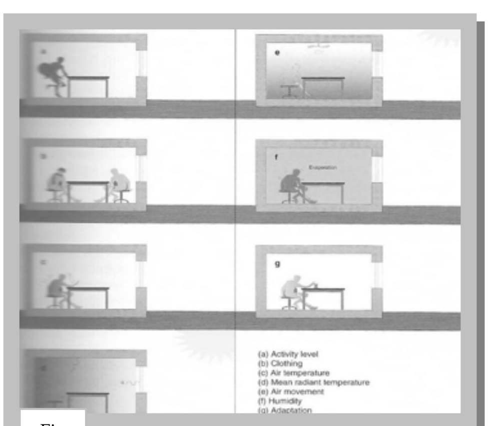


Fig 3

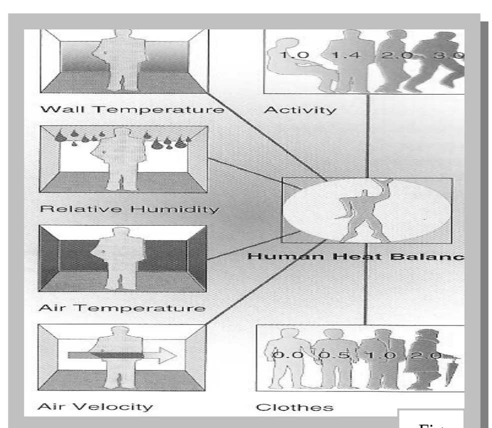


Fig 4

Variables of thermal comfort (Green Vitruvius

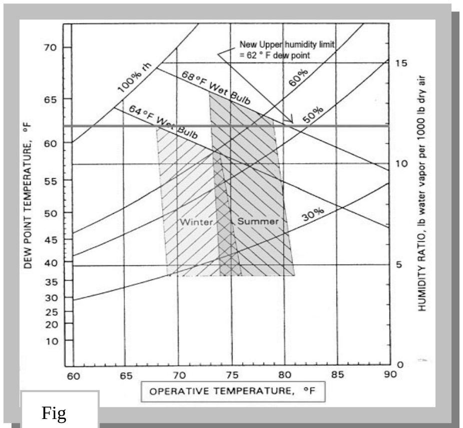


Fig 5

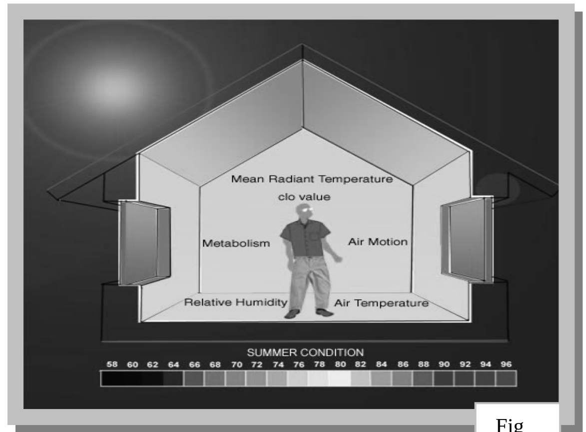


Fig 6

Human body and comfort conditions
(http://www.design.asu.edu/radiant/01_thermalComfort/comfortC_01v

An understanding of the combined effect of these layers will facilitate sustainable design for thermal comfort especially considering that a 1°C reduction in design air temperature for a heating or cooling system can save up to 10% in energy consumption. (A Green Vitruvius 1999)**.**

The psychometric chart covers two key contributors to comfort (temperature and relative humidity).The sun is the primary source of solar heat and humidity is the water contained in a given sample of air at a given temperature. Air velocity also varies with temperature, moisture content and prevailing wind- which are directly related to specific environmental or climatic contexts. Various forms of climate classification recognize up to six contexts e.g. Warm humid, hot-humid, warm dry, hot-dry, moderate and cool. Koppens chart also proposes six major contexts based on prevalent temperature and precipitation; (moist tropical, dry climates, humid middle latitude climates, continental climates, cold and highland climates).

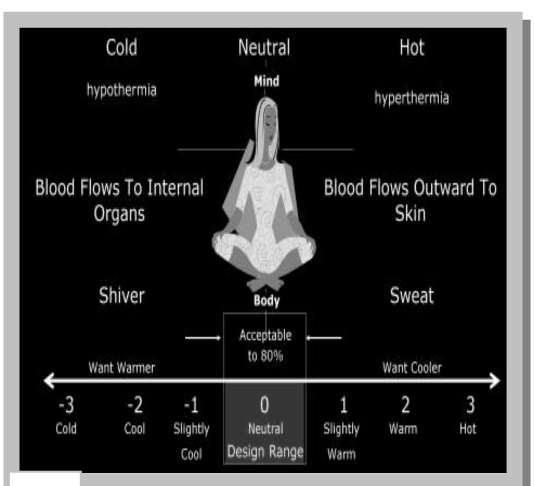


Fig 7

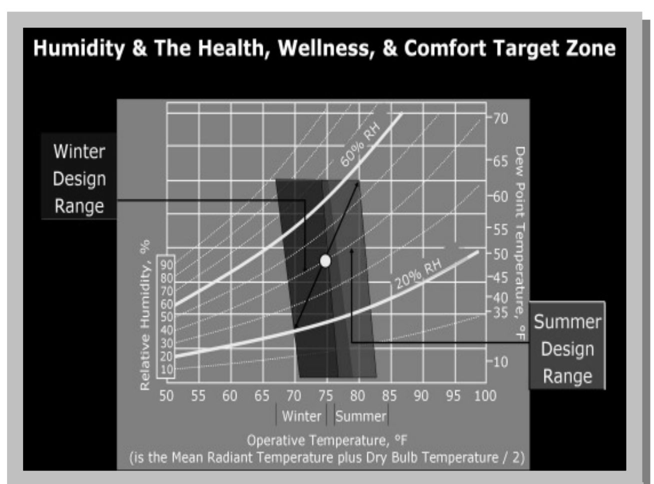
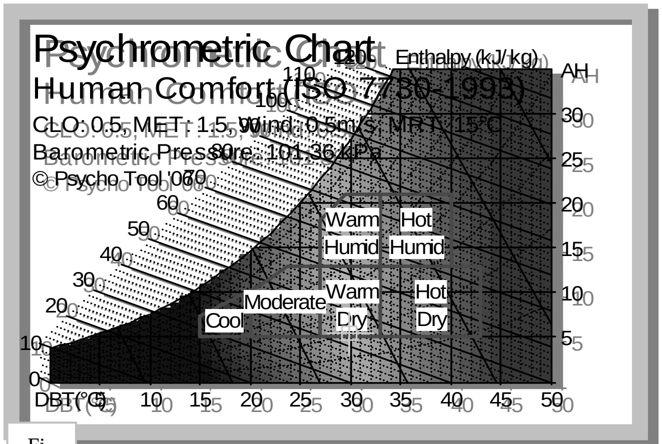


Fig 8

Body comfort conditions



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Six climates type (square1.com)

3. LAYERS AS VALVES AND FILTERS

From an *eco-tectural* perspective, the layers of enclosure can be examined from the closest (skin) to the farthest (the exosphere i.e. the farthest part of the atmosphere).They help keep away adverse conditions of wind, cold, heat and moisture in various climates. Each layer creates a micro-climate concentrically around the body. The skin encloses the body frame and when clothes are worn a new micro-climate is formed. This continues with the building envelope and carriers on to the neighborhood and eventually to the global climate band.

There is an apparent overshadowing and overpowering of inner layers by successive outer layers .So although the body is the focal point; successively distant layers seem to have an upper hand in deciding comfort levels. Perhaps synonymous to governance where the policies from the top flow down to the lowest level.

The layers are not to totally exclude the exteriors but filter and control entry of desirable conditions. They function as valves- a mechanical device for regulating flow of fluids(gases and liquids) by adjustable parts through openings, that open, shut, or partially obstruct in relation to the internal function, level of external environmental experience, space requirement and desired comfort level (Powell 1999)**.**

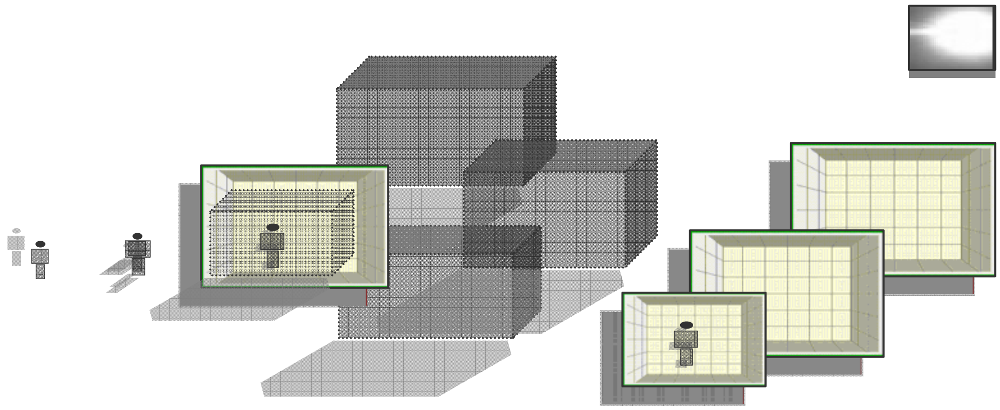


Fig 10

Layers of enclosure

3.1 Skin Layer

The skin is of about 2mm thickness and provides the first barrier between the organism and its environment. In addition, it contains complex vascular systems and sweat glands that allow it to change its conductance in response to thermoregulatory demands of the body. The area of skin on the body can be estimated from the body's height and weight, using a relationship developed by DuBois and DuBois as cited E.Arens and H.Zhang (2001);

$ADubois = 0.202\ M^{0.425}\ L^{0.725m2}$ where *ADubois* is the skin area in m^2, M is the mass in kg, and L the person's height in m.

Skin contains four types of thermally sensitive nerve endings (to cold, warmth, hot and cold pain) that sense the skin's temperature and transmit the information to the brain. Most of the body's heat production is in the liver, brain, and heart, and in the skeletal muscles during exercise. This heat is transferred, through the network of blood vessels and tissue, to the skin, from whence it is lost to the environment. Thermoregulation generally refers to four mechanisms: sweating, shivering, vasoconstriction and vasodilation. Humans maintain their core temperatures within a small range; between 36 °C and 38°C and the skin is the major organ that controls heat and moisture flow to and from the surrounding environment.

Although human body thermal regulation is mainly achieved by regulating blood flow, simulation results confirm that a change of body fat from 14% to 28% can result in a skin temperature change of nearly 1^0 C (Hans 2001).The metabolism itself being influenced by muscular activity, environmental conditions and body size. Evaporative heat loss is another determining factor comprising of respired vapour loss and evaporative heat loss from skin surface. The thermal balance of the body can be expressed as: Met-Evp+/-Cnd+/-Cnv+/-Rad=0 when Gain= Loss (Koenisberger 1974).

Conduction can be a dominant path of heat exchange with the environment: K = hk (Tskin – Tsurface) (W/m2) where K is conductive heat transfer from the skin surface to a contacting surface.

Convective heat loss from the body surface is often expressed as a heat transfer coefficient and the difference between the mean temperature of the outer surface of the body and that of the surrounding air: C = hc (Tskin – Ta) (W/m2) where hc = convective heat transfer coefficient (W/m2 · K).

*The radiation emitted from a surface is proportional to the fourth power of absolute temperature, but it is possible to approximate radiant exchange with a linear coefficient when the surfaces are within a limited range of temperatures.R = hr × ε (Tskin – Tr) (W/m2).where hr = radiative heat transfer coefficient (W/m2 K), ε = emissivity, and Tr = the temperature of the surrounding surfaces. Tr is also represented by the 'mean radiant temperature' (MRT). (Arens and Zhang 2001)***.**

The rates of convection and evaporation at the interface between the human body and the surrounding air are expressed by the parameters convective heat transfer coefficient hc, in W m-2 degrees C-1 and evaporative heat transfer coefficient h(e), W m-2 hPa-1. These parameters are determined by heat transfer equations, which also depend on the velocity of the air stream around the body, that is still air (free convection) and moving air (forced convection). The altitude dependence of the parameters is represented as an exponential function of the atmospheric pressure p: hc approximately pn and h (e) approximately p1-n, where n is the exponent in the heat transfer equation. The numerical values of n are related to airspeed: n = 0.5 for free convection, n = 0.618 when airspeed is below 2.0 ms-1 and n = 0.805 when airspeed is above 2.0 ms-1. (Kandjov 1999)

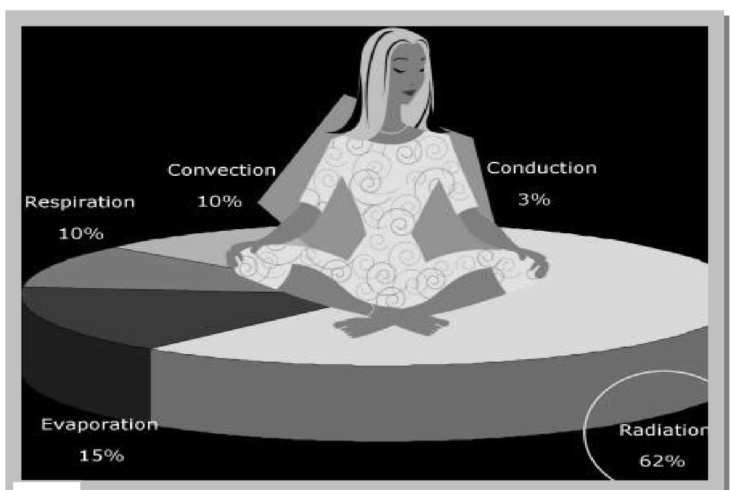


Fig 11

Body heat exchange

Skin color is quite variable around the various climates of the world, ranging from a very dark brown among some Australians, Africans, and Melanesians (near the equator) to almost yellowish pink for northern Europe (higher latitudes). Skin color is due primarily to the presence of a pigment called melanin which is normally located in the epidermis, or outer skin layer. It is produced at the base of the epidermis by specialized cells called melanocytes. (O'Neil 2006)

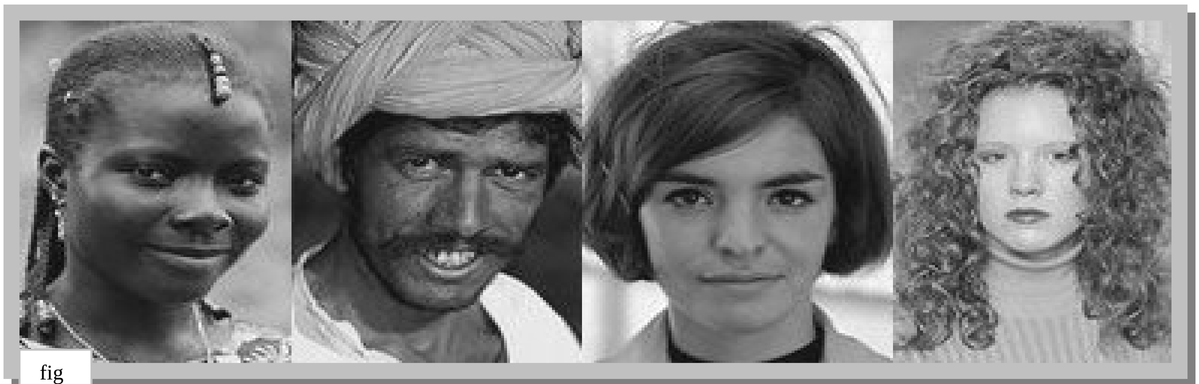


fig 12

Skin colours in various climates
(http://anthro.palomar.edu/adapt/adapt_4.htm)

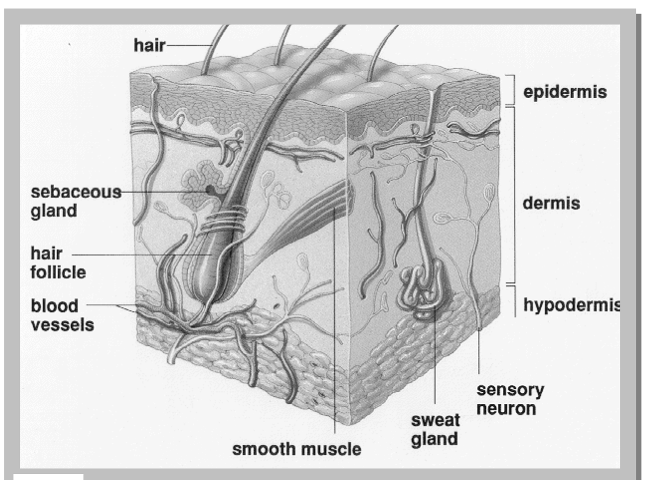
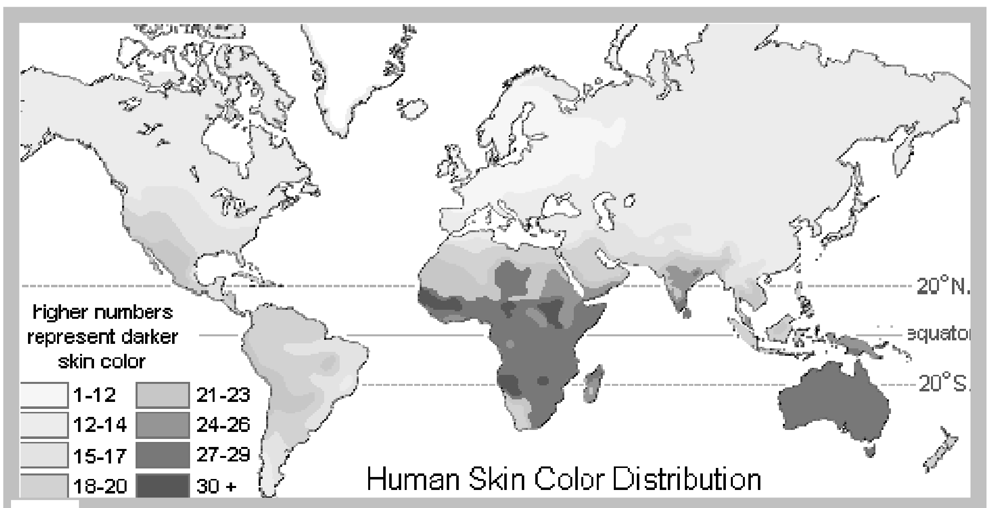


Fig 13

Cross section of skin (http://www.agen.ufl.edu/~chyn/age2062/lect/lect_19/174.gif)

Apparently, nature has selected for people with darker skin to live in tropical latitudes, especially in non-forested regions, where ultraviolet radiation from the sun is usually the most intense. Melanin acts as a protective biological shield against ultraviolet radiation. By doing this, it helps to prevent sunburn damage that could result in DNA changes and, subsequently, melanoma a cancer of the skin. Those at highest risk are European Americans; who are more vulnerable than African Americans.

In northern latitudes, lightly pigmented skins allow more sunlight penetration in the few periods the sun is available for the formation of vitamin D.In more arid climates a familiar adaptation is the high height-to-skin surface ratio, reducing the ease of evaporation from the skin. Cold climates favor deposition of fat, a short stature and white skin. Hot climates favour a lean and tall body frame. Obese people are generally poorly adapted to hot climates .People living in the tropics have less adipose tissue beneath their skin i.e. .A low body weight in relation to skin surface.



Fig

Human skin colour distribution in various climates
(http://anthro.palomar.edu/adapt/adapt_4.htm)

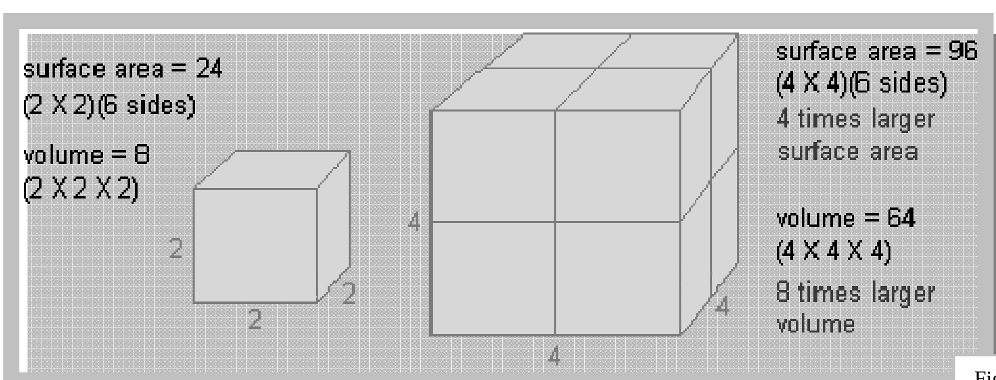


Fig 15

Comparison of cube surface areas and volumes illustrating Bergmann's rule
(http://anthro.palomar.edu/adapt/adapt_2.htm)

The relationship between surface area and volume of objects as seen on the human skin was described in the 1630's by Galileo. It can be demonstrated with the cube shaped volumes (Bergmann’s rule).It shows that the volume of the cubes increases twice as fast as the area. The same reason people with relatively less surface area loose less heat.

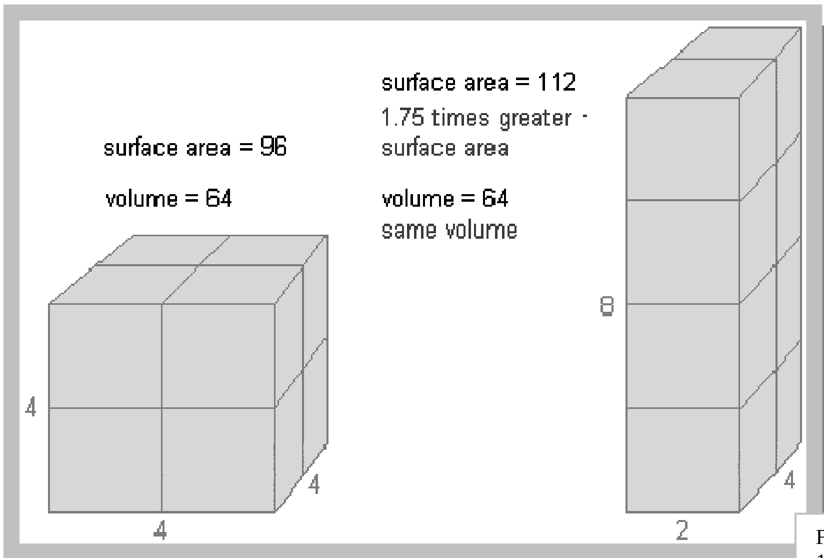


Fig 16

Comparison of different shaped box surface areas and volumes illustrating a corollary of Bergmann's rule relating to body shape (http://anthro.palomar.edu/adapt/adapt_2.htm)

A good example can be drawn from polar bears whose big, dense bodies and small surface areas help retain heat in the attic region. Bergmann's rule generally holds for people as well. So there is an inverse relationship between relative body mass and average temperature. A deduction from this would mean that a linear shaped person will lose heat faster than a more compact one of similar size. Hence the slender, narrow box which has the same volume but greater surface area would lose heat faster than the stout one.

Fig 17

Slender East Africans with long arms and legs predicted by Allen's rule (http://anthro.palomar.edu/adapt/adapt_2.htm)

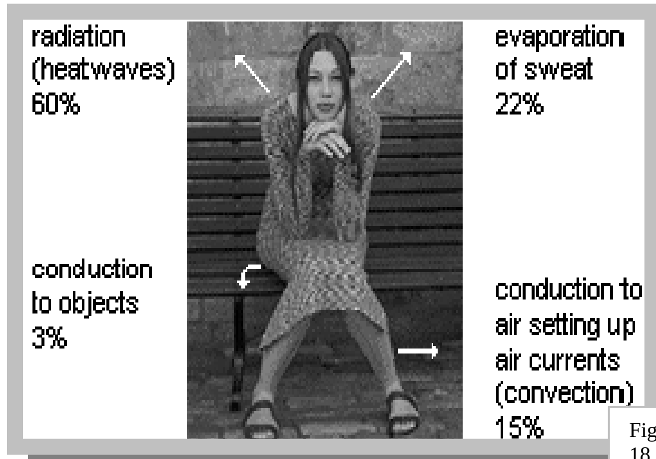


Fig 18

Normal processes of body heat loss in a moderate climate (http://anthro.palomar.edu/adapt/adapt_2.htm)

Joel Allen (1877) advanced the idea further and observed that the limbs and appendages of people living near the equator appear longer that those living farther towards the poles and this is related to adaptation of those parts helping with the release of unwanted heat into the environment by their slenderness ratio. Hence with the overall relative high skin surface area per unit mass, warm-blooded animals and people in warm climates dissipate heat through the skin in other to maintain the desired thermal equilibrium and comfort.

Hence the most favorable body shape in the hot tropical parts of the world is tall slender bodies with long limbs that assist in the loss of body heat .But stocky body with short appendages would be appropriate for people in cold regions. (O'Neil 2006)

3.2 Clothe Layer

Clothing is the second layer or skin that screens the body from external forces and is used outside the skin to extend the body's range of thermoregulatory control. It reduces sensible heat transfer, while in most cases permitting evaporated moisture (latent heat) to escape. It is relatively the easiest regulator to manipulate in other to enhance comfort conditions. Usually simple things as choice of clothing, taking off and putting on appropriate clothes precede mechanical modes of adjusting comfort conditions. Thermal sensation hence varies with type of clothing material, and the fit of the garment. Generally wool makes people feel more warmth when entering a humid space (Fanger 1989)**.**Polyester or bare skin creates a passing effect of change in humidity whereas the effect is longer with wool simply because of absorption or disorption in wool unlike the polyester which is scarcely affected by change in humidity. The clothing insulation of clothing worn is characterized as a single layer covering the whole body surface (approximately $1.8m^2$) measured in Clo units or $K.m^2/W$.

People usually change clothing according to outside temperatures; i.e. people choose clothes more for outdoor than for indoor climate which is very understandable. In practice however, women are able and tend to adapt (the insulation level of) their clothing more to the outside temperature than men. In addition to this, individual people are different not only in choosing their clothes but in thermal responses and thermal adaptation to the environment as well. Factors reducing clothing insulation include; wind speed, body movements, Chimney effect, bellows effect and water vapor transfer.

Clothes are very flexible as filters because of the ease with which they can be changed or enhanced as compared to other layers. They are a relatively cheap way of amending the micro-climate around the body. Someone said “There is no such thing as bad weather, only bad clothing choices.” People have the choice to achieve appropriate thermal conditions by the right choice of clothing with respect to the prevailing climate or micro-climate but sometimes they don’t. Rather they go for a fashion or style oriented dressing. In cold climates, layers of clothes are better than one thick coat and the air space in between are considered as an additional layer of insulation. The purpose is to insulate skin surface and prevent heat loss by trapping air and modifying skin micro-climate. Here weave is more important than nature of fabric. A common recipe would be soft textured but tightly-ribbed thermal underwear made of wool or wicking polyester, then a heavy sweater maybe of wool or synthetic fleece that can hold body heat preferably with insulting lining and finally a winter moisture-repellant jacket. Cotton is not favored as much since it stays wet and feels wet if it gets wet which in extreme cases can cause hypothermia.

Sun protection is the primary function of clothing in the hot climates and one that will allow air passage especially in hot-humid zones. Cotton or polyester with loose comfortable fit is recommended. Dehydration is a major issue hence excessive sweating is addressed by appropriate dressing and regular water intake. Light colors that reflect rather than absorb solar radiation are always preferred and the reverse applies in cold regions. But fashion obsession sometimes overrides common sense in some quarters consequently you see people in dark three-piece suits in the hot-humid zones sat in air-conditioned offices with window blinds to shut off radiation penetrating the all-glass envelope!. Simply because they are following the so-called “international dressing style” at all cost. The comfort margin within building interiors of a hot climate is clearly reduced by thick dressing except of course if unnecessary energy is spent to cool the space mechanically.

Fig 19

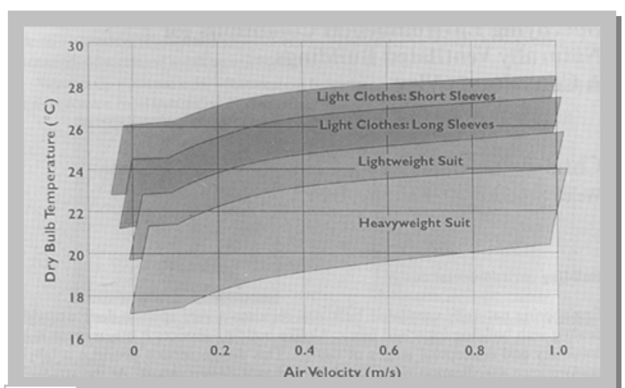
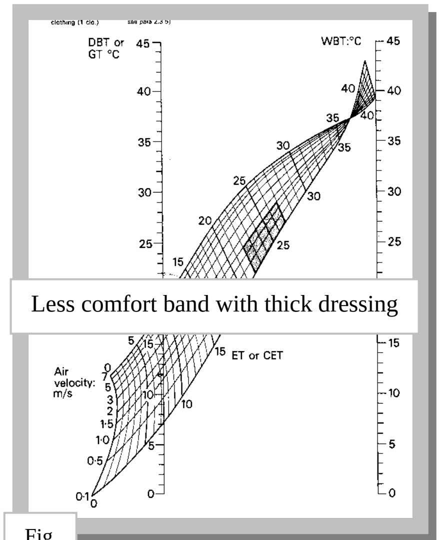
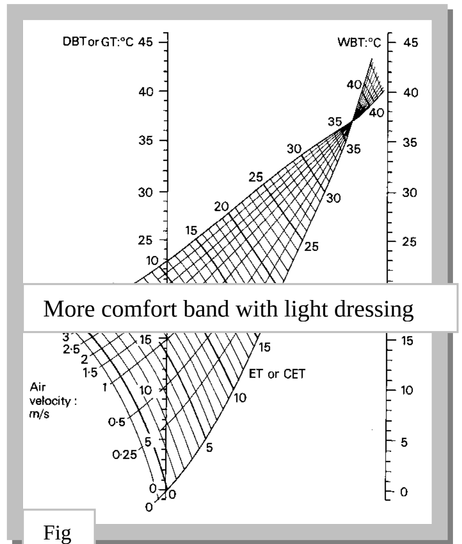


Fig 20



Less comfort band with thick dressing

Fig 21



More comfort band with light dressing

Fig 22

(19-22) in hot climates, comfort band varies inversely with heavy dressing *(20-22) (Koenigsberger 1974)*

3.3 Building Skin

The building skin or envelope comprises roofs, foundations, walls, windows, doors and any other part of the building that comes in contact with surrounding external forces. It may also include various fixed and movable filters such as screens, shutters, blinds, louvers, awnings and curtains. The envelope is the third skin or filter regulating exchange of moisture, air, vapour and heat between the building and environment. They basically provide tightness and insulation while allowing positive or profitable permeability when necessary. The building form, elevation and geometry as well as its color and finishing being important considerations.

High thermal mass and high R-value envelopes are desirable in cold climates with the insulation as close as possible to external face of envelope. Various forms of thermal insulation are applicable including insulating concrete forms and structural insulated panels. Low U-value windows with low transmissivity are desirable and usually doubled or tripled with noble gas sealants sandwiched in between the layers. Sometimes the glass fenestrations are finished with low-emissivity coating. The concept being to trap as much warmth from the low winter sun by eco-design and efficient application of materials.

In hot climates, lightweight skins with low thermal mass is desirable e.g. a steel or timber frame with lightweight panels.Traditonal hot-humid architecture reflects little or no envelope to allow desirable air speed. The fenestrations and sometimes the entire envelop is shaded from unfavorable levels of solar radiation. Various shading devices interior and exterior, fixed and adjustable are designed following the sun-path diagram. Sometimes radiant barriers in form of reflective materials are applied to the walls and roof**.**

Fig 23

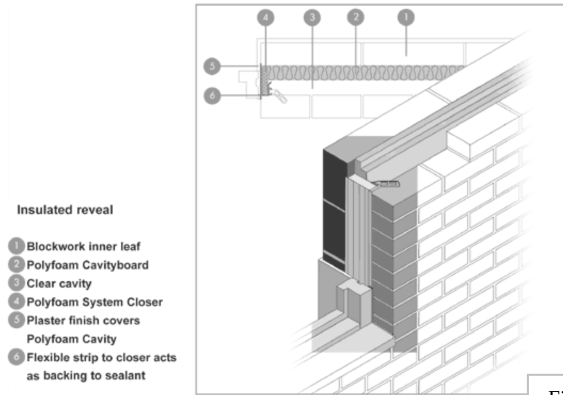


Fig 24

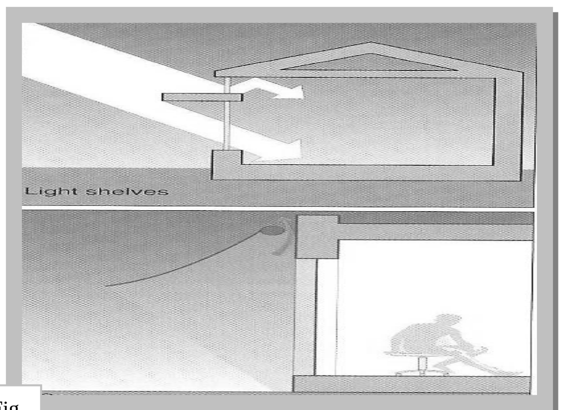


Fig 25

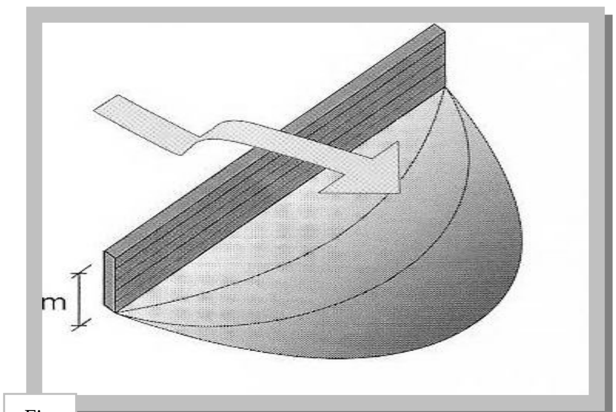


Fig 26

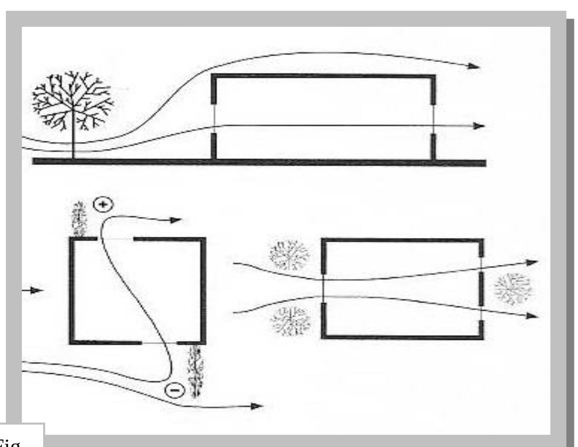


Fig 27

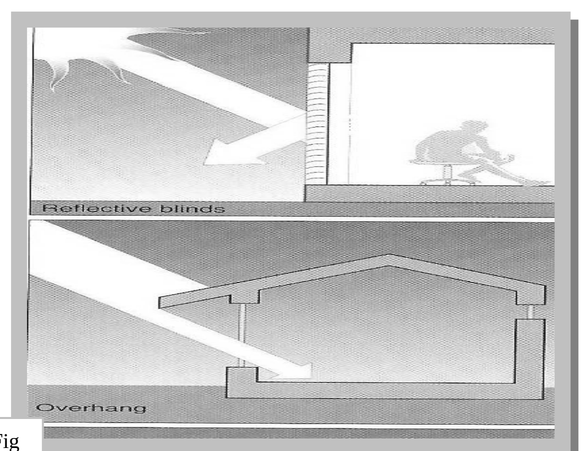


Fig 28

22-27 Building envelopes as filters in various climatic conditions, (24-27 *source A Green Vitruvius 1999*)

3.4 Neighbourhood Layer

A neighbourhood form as a smaller unit of the larger urban context is shaped by several forces including climatic,social ,political, aesthetic ,technical and financial forces.The layout can and should be designed with respect to local wind patterns and solar path to serve as a microclimate filter to enhance comfort conditions,the various building geometries and orientations emerging as key elements.Therefore neighbourhood blocks can be laid out to shelter public spaces and enhance comfort.

A common error is to imagine climate or regional conditions to be even over a particular area.The truth is; minor physical alterations such as change of gradient, terrain or use of materials in a certain neighbourhood can easily set up a significant change of condition within the neighbourhood –hence the need to define this layer as different from global climate regions.

In cool climates solar orientations are chosen to allow for solar penetration into public areas and avoidance of overshadowing by vegetation and big structures. The cool zone neighbourhood envelope is usually insolated and very dense with restricted wind flow but allowance for solar penetration.

The hot-arid neighbourhood reveals mutual solar shading with high walls and compact layout enclosing sheltererd cores.In some neighbourhoods such as in Damascus (fig 37-38), buildings thrive under mutual shading but may not be appropriate as stand alone units.In hot-humid neighbourhood envelopes, the aim is to maximse shading as well as enhance wind flow hence it is usually more elongated with wind paths .On the horizontal plane, attention is given to the relative percentage of hard and soft landscape areas and the cooling, reflective and absorption potentials of various landscape elements. Comfort considerations for the neighbourhood layer appear more complicated to analyse than the skin, clothing and building envelope since it involves more factors including the natural ventilation potential of the neighbourhood.

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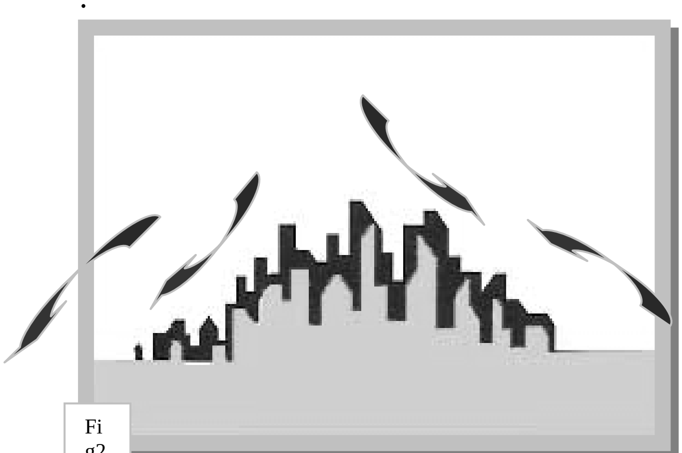


Fig2

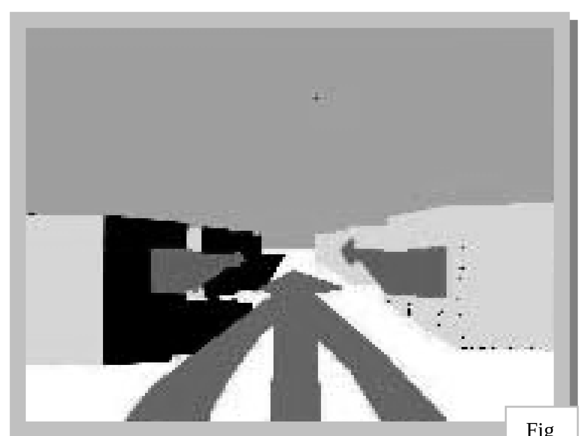


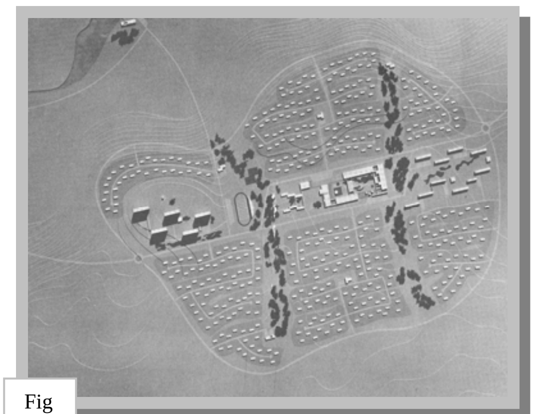
Fig 30

43- Neighbourhood envelopes as filters in various climatic conditions

Fig
31

Fig
32

Neighbourhood layer in cold climates (*Olgyay 1963)*



Fig
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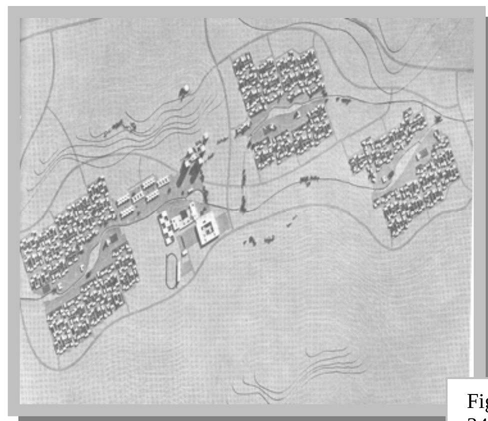
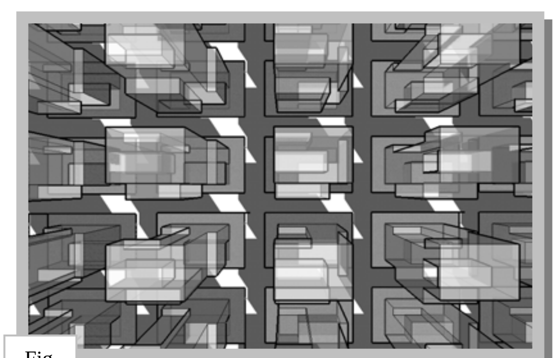


Fig
34

Neighbourhood layer in hot-humid (47) and hot-arid climates (48) (*Olgyay 1963)*



Fig
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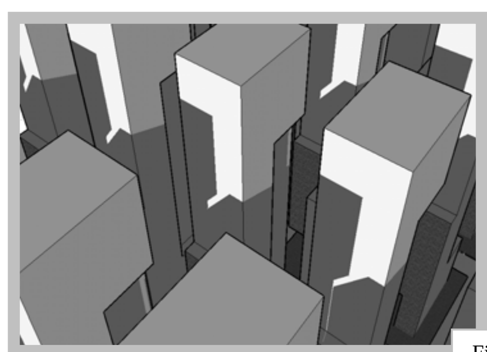

Fig
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Neighbourhood envelope with mutual shading

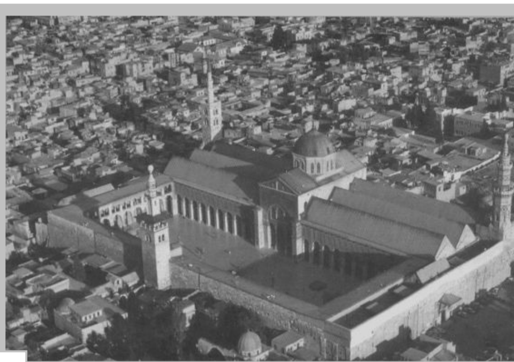

Fig
37

Fig
38

(37-38)Mutual shading in Damascus neighbourhoods
http://www.sacredsites.com/middle_east/syria/images/damascus.jpg,http://www.trekearth.com/gallery/Middle_East/Syria/photo373062.htm

3.5 Global Regions Layer

According to the astronomical relationship between the sun and the earth and other geographical factors, different climates emerge in various locations with flexible boundaries. They comprise certain conditions of the earth's atmospheric elements which have overriding influence over smaller layers. The rotation of the earth in a tilted location causes different seasons in various parts of the world. Le Corbusier said" the symphony of climate…has not been understood. The sun differs along the curvature of the meridian, its intensity varies on the crust of the earth according to its incidence…"...Vitruvius in de Architectura said "for the style of a building ought to manifestly be different in Egypt and Span, in Pontus and Rome, and in countries and regions of various characters. For in one part, the earth is oppressed by the sun in its course; in another part the earth is far removed from it; in another it is affected by it in a moderate distance".(Olgyay 1963)

On the global regions layer, particular combination of climatic circumstances define regions as cold temperate, hot-arid, hot-humid et cetera depending on the climatic classification employed. While this may not readily come into sight as a layer of enclosure, it is obvious that the combination of the effects of temperature, wind velocity, precipitation and solar radiation creates an envelope of conditions enclosing and affecting the comfort conditions in a given region. The global climatic conditions and there effects according to their regions exist from the troposphere to the farthest part of the atmosphere (exosphere).

Put expansively; our bodies are covered by skins which are covered by clothes within building envelopes which are bounded by neighbourhoods which are located within specific climatic regions or envelopes. This is important considering that boundary layers vary with altitudes and is also fairly related to the work of Kanjov I.M (1999) on the heat and mass exchange processes between the surface of the human body and ambient air at various altitudes. It may thus be significant to further investigate thermal comfort beyond the boundaries of the atmospheric envelope.

Interestingly apart from industrial activities that seem to change or redirect climatic patterns in regions, this layer is mostly adjusted-to rather than adjusted in order to improve thermal comfort.

Another consideration is as regards what the thermal comfort indices would be if life was in a different planet or if global climatic regions evolve different characteristics due to increasing effect of climate change.

3. CONCLUSION

To evaluate the importance and input of each layer in achieving thermal comfort involves the simulation and testing of varying conditions of each layer. This would entail evaluating comfort levels in various layer contexts and micro-climates and comparing them with ideal comfort scenarios and also highly related to the behaviour of various individuals in the different settings. Guy Newsham using FENESTRA ;a computer based thermal model discovered the huge influence of individual adjustment in simulation output.(Newsham 1997)

A short stout person dressed in three layers of well insulated clothing,inside a well insulated ICF (insulated concrete form) building envelope with a North-South orientation in a wind shielded (possibly on the leeward side of a highland)-solar penetrating neighbourhood envelope within a cold climate can be chosen for a cold climate .Another scenario is a slender person with a high surface area to weight ratio dressed in light coloured cotton t-shirt inside a thin layered E-W oriented building envelope in a wind velocity-enhanced neighbourhood, with shady trees within a hot-humid zone.

Although these are seldomly the situations within these climates they represent desirable or close to desirable conditions that can serve as reference models.

Developing a theoritical framework for this test will also entail awarding the right scale and rating to the various variables, boundary layers and thermal comfort co-efficients as well as determinnig which times or seasons each criteria would matter the more or less.The gaps between these layers being equally important.

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