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Structures as climatic modifiers—the influence of vernacular architecture

L'influence de l'architecture locale sur la situation climatique d'une structure

Klimaveränderung durch Tragwerke – Der Einfluss einheimischer Architektur

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SUMMARY
Environmental conscious building design involves the use of fabric for absorbing and distributing ambient energy. This paper reviews historical and current ideas from which an environmental design process can be evolved which aims to achieve comfortable but economical solutions to the interaction problems of climate, buildings and people.

RESUME
Un projet de structure tenant compte de l'environnement implique l'utilisation de tissus absorbant et distribuant l'énergie ambiante. Cet article passe en revue l'historique et les idées actuelles à partir desquelles un processus de projet tenant compte de l'environnement peut être développé afin de proposer des solutions confortables mais économiques aux problèmes interactifs entre climat, structure et utilisateurs.

ZUSAMMENFASSUNG
Bei einer unweltbewussten Planung von Tragwerken wird die Verwendung von Stoffen zur Absorption and Verteilung der ungebundenen Energie miteinbezogen. Der Beitrag gibt einen Ueberblick über historische und aktuelle Ideen, aus denen en umweltbewusster Entwurfsprozess erarbeitet werden kann, der komfortable aber wirtschaftliche Lösungen bezüglich des Zusammenwirkens von Klima, Tragwerk und Mesch ermöglicht.

Over the ages man has used his ingenuity to make his habitat safe, warm and weather protected. Troglodytic architecture sculpted out of the hillside landscapes of Morocco; the igloo of the eskimos; African courtyard houses; the Malaysian tree-dwelling and even the English thatched cottage all have features which aim to orientate, to shape buildings and to construct them from materials so that the inhabitents can sustain the hot or cold rigours of the regional climate.

Buildings in cold climates should offer protection against wind, cold and snow; curved igloo shapes present the minimum surface area for the largest volume and use few openings at right angles to the wind direction. At lower latitudes the climate moderates and summer heat as well as rain becomes significant. Thus windows are designed to admit the winter sunshine whilst excluding it in the summer; insulation is used to minimise heat loss and ventilation helps to counteract heat gain. Heavy mass buildings with shaded courtyards are common in hot, dry tropical regions which usually have a large diurnal temperature range; advantage is taken of evaporative cooling from pools and even the soothing sound qualities of running water in fountains; sand and dust are further factors requiring consideration. Hot humid tropical areas are most demanding on the human system because evaporation from the body by sweat is limited; every advantage has to be taken to allow cross-ventilation currents to flow through the roof space and through the preferably high rooms.

The value of vernacular architecture was not generally recognised until Viollet le Duc wrote his book *'The Habitation of Man in All Ages'* in 1876. Ozkan (1) describes vernacular architecture in terms of four major characteristics - experiential value, participation, intended meaning, and environmental adequacy. The idea of experiential value refers to the fact that with the growth of professionalism building designers have become alienated from nature and the environment. This lack of direct experience has in the words of Fitch (2)

> *'... made the citizen into an ignorant consumer, the designer into an isolated powerless specialist.'*

and contrasts strongly with history before the Industrial Revolution when direct involvement came naturally. But the shaping of a socially acceptable and individually satisfying environment demands participation with the people as well as with the environment and there are many examples around the world that reveal how people under given environmental, social and technical limits have striven to create the most suitable living conditions in accordance with nature (3) (4). Good purposeful design of anything has intended meaning which blends form, function and human values. There is a coherent unity or wholeness which is difficult to define except by a phrase like 'it feels just right'. The designer, and examples abound in architecture, science, engineering and the arts, has interpreted a series of needs and blended these into a whole. Environmental adequacy has three essential attributes - flexibility in environmental control, identification of need and economy of material and manpower resources.

Iranian architecture displays a lot of evidence showing how ingenuity can combine planning, building shape, materials and systems design to produce simple but effective solutions to environmental control problems. Although the control is coarse there is an inherent flexibility which allows the building to be in rhythm with the natural cycles of temperature and sunshine. Buildings were clustered partly to aid defence but also to reduce the impact of solar radiation and dust. Tall walls and narrow streets provided shade for pedestrians. Curved roofs were incorporated into buildings as early as 3000 BC. The curvature accelerates the rate of airflow over the surface so that the consequent decrease in pressure induced any hot air which is stratified on the underside of the roof to flow out through air vents (Fig 1). Thick adobé walls retain the heat and release it to the interior and to the night sky as the cooler evening descends. Landscaping has always played a role in shielding walls from solar heat and courtyards are used to entrap cool night air for several hours.

Wind towers harness summer breezes;they are usually closed during winter. During the day heat is absorbed from the air which passes downwards by the walls of the passageways, to be released at night so warming the air and causing it to move upwards (Fig 2). Doors and windows can be opened to assist the upward air movement at night; if there is a wind at night the flow is downwards and the air warms slightly but still allows some cooling. When there are no daytime breezes air can flow through openings in the side of the tower

Sometimes use was made of a fountain or an underground stream placed at the basement of a tower to permit cooling by evaporation with some increases in moisture content (Fig 2). Ice was produced during winter nights and stored in deep underground storage pits for summer use.

The way people use buildings has an important bearing on their effectiveness, living in the basement during the hours of hot sun, sleeping on the roof at night, heating only those rooms being used are commonsense measures which give some adjustment between man, the buildings and the climate.

In contrast to the hot arid regions of Iran the people living in the cold frozen arctic evolved a curved structure - the igloo. The dome is the most compact shape offering a minimum surface area for heat loss and quantity of materials whilst providing resistance to winter blizzards. The only sources of heat are a blubber stove and body heat. The snow blocks are 450mm thick and develop a glaze of ice on the inside surfaces; the eskimo drapes the interior with skins and furs. Although the igloo has a short life it provides a satisfactory thermal control which opposes the rigours imposed by the climate. Fitch (5) shows data giving an inside to outside temperature differential in the range of 20 to 30°C and an internal temperature gradient of about 6°C (see Fig 3). These data should be compared with those given by Fitch (5) for mud masonry Indian houses in the American south west; the adobé walls and mud roof attenuate the high temperatures characteristic of dry desert climates (see Fig 3).

History as reflected in the patterns of vernacular architecture has shown that orientation, shape, materials and mass are key starting points in building design for any climate. Moreover experiential value, participation, intended meaning and environmental adequacy require interpretation at any time in the future if social, technical and economic commitments are to be fulfilled.

INTERACTION OF ENVIRONMENT, BUILDINGS AND PEOPLE

Aesthetic and economic architecture emphasises a natural response between materials and nature which in turn reverberates the spirit of man and lets buildings breathe with the minimum of mechanical effort from active systems. The disadvantages of active systems are that they require heavy duty plant and complex networks to distribute hot and cold fluids; these things need maintenance, introduce unwelcome noise and demand space. Passive control means the building rather than equipment controls the environment (Fig 4).

The degree of interaction between the internal and external environment depends on the elements comprising the fabric. By that is meant the material used, the way the elements fit together and the surface conditions. Human factors set the level and quality of environment required.

Consider the simple relationship between the U value of the fabric, the internal surface conductance h, the external and internal temperatures θ_o and θ_i respectively and the surface temperature θ_s.

$$U(\theta_i - \theta_o) = h(\theta_s - \theta_i)$$

$$\therefore \quad (1 - \frac{\theta_o}{\theta_i}) = \frac{h}{U} (\frac{\theta_s}{\theta_i} - 1)$$

For a heat loss $\theta_s / \theta_i <$ but for a heat gain $\theta_s / \theta_i > 1$.
A more general relationship is given by:

$$\frac{E_o}{E_i} = 1 + \frac{S}{F} (\frac{E_s}{E_i} - 1) \qquad (1)$$

where S is surface function and F is fabric function; E_o, E_i and E_s are external, internal and surface properties of heat, light or sound. E_i is really a background level whereas in practice there will be a human factors criterion E_h so that

$$E_i = E_h + \frac{(E_o - \frac{S}{F} E_s)}{(1 - \frac{S}{F}}$$

the services imput clearly depends on S and F for given values of E_h, E_o and E_s.

THE HUMAN FACTOR

The art of building environmental engineering is providing a balanced quality of environment at a minimum total cost and with the minimum use of fossil fuels for providing energy. To achieve this we have to understand what environment is, how it affects people, how properties interact and then how the ideals may be obtained in practice on an economic basis. Buildings have been too often viewed as static things whereas they demonstrate dynamic cyclic energy behaviour. There is a microcosm within building materials that remains to be known whether it is heat flow or radon emission. The flow of sound, light, heat and energy through and around building elements needs to be measured if an energy-time balance is to be described in quantitative terms.

What are the effects of climate on man? Man may be aware or unaware of these influences. The environment links the building occupants with the outside world; provides the different atmospheres necessary for the particular work task; it provides people with the health and safety conditions which are vital for the care of mind and body. The content of the information received from our surroundings may create associations with past or expected events; social and spatial aspects intermingle with physical factors. Aside from social and spatial attributes light and sound are the most important partial climates from the point of view of information transmission because they dimension the world about us. A model of comfort has been proposed (6) which uses four cardinal dimensions - arousal level, physiological sensitivity level, psychological sensitivity level and distraction level.

DYNAMIC ENVIRONMENTAL SERVICES STRUCTURES

In recent years more attention has been given to exploring the links between buildings and their surroundings. Buildings can collect and distribute ambient energy using simple principles such as gravity forces to circulate air, mass to delay and attenuate heat flow and built form to protect from the sun but to encourage breezes to pass through the interior. The Trombe wall allows winter sun to warm the airstreams circulating around the room whilst in summer they can carry room heat away and the thick wall acts as a solar barrier. Heavy floors permit energy to be stored and may even have channels for night air to pass through them and cool the buildings down, whilst the mass does not only attenuate but retards the maximum summer heat aso that it does not occur when the people are working.

Ideally a building structure should act like the skin which covers the body with capilliary like dilation and contractions controlling the flow of a heating medium through the fabric. In practice air is a more convenient medium to circulate through structural elements than water although it needs more space; electricity would be even more convenient but economic factors prohibit this possibility at present; chemical storage is another possibility.

Little attention has been given to circulating heat through the fabric although the idea is an ancient one employed at a simple level by the Romans. There are several advantages in using environmental services structures such as air vent windows (7), hollow block ventilated floors (8), thermic-diode panels (9) or ventilated floors and walls (10).

The moving airstreams form an artery-vein system within the structure near to where the climate is having its maximum effect so that the thermal response is quick. Because the airstream is controlled, varying levels of heat transfer can be achieved, at the same time the distribution system contributes towards the insulation of the system. Internal space requirements for equipment can be reduced. Thermal comfort is more effectively achieved because there can be independent control of air and surface temperatures; like the human body thermo-regulatory system there can be much more control by surface temperatures and hence by radiation rather than by the more spurious convective component.

By using the building fabric which has a natural heating-cooling cycle throughout the day and night it is easy to correct the heat gains from internal and external sources and put them into storage for use at a later time or for use in another part of the building. It is also possible to cool the building down by using night air to offset daily heat gains.

There are several factors which need consideration if buildings are to be effective climatic modifiers. On the outside of the building sufficient protection needs to be given against excessive solar gain, wind, rain and noise penetration and in these respects facade design is very important. The fabric itself must produce the level of heat flow and delay the passage of heat by an amount depending on the climate and the activities within the building; ventilated airways can act as a dynamic controller which varies the heat flow and the heat retention capacity of the structure. Near the inside surface a vapour barrier limits the migration of moisture into the structure, hence avoiding interstitial condensation. On the inside surface a varierty of materials may be used to give 'hard' or 'soft' textured finishes to fulfil particular combined needs of sound, light, temperatures and aesthetics. The outdoor temperature pattern is damped as it passes through the structure by an amount which is proportional to the thermal diffusivity ($D = \frac{k}{\rho c}$). Figure 5 shows the temperature distributions occurring within the wall and it can be seen that in addition to the attenuation of the temperature wave there is a phase change. The pattern of events can be altered by repositioning the insulation on the inside surface, by internal heating or cooling sources, or by ventilating the structure. The magnitude of the temperature damping is defined by the ratio of daily internal to external temperature amplitudes thus the

decrement factor (f) sometimes referred to as temperature amplitude ratio (TAR) is defined as

$$f = \frac{\Delta\theta i}{\Delta\theta_o} \qquad (2)$$

Some typical values of decrement factor are shown in the table below.

Construction	f
200mm expanded polystyrene	0.52
200mm concrete	0.39
200mm concrete + 20mm mineral wool on outer face	0.05
200mm concrete + 20mm mineral wool on inner face	0.26

Placing the insulation further away from the climate renders it less effective, a fact that can be deduced by comparing the temperature gradients for each type of construction. There are further considerations however concerning the position of the insulation. Quicker response is achieved by placing insulation on the inside surfaces which can be an important factor in buildings which are intermittently occupied; this will also help to limit condensation.

Inserting f into equation 1 gives

$$\frac{1}{f} = 1 + \frac{S}{F}\left(\frac{\Delta\theta s}{\Delta\theta i} - 1\right) \qquad (3)$$

If $S = 3\ W/m^2K$ and $F = 0.3\ W/m^2K$ (U value).

$$\frac{1}{f} = 1 + 10\left(\frac{\Delta\theta s}{\Delta\theta i} - 1\right) \qquad (4)$$

The surface temperature of materials is inversely proportional to the contact coefficient defined by $\sqrt{k\rho c}$ thus the difference in surface temperature between concrete and insulating glass wool is about 20°C. A comparison can be made between the inside (i) and outside (o) positions of the insulation thus using equation (4)

$$\frac{\left(\frac{1-f}{f}\right)_i}{\left(\frac{1-f}{f}\right)_o} = \frac{(\Delta\theta s - \Delta\theta i)_i}{(\Delta\theta s - \Delta\theta i)_o}$$

For an internal rise of $\Delta\theta i = 4^{o}C$ and allowing a temperature drop of $6^{o}C$ through the surface film of the insulation but $20^{o}C$ through that of the concrete gives the RHS a value of $\frac{(6-4)}{(20-4)} = 0.125$

Using the values of $f_i = 0.26$ and $f_o = 0.05$ given in the table the LHS has a value

$$\left(\frac{1 - 0.26}{0.26}\right) \Big/ \left(\frac{1 - 0.05}{0.05}\right) = 0.15$$

The values obtained are in the same order and show that equation 1 has a relevance in linking a number of ingredients which determine the effectiveness of architectural engineering in structures namely materials, fabric, surface factors, comfort criteria, inside and outside temperature and decrement factor.

The effect of night cooling with the consequent saving in expensive refrigeration plant and maintenance costs are shown in Fig 5. The daily temperature variations internally are reduced in level and amplitude. Night operation of fans needs caution regarding noise otherwise a further advantage is that electricity is being used during the off-peak period.

The Trombe wall is perhaps the simplest method of natural response. An example of this system operating in the UK is the house design used for nine houses at Bebington on the Wirral near Liverpool (11). Double glazing admits winter or summer sun forming a body of air next to a mass concrete wall having a blackened surface. Warm air can be circulated around the living room spaces or in summer can be vented to outside. The system is shown in Fig 6. Justin et al (11) report that the average energy consumption is almost half and yet the living room temperatures in the solar houses are over $1^{o}C$ higher than those in the comparison group built in accordance with 1976 Building Regulations and without a Trombe wall. Economy and an improvement in the human factor have been achieved by the juxtaposition of light and heavy materials. The need of glass as well as concrete is paramount because it admits solar heat and promotes strong convection currents whereas the concrete regulates the events so that the climate and the life within buildings are working in harmony.

MASS, LENGTH AND TIME

Mass, length and time are the principal dimensions of the universe and it is these that are reflected in the building time constant defined by the mass and the specific heat capacity of the materials used. For passive control, buildings should have time constants which not only exceed the occupancy period for the building but are also longer than the likely minimum time period for the lowest and highest climatic changes to occur. Energy balance primarily depends on selecting building materials whilst taking into account building use and the regional weather patterns.

For a volume of material, V, density, ρ and specific heat capacity, c undergoing a rate of temperature change $\frac{d\theta}{dt}$ the heat release dQ over an area A above a base temperature θ_o is

$$dQ = \rho\, c\, V\, \frac{d\theta}{dt} = -h\, A\, (\theta_i - \theta_o)$$

If the temperature differential is

$(\theta_i - \theta_o)$ at t=0 and $(\theta_t - \theta_o)$ at t=t

$$\int_{\theta_i-\theta_o}^{\theta_t-\theta_o} \frac{d\theta}{\theta} = - \frac{hA}{\rho cV} \int_o^t dt$$

$$\left(\frac{\theta_t - \theta_o}{\theta_i - \theta_o}\right) = \exp\left(-\left(\frac{hA}{\rho cV}\right)t\right) \qquad (5)$$

This is Newton's Law of cooling and the time constant $\tau = \frac{\rho cV}{hA}$ thus

for a reference temperature $\theta_o = \theta^oC$

$$\theta_t = \theta_i \exp - \left(\frac{t}{\tau}\right)$$

and when $t=\tau$

$$\theta_t = 0.368\theta_i \qquad (6)$$

Newton's Law is sometimes expressed in terms of the Biot and Fourier Numbers

$$\theta_t = \theta_i \exp (- Bi\ Fo) \qquad (7)$$

where $B_i = \frac{hL}{k}$ for material thickness L

$F_o = \frac{Dt}{L^2}$ for thermal diffusivity D

$D = \frac{k}{\rho c}$

The thermal time constant can be defined as the heat stored in the structure per unit of heat transmitted through it for a unit step temperature change. For a building comprising n elements

$$\tau = \sum_n \frac{Q}{U} \qquad (8)$$

Note that the rate of cooling or heating

$$q = Q \frac{d\theta}{dt} \qquad (9)$$

A concrete slab 300mm thick has a thermal capacity of 560 $kJ/m^2\ ^oC$

[i.e $\rho\ c\ V = (2100) \times (0.88)\ (0.3 \times 1 \times 1)$];

if the heat gain in a space causes the temperature in the slab to rise by 0.5^oC per hour then the required cooling capacity will be

$$q = \left(\frac{0.5}{3600}\right) 560 \times 10^3$$

$$= 77.6\ W/m^2$$

Applying Newton's Law of cooling

$$\theta_t = \theta_i \exp\left(-\frac{t}{Q/U}\right) \quad (10)$$

or expressing U in terms of thermal resistance
(note: Q is analogous to capacitance in electrical terms)

$$\theta_t = \theta_i \exp - \left(\frac{t}{RQ}\right) \quad (11)$$

the mass of the structure is $M = \rho V$ or $M = \frac{Q}{c}$

since $Q = q \Big/ \left({}^{d\theta}/dt\right)$

$$\theta_t = \theta_i \exp \left(\frac{t}{Rq} \frac{d\theta}{dt}\right) \quad (12)$$

The equations show how thermal performance depends on mass, length and time and enable the optimum mass to be established for the given conditions of rate of temperature change $\left(\frac{d\theta}{dt}\right)$, choice of materials (R) and time period (t).
Newton's Law of cooling represents a fundamental link between architecture and environmental engineering.

CLIMATE MODIFICATION BY MEMBRANE STRUCTURES

Weather outlines the expected ambient energy patterns depicted by mappings of pressure, temperature and wind potentials. Energy flows between positions in space at different potentials. Obstructions placed in the flow stream stagnate and divert energy as classic aerofoil experiments show. Buildings are complex obstructions not only because they have irregular openings but because they are psychological as well as physical barriers. They separate man from the natural environment, they are also reservoirs for energy to flow into or out of.

The influence of materials on climate can be appreciated at a fundamental level by considering Equation (1) it can be seen that when $F >> S$ then $\frac{Eo}{Ei} \rightarrow 1$, i.e. the internal climate follows the external conditions closely. Some results of airhouse experiments being carried out at Bath University are shown in fig 7 and these may be compared with the patterns of temperature also shown in fig 7.

The airhouse is made of a membrane in a single skin polyester fabric having a U value of about 5.5 W/m^2K; the single pane glass has a U value slightly lower. The thermal resistance of these materials is negligible hence the thermal response is greatly influenced by the surface boundary heat transfer coefficients and the outside value is susceptible even to small changes in the climate. In summer the internal space acts as a heat sink whereas in winter it acts as a heat source. How far surface jets can be used to act as a heat distribution medium for solar heat or internal heat sources whilst effectively being an airspace insulation layer is currently being investigated.

Equation (1) neglects the spectral content of the heat from the internal or external sources. Glass and polyester fabrics have different infra red transmission characteristics besides different mass and surface properties. For example condensation usually remains as a mist on a glass surface but streams as water on polyester surfaces because of a difference in surface tensions.

GENERAL ENERGY EQUATIONS

Energy flow studies are interesting from several points of view in building design. The environmental profiles around a building are the starting points for considering the transfer of energy in the form of heat, light, sound, moisture or airflow through the building shell. The potential inside a space is set by the human and functional requirements; people need specific ranges of heating, lighting, sound and ventilation to carry out their work. In the urban context wind, noise and smoke patterns are particularly important.

The analysis of energy flow is the common link between the natural sciences and engineering. Just so in our more confined context of environmental and structural engineering the premises of Newton and Laplace-Poisson are valid. The diffusion or transfer of heat, moisture, sound or air through a material is expressed as a mass flow vector

$$J = -a^2 \text{ grad } p$$

where a is the diffusion constant and grad p is the potential gradient expressed in terms of temperature or pressure. Combining this with the equation of continuity

$$\frac{\partial p}{\partial t} = a^2 \nabla^2 p$$

gives the equation of motion for a linear system which provides a common base for studying external loads on a structure or the passage of sound around and through building thus

$$m \ddot{\Psi} + r \ddot{\Psi} + k \Psi = F\sin \omega t$$

defines the entire pattern for noise control mechanisms by mass (m), damping (r) and stiffness (k) the noise being generated by the source, F sin ωt.

In terms of temperature ($p = \Theta$) and the Fourier's heat conduction equation takes the form

$$\frac{\partial \Theta}{\partial t} = D \nabla^2 \Theta$$

Time lag and decrement factor can be expressed in terms of the conductive and capacity index and

$$\gamma \quad \frac{\rho c L^2}{2k} = \frac{\rho c L}{2C} = \frac{L^2}{2D}$$

for material thickness L and conductance C. (fig (8)) The use of time lag is illustrated in fig 8B; the solar excess is delayed by an amount of time ϕ hours when it becomes useful for space heating.

CONCLUSIONS

Tuned buildings are becoming a reality. History provides examples of man's ingenuity to match buildings and climate with human needs. Deeper understanding is required to probe the internal behaviour of materials excited by cyclic patterns of temperature at the boundary surfaces. Dynamic thermal analysis methods are available but validation of these techniques is now required. The influence of climate, the role of built form and its optimisation; the behaviour of buildings as climatic modifiers; the general issue of energy use and conservation and the current methods of analysing and designing minimum energy buildings have been designated as the key issues from which the questions will spring to enlarge our knowledge and experiences remembering that the skill of the building environmental engineer depends on designing for a technical, an economic but human scale. Safety factors are too crude and cause a waste of energy. The art is to learn from experience and study interactive methods for making decisions about buildings, environment and energy.

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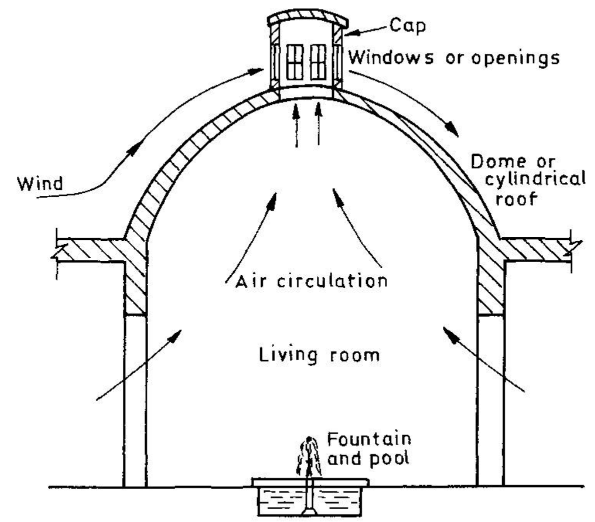


Figure 1. The air circulation pattern in a room with a curved roof (12)

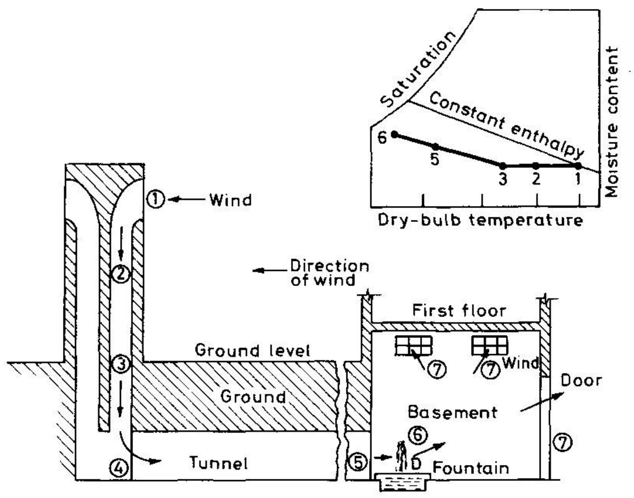


Figure 2(a) The cross-section of a wind tower connected to the basement by a 50-m-long moist underground tunnel (12)

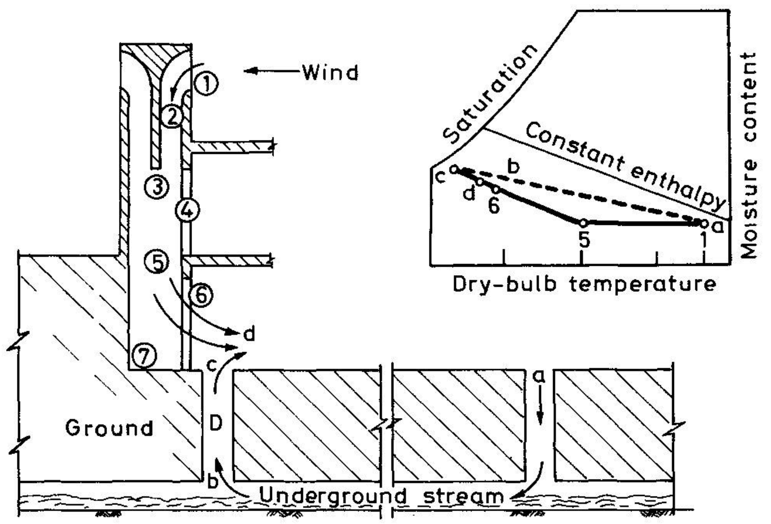
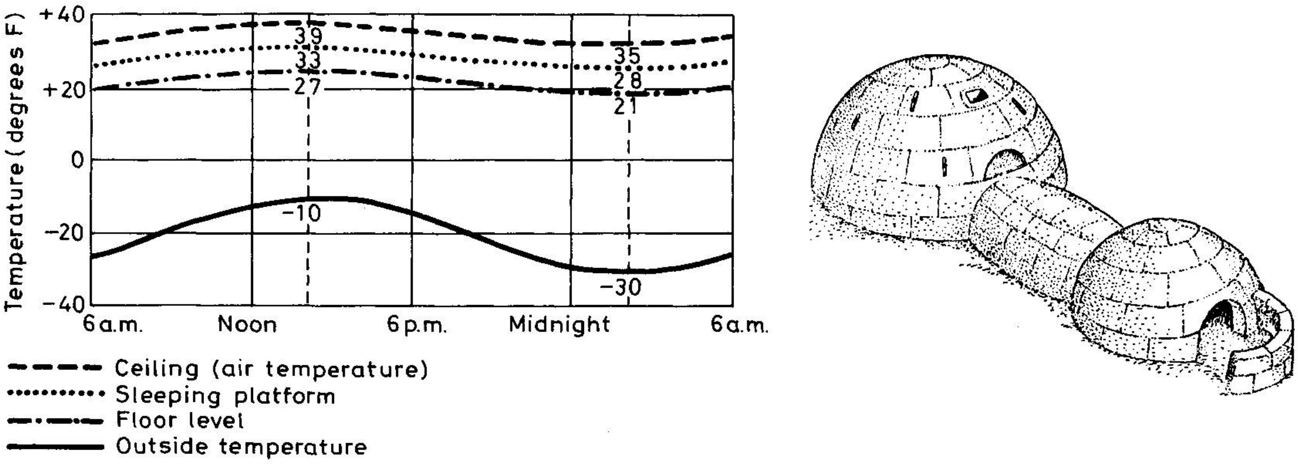
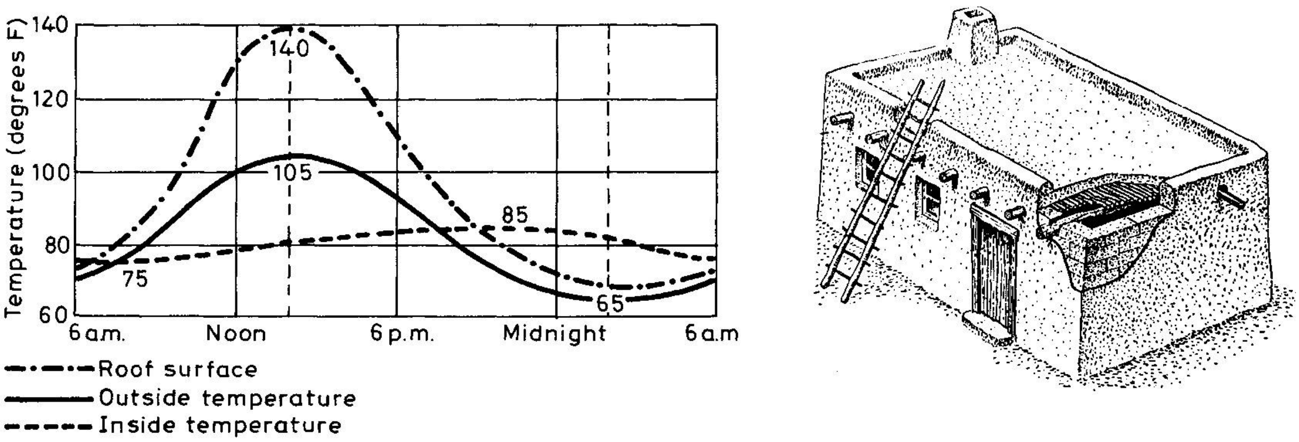


Figure 2(b) The cross-section of a wind tower used in conjunction with an underground stream (12)



(a) Thermal performance of the igloo. Chart plots air temperatures: radiation from stove and bodies keeps effective temperature so high that family needs to wear few if any clothes for comfort



(b) Thermal performance of mud masonry house. High heat capacity of thick adobe walls and mud roof acts to flatten out stressfull thermal curve of desert climate

Figure 3. Thermal performance of igloo and mud masonry house (5)

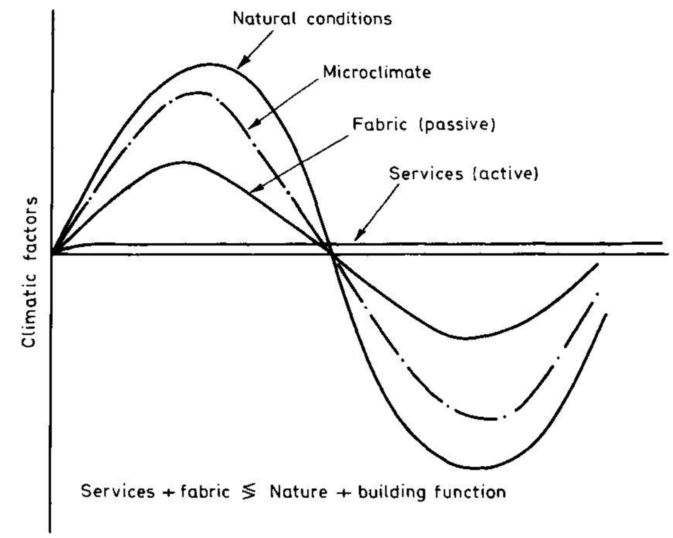
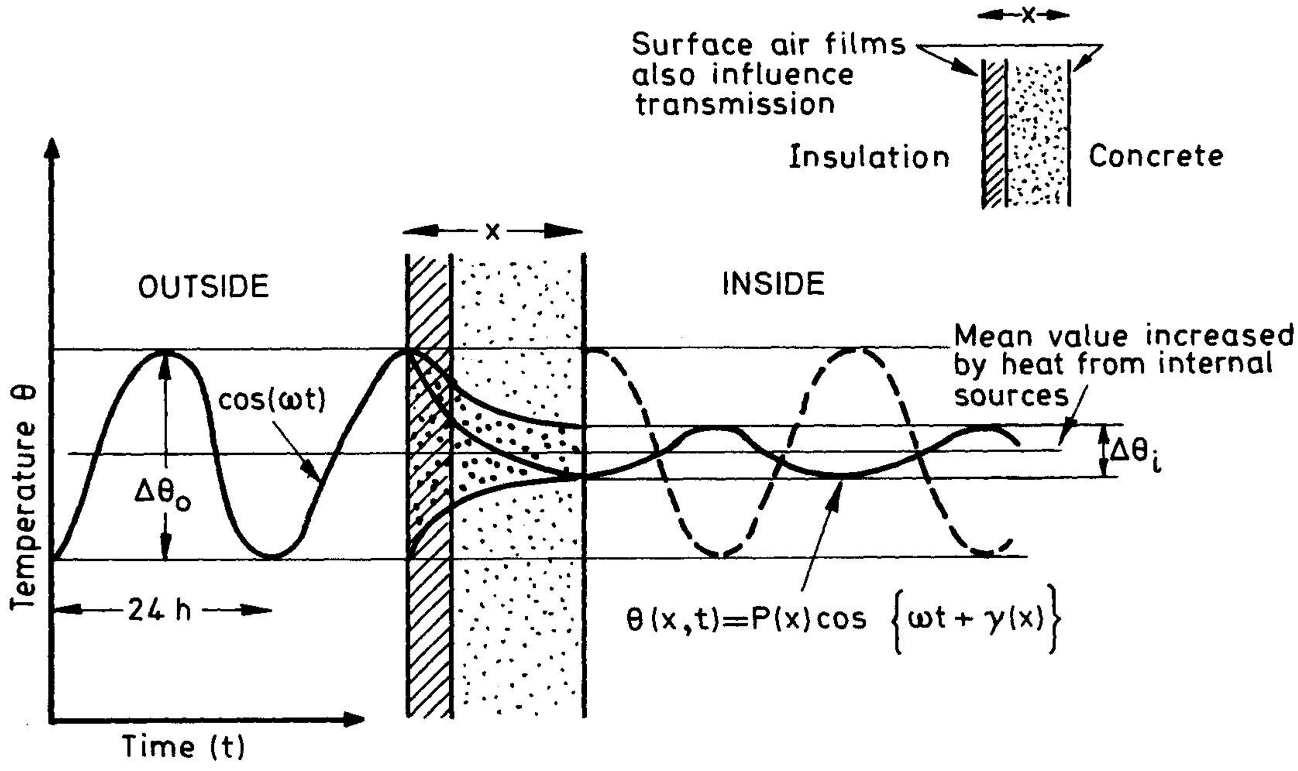


Figure 4. Environmental control



$P(x)$, $\gamma(x)$ are thermal properties of the construction
$\cos(\omega t)$ is climate function
Decrement factor $f = \frac{\Delta\theta_i}{\Delta\theta_o}$

Figure 5 (a) Effect of structure on temperature damping

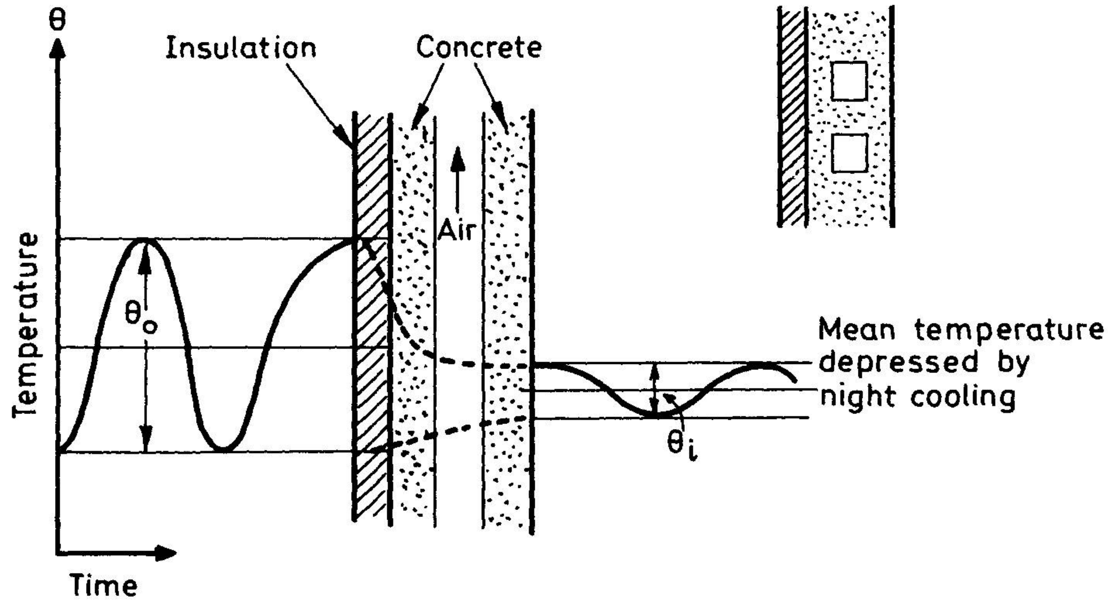
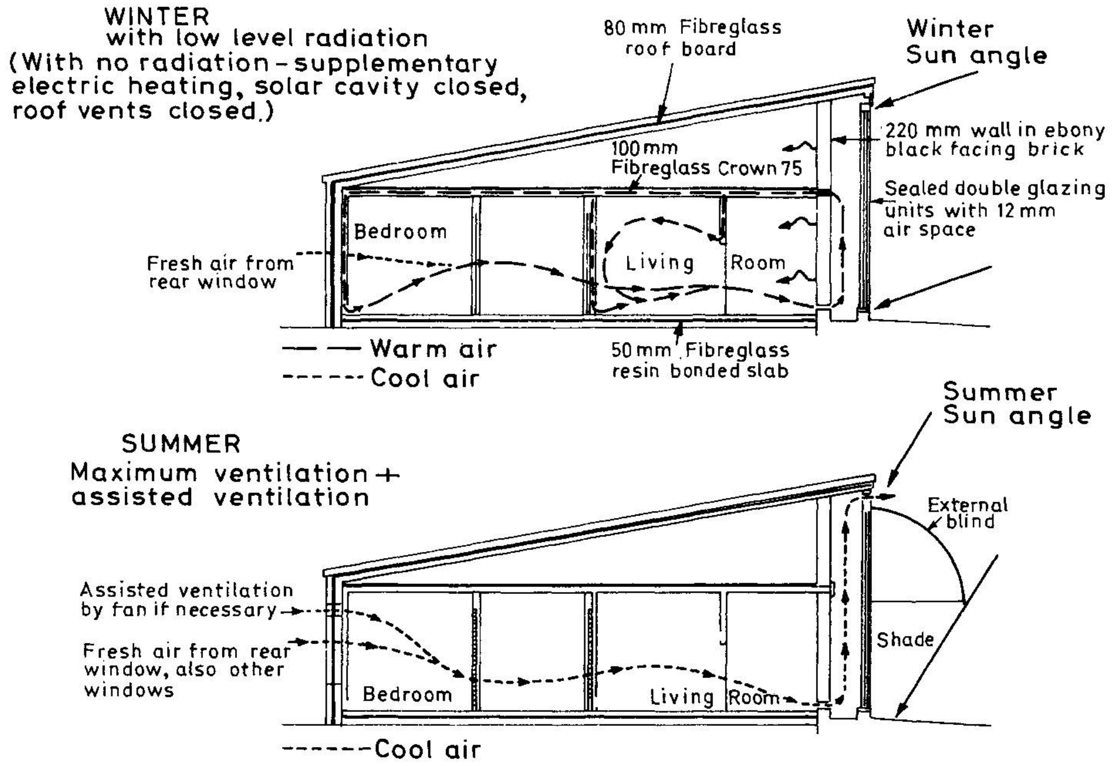
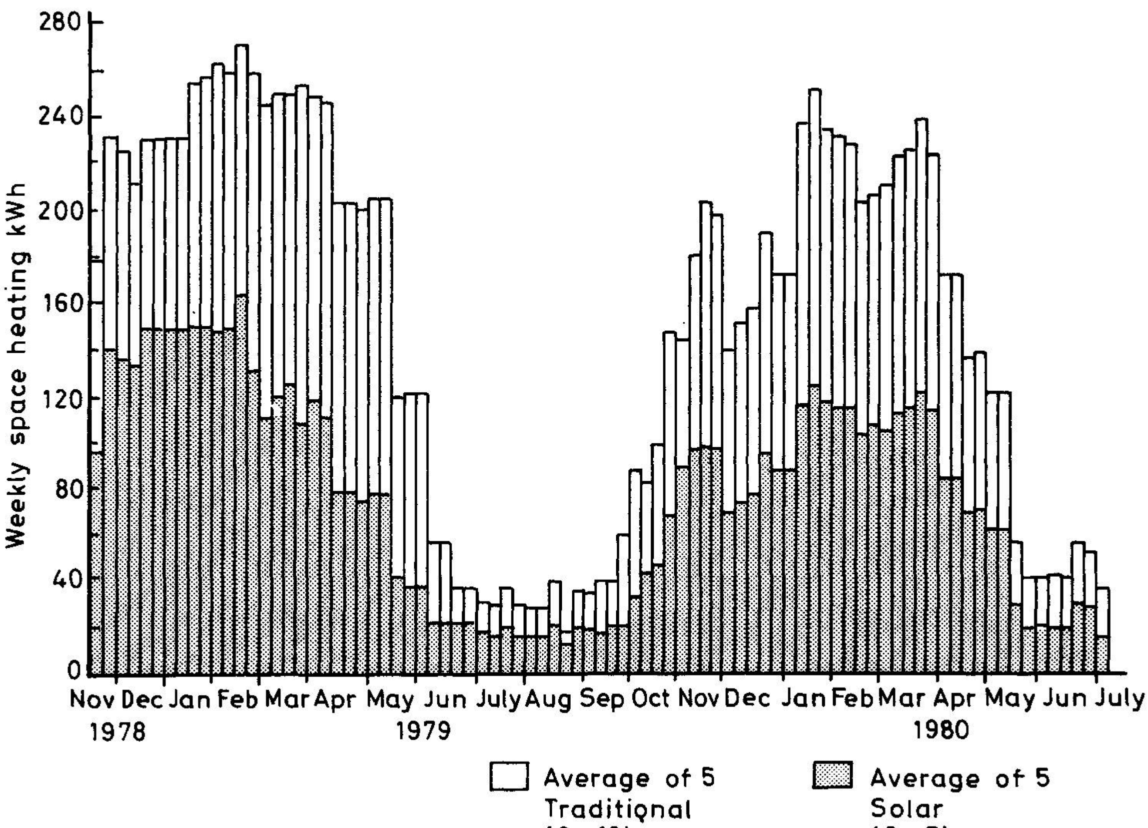


Figure 5(b) Effect of night cooling using hollow block ventilated structures

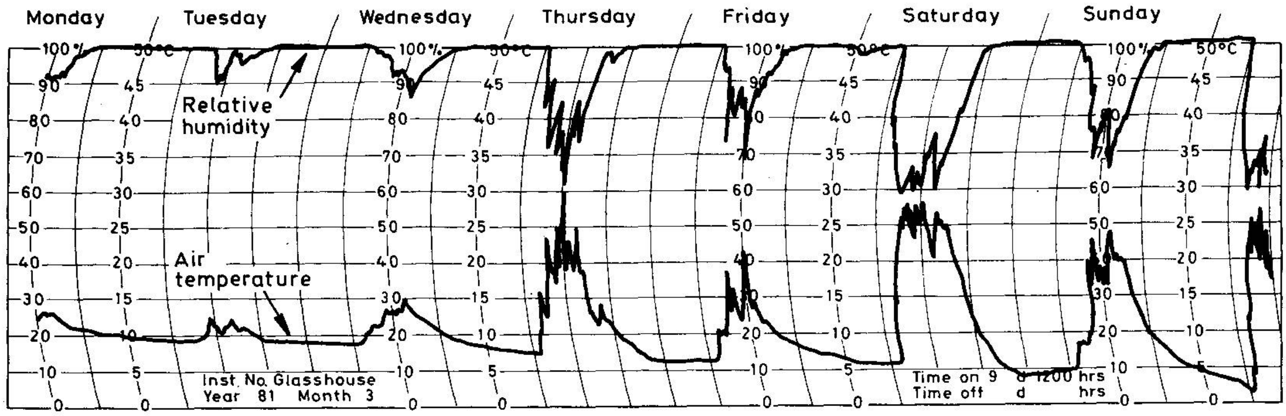


(a) Acorn Close, Bebington: Heating and ventilation systems using Trombe wall

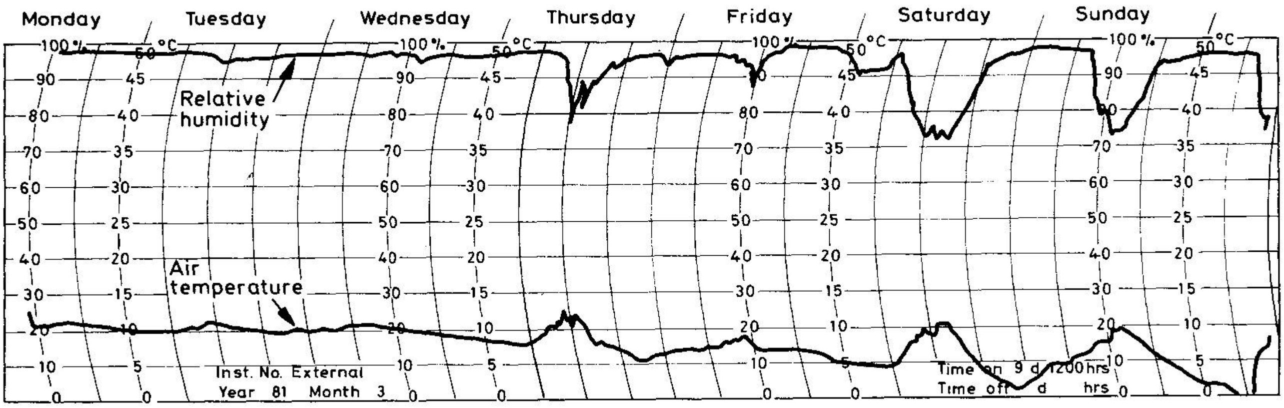


(b) Bebington houses weekly heating consumption (kWh)

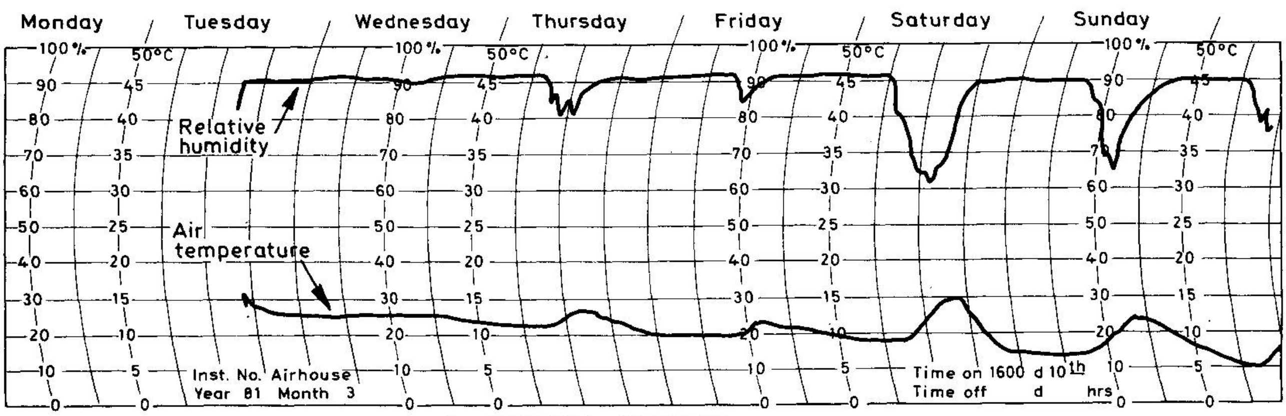
Figure 6. Performance of houses using Trombe wall (11)



A INTERNAL GLASSHOUSE



B EXTERNAL AMBIENT



C INTERNAL AIRHOUSE

Figure 7. Dry bulb temperatures and relative humidities 9—16 March 1981

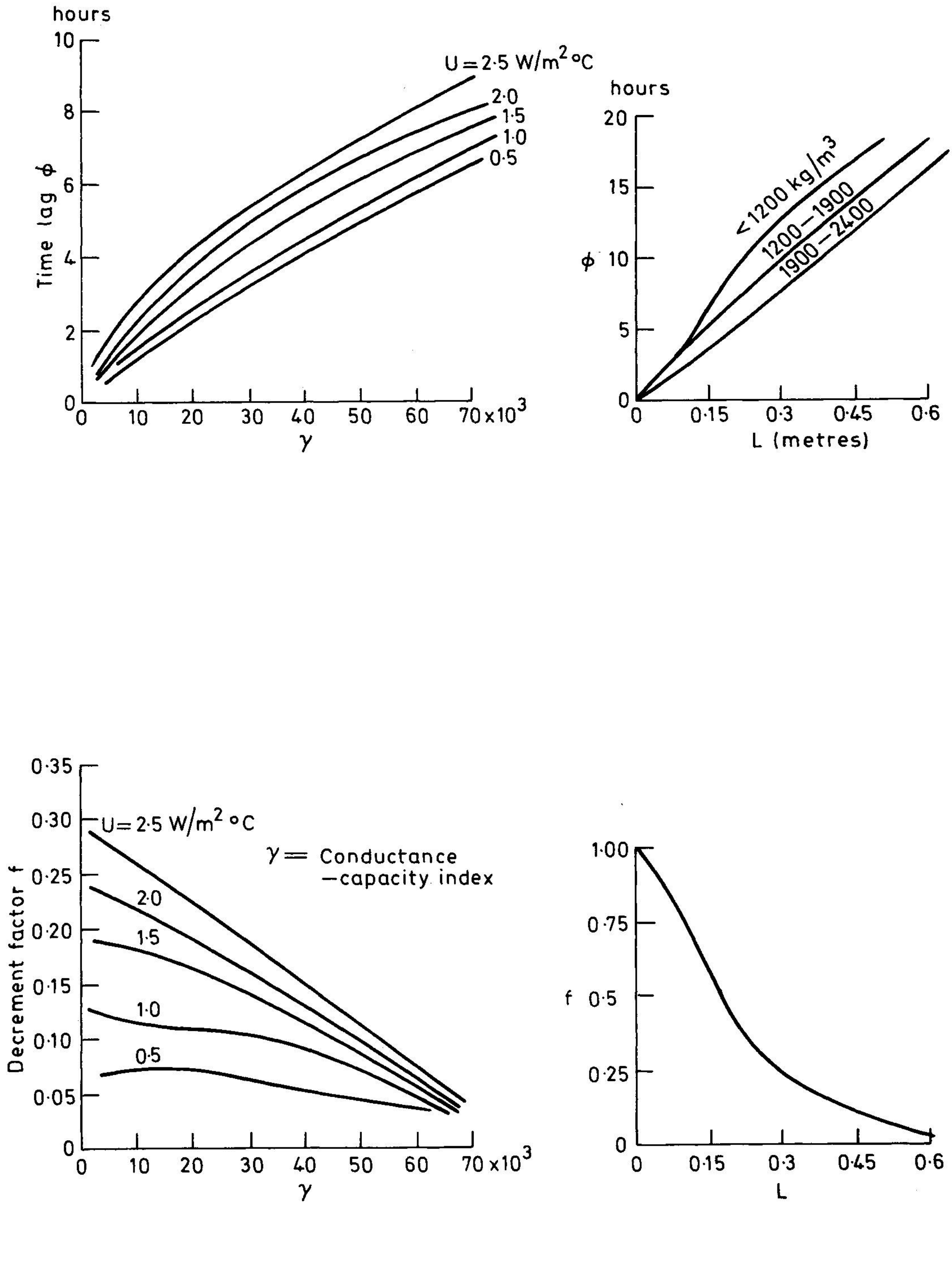
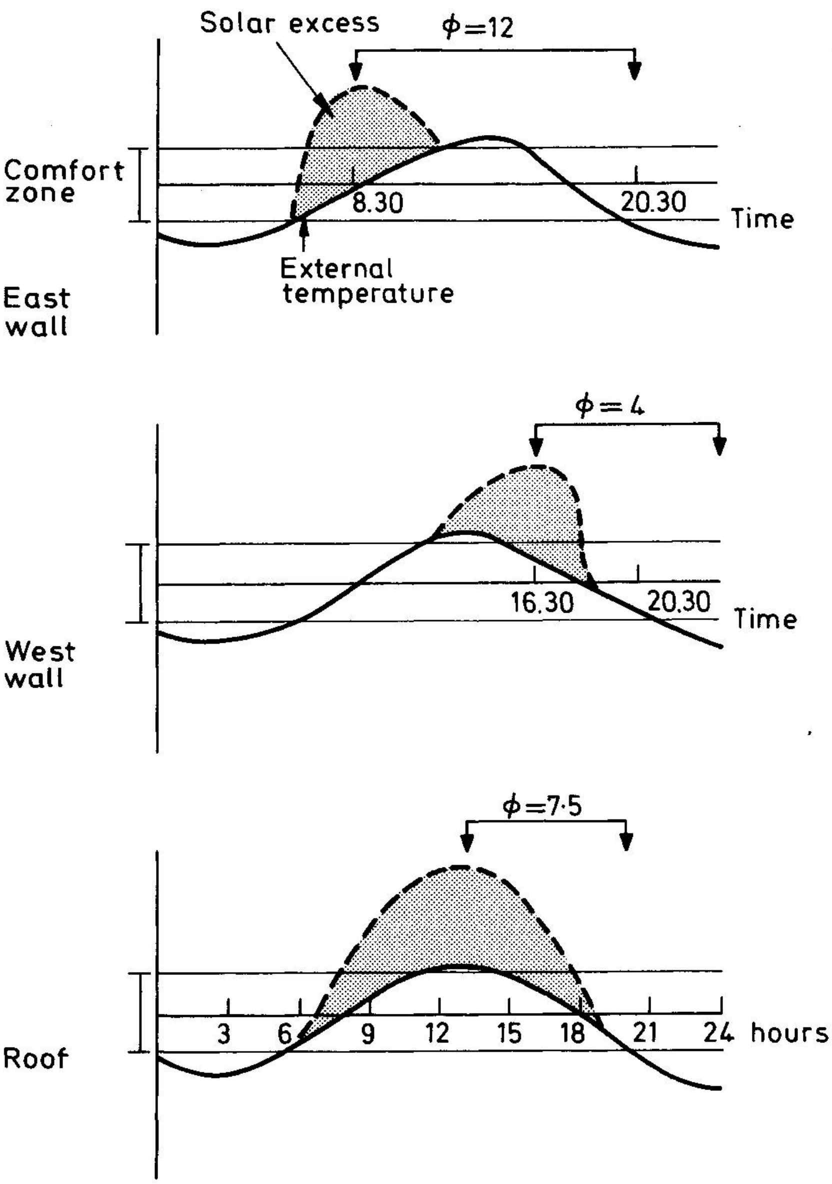


Figure 8 (a) Relationship between conductance—capacity index, decrement factor and time lag for different materials



Maximum excess occurs at:	—	Time heating required	=	ϕ hours
8·30	—	20·30	=	12
16·30	—	20.30	=	4
13.00	—	20.30	=	7·5

Figure 8(b) Solar gain, time lag and heating requirements