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SESSION 2

Environmental influences on the selection of structural form

Influence de l'environnement sur le choix du système et de la forme des structures

Einfluss der Unwelt auf die Wahl des Systems und der Form von Tragwerken

Chairman:	P. C. Bhasin, India
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I

History of climatic influences in building design

Influences du climat sur le projet de construction

Einfluss des Klimas auf den Entwurf von Bauwerken

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SUMMARY
Over the ages there have been many examples of building environmental design in hot, temperate and cold climates. This paper aims to examine some of the more outstanding ways in which man has adapted to the environment by the use of buildings and considers the features which remain important in recurrent building design.

RESUME
Il y a eu, au cours des siècles, de nombreux exemples de construction dans des climats chauds, tempérés et froids. L'article présente quelques cas remarquables d'adaptation de l'homme à son milieu par l'intermédiaire de constructions; il présente les caractéristiques importantes qui restent constantes quel que soit le projet de construction.

ZUSAMMENFASSUNG
Seit Jahrhunderten sind viele Beispiele umweltbezogener Bauten in heissem, gemässigtem oder kaltem Klima bekannt. Der Artikel berichtet über die bemerkenswertesten Fälle der Anpassungsfähigkeit des Menschen an seine Umwelt dank seiner Gebäude und behandelt die sich beim Entwurf eines Bauwerks wiederholenden wichtigen Eigenschaften.

In the building of his shelter primitive man faces one supreme and absolute limitation: the impact of the environment in which he finds himself must be met by the building materials which that environment affords. The environment is scarcely ever genial, and the building materials are often appallingly meager in quantity or restricted in kind. The Eskimo has only snow and ice; the Sudanese, mud and reeds; the Siberian herdsman, animal hides and felted hair; the Melanesian, palm leaves and bamboo. Yet primitive architecture reveals a very high level of performance, even when judged in the light of modern technology. It reflects a precise and detailed knowledge of local climate conditions on the one hand, and on the other a remarkable understanding of the performance characteristics of the building materials locally available.

Of course primitive architecture, like primitive medicine or primitive agriculture, often has a magico-religious rationale that is of interest only to anthropologists. But its practice - that is, how things are done, as distinct from the reasons offered for doing them - is apt to be surprisingly sensible. (This illogical situation is characteristic of prescientific technologies: the Roman architect Vitruvius, writing during the reign of Augustus, gives excellent formulas for concrete and stucco, but his explanation of their 'chemistry' makes no sense at all.) The primitive architect works in an economy of scarcity - his resources in materials and energy are severely restricted. Yet he has little margin for error in coping with natural forces: gravity, heat, cold, wind, snow, rain and flood. Both his theory and his practice are strictly determined by these conditions.

An understanding of this primitive experience is of more than academic interest today because, with the rapid industrialisation and urbanisation of the Western world, there is a growing tendency to minimise or ignore the importance and complexity of the natural environment. Not only is the modern architect quite removed from any direct experience with climatic and geographic cause-and-effect; he is also quite persuaded that they 'don't matter any more.' Yet the poor performance of most modern buildings is impressive evidence to the contrary. Many recent buildings widely admired for their appearance actually function quite poorly. Many glass-walled New York skyscrapers have leaked badly during rainstorms, and have had to be resealed at large cost. The fetish of glass walls has created further problems. The excessive light, heat and glare from poorly orientated glass places insuperable loads on the shading and cooling devices of the building a problem that is often compounded in the winter when the air-conditioning machinery is turnned off (1).

Thus Western man, for all his impressive knowledge and technological apparatus, often builds comparably less well than did his primitive predecessor. A central reason for his failure lies in consistent underestimation of the environmental forces that play upon his buildings and cities, and consistent over-estimation of his own technological capacities. Still, the worst he faces is a dissatisfied client. When the primitive architect errs, he faces a harsh and unforgiving Nature.

A few definitions are perhaps in order. As used here, the term 'primitive' describes the buildings of preliterate societies, whether historical or current, whose general knowledge comes by word of mouth, whose training is by apprenticeship, whose industry is handicraft and whose tools are pre-Iron Age. Although the folk architecture of modern civilization often display the same kind of pragmatic sagacity as the primitive, they are of a qualitatively different order. The iron tools and the measurement systems of civilization immediately introduce factors such as modular building material (eg brick, tile, dimensioned lumber) and repetitive structural systems (eg Roman arcade, vaulted Gothic bay) which are antithetical to the plasticity of primitive structure.

Literacy, on the other hand, introduces the disconcerting concept of a spectrum of building styles - an inconceivable situation to the primitive architect, to whom it has never occurred that there is more than one way to build. It is obvious that even primitive structures must have changed and evolved gradually over millennia, but at any given time the primitive architect was spared this unrecorded and forgotten history of styles. Indeed, knowledge of prehistoric architecture, as expressed in ordinary humble dwellings, is so scanty that this article will deal almost entirely with examples of primitive dwellings still being built in various parts of the world.

As used here, the term 'performance' refers to the actual physical behaviour of the building in response to environmental stresses, whether they be mechanical (snow load, wind pressure, earthquake) or purely physical (heat, cold, light). Civilization demands other sorts of performance from its architecture, but those faced by the primitive architect are basic and must be satisfied before more sophisticated performance is possible.

For the purposes of this discussion we are not concerned with plan, that is, the shape, size, scale or compartmentation given to architecture by problems of social exigency or cultural convention. For example, the exigency of organised warfare would add a moat and a wall to one plan, and the convention of polygamy would introduce a harem into another. Neither will have any significance except in relation to the culture that gave it birth. The significance of architectural structure, on the other hand, is absolute: a roof either supports a load of snow or it collapses; a wall either stands up to the wind or it falls. Even the simplest hut will have a plan, just as the most primitive society will have its taboos and conventions. But the simpler the plan requirements of a building, the clearer will be its aspect of environmental response.

When we contemplate the world's enormous range of temperature and precipitation, whose summation largely describes climate we must be impressed by man's ingenuity. Of these two chief components of climate, it is heat and cold that present the primitive architect with his most difficult problem. In culture after culture the solutions that man has found show a surprising delicacy and precision. Since thermal comfort is a function of four separate environmental factors (ambient and radiant temperatures, air movement, humidity), and since all four are in constant flux, any precise architectural manipulation of them demands real analytic ability, even if intuitive, on the part of the designer. In the North American Arctic and in the deserts of America,Africa and the Middle East he has produced two classic mechanisms of thermal control; the snow igloo and the mud-wall hut.

On a purely theoretical basis it would be hard to conceive of a better shelter against the arctic winter than the igloo. Its excellent performance is a function of both form and material. The hemispherical dome offers the maximum resistance and the minimum obstruction to winter gales, and at the same time exposes the least surface to their chilling effect. The dome has the further merits of enclosing the largest volume with the smallest structure; at the same time it yields that volume most effectively heated by the point source of radiant heat afforded by an oil lamp.

The intense and steady cold of the Arctic dictates a wall material of the lowest possible heat capacity; dry snow meets this criterion admirably, though at first glance it seems the least likely structural material.imaginable. The Eskimo has evolved a superb method of building quite a strong shell of it composed of snow blocks (each some 18 inches thick, 36 inches long and six inches high) laid in one continuous, insloping spiral. The insulating value of this shell is further improved by a glaze of ice that the heat of an oil lamp and the bodies of occupants automatically add to the inner surface. This ice film seals the tiny pores in the shell and, like the aluminium foil on the inner face of modern wall insulation, acts as a radiant heat reflector. When, finally, the Eskimo drapes the interior of his snow shell with skins and furs, thereby preventing the chilling of his body by either radiant or conductive heat loss to the cold floor and walls, he has completed an almost perfect instrument of control of his thermal environment. For the civilised Western nostril, the ventilation may leave something to be desired (it usually consists of a small opening somewhere near the top of the igloo). But odour is a subjective matter, and the oxygen supply is adequate for breathing and keeping the oil lamp alight. Like most primitive architecture, the igloo sacrifices permanence to high performance. The wife of the noted explorer Vilhjalmur Stefansson, Evelyn Stefansson, reports on one that she observed. The inside walls began to drip when the outside temperature rose to 21 degrees Fahrenheit, and the structure collapsed the next day, when the temperature rose to 32½ degrees Fahrenheit and it began to rain. But the Baffin Land Eskimos build permanent igloos of several units, connected by vaulted tunnels and airlocks to subsidiary units for food storage, dogs and equipment. In any case, the igloo melts no sooner than the Eskimo is ready to discard it. It didn't take him long to build, and it gives him first-class protection while it lasts.

If we turn to quite another type of thermal regime, that of the great deserts of the lower latitudes, we find an architectural response equally appropriate to radically different conditions. Here the characteristic problem is extremely high daytime temperatures coupled with uncomfortably low temperatures at night. Sometimes, as in the US South West, wide seasonal variations are superimposed upon these diurnal ones. Against such fluctuations the desirably insulation material would be one with a high heat-capacity. Such a material would absorb solar radiation during the day-light hours and slowly reradiate it during the night. Thus the diurnal temperature curve insude the building would be flattened out into a much more comfortable profile: cooler in daytime, warmer at night. Clay and stone are high heat-capacity materials; they are plentiful in the desert, and it is precisely out of them that primitive folk around the world make their buildings. Adobe brick and *terra pise* (molded earth) as well as mud and rùbble masonry, appear in the South West; massive walls of sun-baked brick in Mesopotamia; clay mortar on reed or twig mesh in Africa from the Nile Delta to the Gold Coast. And the native architect evolves sophisticated variations for subtle changes in environment. Here, to avoid a sharp winter wind, the entrance door will be moved around to the lee; there, to get early morning solar heat, it will face the east. Where afternoons are cool, dooryard benches face the west; where hot, the shaded east.

Limited to what for us would be a pitifully meager choice of materials, the primitive architect often employs them so skillfully as to make them seem ideal. Africa, for example, has developed dozens of variations of the structural use of vegetable fibres (grasses, reeds, twigs, saplings, palm trunks) both independently and as reinforcement for mud masonry. In Egypt, where it seldom rains, flat roofs are practicable; hence mud walls carry palm-trunk roof beams which in turn support a mud slab reinforced with palm fronds. Other regions, although arid, will have seasonal rains; here sloping forms and water-shedding surfaces are necessary. The beautiful beehive hut appears. Built like a conical basket on an elegant frame of bent saplings and withes, the beehive hut is sometimes sheathed with water-repellent thatch; sometimes mud plaster is worked into the wattle; sometimes the two are combined, as in the huts of the Bauchi Plateau of Nigeria.

The Nigerians construct a double-shelled dome for the two seasons. The inner one is of mud with built-in projecting wooden pegs to receive the outer shell of thatch. An air space separates the two. This construction accomplishes three things: the thatch sheds water and protects the clay dome during the rainy season; the air space acts as additional insulation during hot days and the mud dome conserves heat for the cool nights.

The principle of reinforcing is well understood. The Ashantis of West Africa build truly monolithic structures of mud beaten into a reinforcing web of woven twigs. Moreover, we find that the mass of the wall is adjusted to meet varying temperature regimes. In the colder desert areas the walls will be very thick to increas their heat-holding capacity. Often, in fact, to benefit from the more stable earth temperatures, the houses will be built into a southern cliff face (US South West, southern Tunisia, Shensi province in China). In warmer desert regions where diurnal or seasonal variations are smaller, the wall mass can be greatly reduced by the reinforcing techniques described above. In these regions, too, intense radiation and glare are the source of discomfort. Here again we find the primitive architect alertly responsive. Door and window openings are reduced in size to hold down interior light levels, and walls are painted or stuccoed white to reflect a maximum amount of radiant heat.

The inner tropical zones of the earth confront the primitive architect with quite another set of comfort problems. Here heavy rainfall and high humidity are combined with moderate air temperatures and intense solar radiation. There is no seasonal, and very little diurnal, variation in temperature. Thus shade and maximum ventilation are the critical components of comfort. To reduce the heat-holding capacity of the walls and to maximise the air flor across the interior, the primitive architect reduces the wall to a minimum, or gives it up altogether. The roof becomes the dominant structural element: a huge parasol, steeply sloping to shed torrential rains, opaque to solar radiation and of minimum mass to avoid heat build-up and subsequent reradiation into the living space. This parasol roof usually extends far beyond the living space to protect the inhabitants against slanting sun and blowing rain. And the floors of these airy pavilions are sometimes raised on stilts for better exposure to prevailing breezes as well as for protection from snakes, rats and crawling insects. This is the basic architectural formula of the Seminoles of Florida, of the tribes of the Caribbean littoral and of the Melanesians. The materials employed are predominantly vegetable fibres of all sorts: saplings and bamboo, vines for lashing them together, shredded fronds and grasses. In the absence of iron tools the cutting and fitting of carpentry is totally missing; instead the techniques of assembly are the tying and weaving of basketry or textiles. Here again, from the point of view of environmental response, the primitive designer shows an acute understanding of the local problem and a precise understanding of the properties of local materials.

In the outer tropical zones other refinements appear. Here the climate is characterised by two distinct seasons: one very wet and one very dry. (Both are hot.) Vegetable fibres are still employed, but in varying techniques, to achieve a wide range of permeability to heat and air. Thus certain tribes of Natal in South Africa build a hut whose light wooden frame is sheathed in woven fibre mats. The weave of these mats contracts in dry weather, permitting the movement of air through its interstices; but the fibres expand in wet weather, converting them into nearly waterproof membranes. In the huts of the Khosian tribe of South Africa these mats are detachable and can be moved from wall to wall according to wind direction.

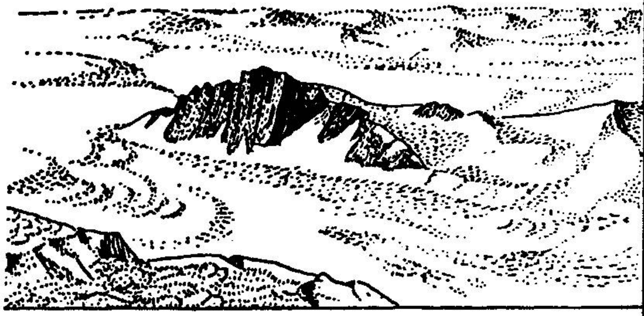
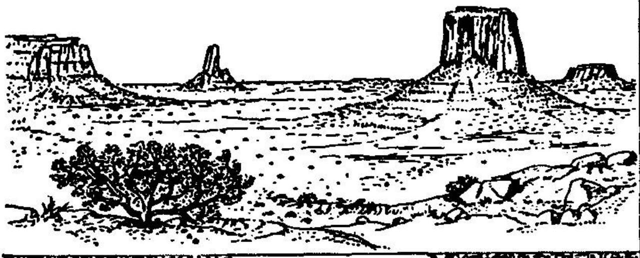
Naturally many other forces beyond the purely climatic are at work in shaping primitive architecture. The culture and means of subsistence will determine whether the shelter be permanent, mobile, seasonal or purely temporary. If the culture is a hunting one, like that of the Indians who once inhabited the Great Plains of North America; or a herding one, like that of the peoples of the Asiatic steppes, the architecture will tend to be demountable and mobile. But it will not be expendable, because suitable building materials are not readily available on the open steppe or prairie. (The sod dugout would make sense only in a permanent settlement.) Hence the structurally brilliant invention of the tent - light in weight, composed of small members and easily erected, dismantled and packed. At the same time, if we judge it by the modern structural criterion of 'the most work from the least material', the tent (like all tension structures) ranks as a very advanced form of construction. The basic type has been modified to meet a wide variety of climates: The American Indians covered the skeleton with skins; the Australian aborigines, with bark; the nomads of northern Asia, with felted hair; the nomads of the Middle East, with woven cloth. Perhaps the most advanced form, in the bitter cold of Siberia, was that developed by the Mongol herdsmen. Here the demand for effective thermal insulation is met by two layers of felt stretched over the inside and outside of a collapsible wooden trellis. The elliptical dome, staked to the earth, furnishes excellent protection against the high winds and bitter cold of Siberia.

One could extend this catalogue of human ingenuity indefinitely. But the examples cited are surely adequate to establish the basic point; that primitive man, for all his scanty resources, often builds more wisely than we do, and that in his architecture be establishes principles of design that we ignore at great cost. It would be a mistake to romanticize his accomplishments. With respect to civilised standards of scale, amenity, safety and permanence, the actual forms of his architecture are totally unsuitable. Neither is there any profit in the literal imitation of his handicraft techniques or in the artificial restriction of building materials to those locally available. Primitive architecture merits our study for its principles, not its forms; but these have deep relevance for our populous and ill-housed world. If we are to provide adequate housing for billions of people, it cannot be on the extravagant model of our Western urbs, suburbs and exurbs. The cost in building materials and in fuels (for both heating and cooling) would be altogether prohibitive for the forseeable future. Western science may be able to measure with great accuracy the environmental forces with which architecture deals. But Western technology - especially modern American technology - too often responds with the mass production of a handful of quite clumsy stereotypes. This is obvious, for example, in the thermal-control features of our architecture. In the house or the skysracper, generally speaking, we employ one type of wall and one type of roof. The thermal characteristics of these membranes will be roughly suitable to a thermal regime such as that of Detroit. Yet we duplicate them indiscriminately across the country, in climates that mimic those of Scotland, the Sahara, the Russian steppes and the subtropics of Central America. The basic inefficiency of this process is masked by the relative cheapness of fuels and the relative efficiency of the equipment used to heat, cool and ventilate our buildings. But the social waste of energy and material remains.

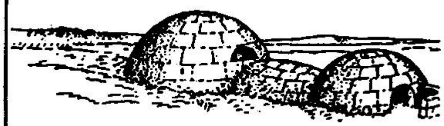
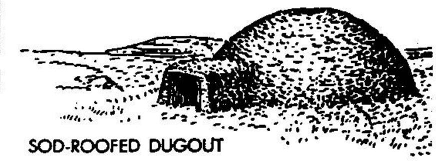
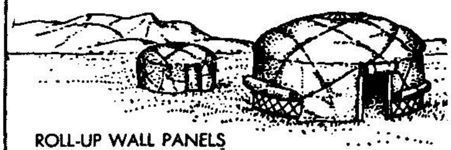
Contemporary US architecture would be greatly enriched, esthetically as well as operationally, by a sober analysis of its primitive traditions. Nor would it be stretching things to include in these traditions the simple but excellent architecture of the early white settlers who, in many respects, were culturally closer to primitive man than to 20th-century man. The preindustrial architects of Colonial and early 19th-century America produced designs of wonderful fitness; the snug, well-orientated houses of New England, the cool and breezy plantation houses of the deep south, the thick-walled, patio-centred haciendas of the Spanish South West. All these designs should be studied for the usefulness of their concepts, and not merely be copied for antiquarian reasons.

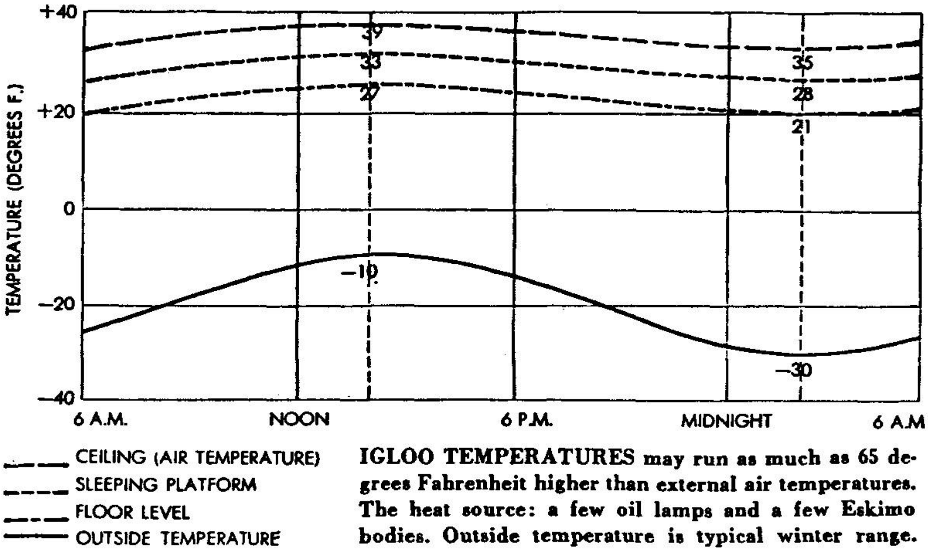
REFERENCE

(1) "The Curtain Wall" by James Marston Fitch; Scientific American, March 1955.

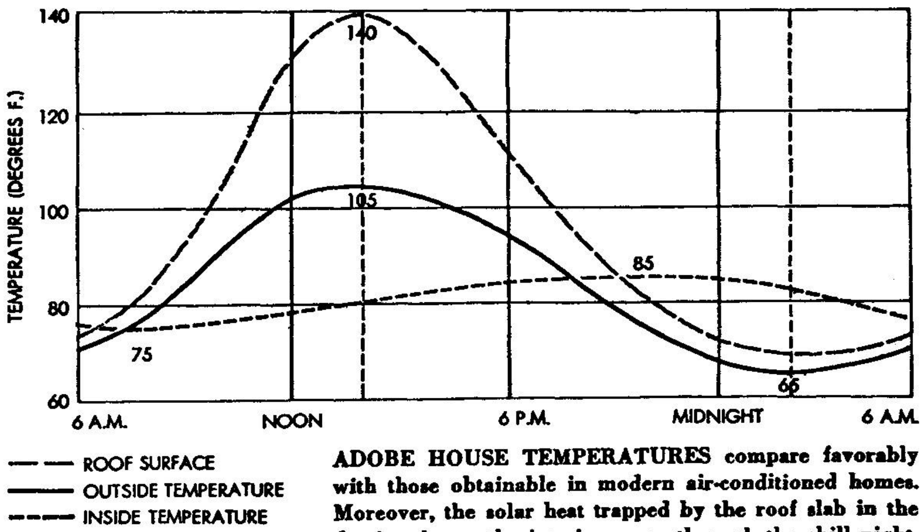
CLIMATE	THERMAL CHARACTERISTICS
ARCTIC AND SUBARCTIC 	WINTER INTENSE, CONTINUOUS COLD LITTLE SOLAR LIGHT OR HEAT HIGH WINDS SUMMER MODERATE TEMPERATURES INTENSE SOLAR RADIATION
CONTINENTAL STEPPE 	WINTER INTENSE, CONTINUOUS COLD NEGLIGIBLE SOLAR HEAT HIGH WINDS SUMMER LONG, WARM DAYS COLD NIGHTS
DESERT 	LITTLE OR NO SEASONAL VARIATION HOT DAYS-COLD NIGHTS INTENSE SOLAR LIGHT AND HEAT VERY LOW HUMIDITY LITTLE RAIN
TROPICAL RAIN FOREST 	NO SEASONAL VARIATION HOT DAYS WARM NIGHTS INTENSE SOLAR RADIATION HIGH HUMIDITIES HEAVY RAINFALL

IMPACT OF CLIMATE and available building materials on the design of primitive dwellings is summarised in this chart. It describes the four climatic regions where the greatest variety of primitive architecture is still to be found. In the first three climate zones, control of temperature is the crucial architectural problem. In the fourth heavy seasonal rains add to the difficulty.

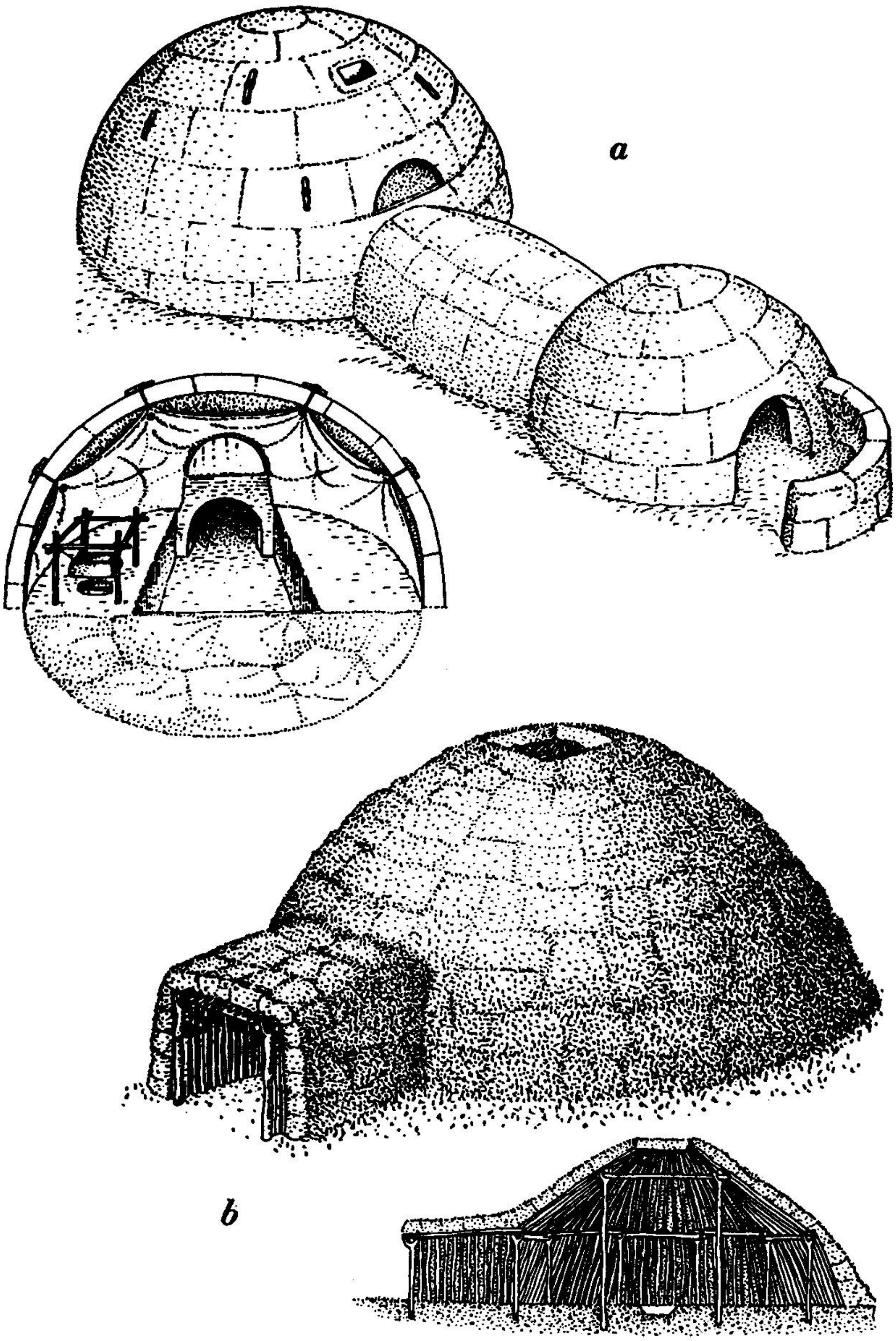
REQUIRED ARCHITECTURAL RESPONSE	RAW MATERIALS AVAILABLE	TYPE OF TENANCY	STRUCTURAL SYSTEM EVOLVED
LOW HEAT CAPACITY WALLS AND ROOF MINIMUM SURFACE, MAXIMUM STABILITY	SNOW	SEASONAL (HUNTING)	 SNOWDOME, ICE-AND FUR-LINED
HIGH HEAT CAPACITY ROOF AND WALLS	TURF, EARTH, DRIFTWOOD	SEASONAL (HUNTING-FISHING)	 SOD-ROOFED DUGOUT
LOW HEAT CAPACITY WALLS AND ROOF MINIMUM EXPOSED SURFACE, MAXIMUM STABILITY	ANIMAL SKINS, HAIR SAPLINGS	NOMADIC (HERDING)	 PORTABLE TENSION STRUCTURE HIDE AND FELT MEMBRANES ON FRAME
SHADE, VENTILATION LOW HEAT CAPACITY WALLS AND ROOF			 ROLL-UP WALL PANELS
HIGH HEAT CAPACITY ROOF AND WALLS SHADE MINIMUM VENTILATION NONWATERPROOF	MUD, STONES REEDS, PALMS, SAPLINGS	PERMANENT (AGRICULTURE)	 SOLID, LOAD-BEARING MUD-MASONRY WALLS ROOFS: MUD CEMENT ON WATTLE; POLE OR PALM TRUNK RAFTERS
LOW HEAT CAPACITY WALLS AND ROOF MAXIMUM SHADE MAXIMUM VENTILATION	VINES, REEDS, BAMBOO, PALM-FRONDS, POLES	PERMANENT (AGRICULTURE, FISHING)	 SKELETAL FRAME, THATCHED ROOF, WALLS SLOPING PARASOL ROOF STILTED FLOORS



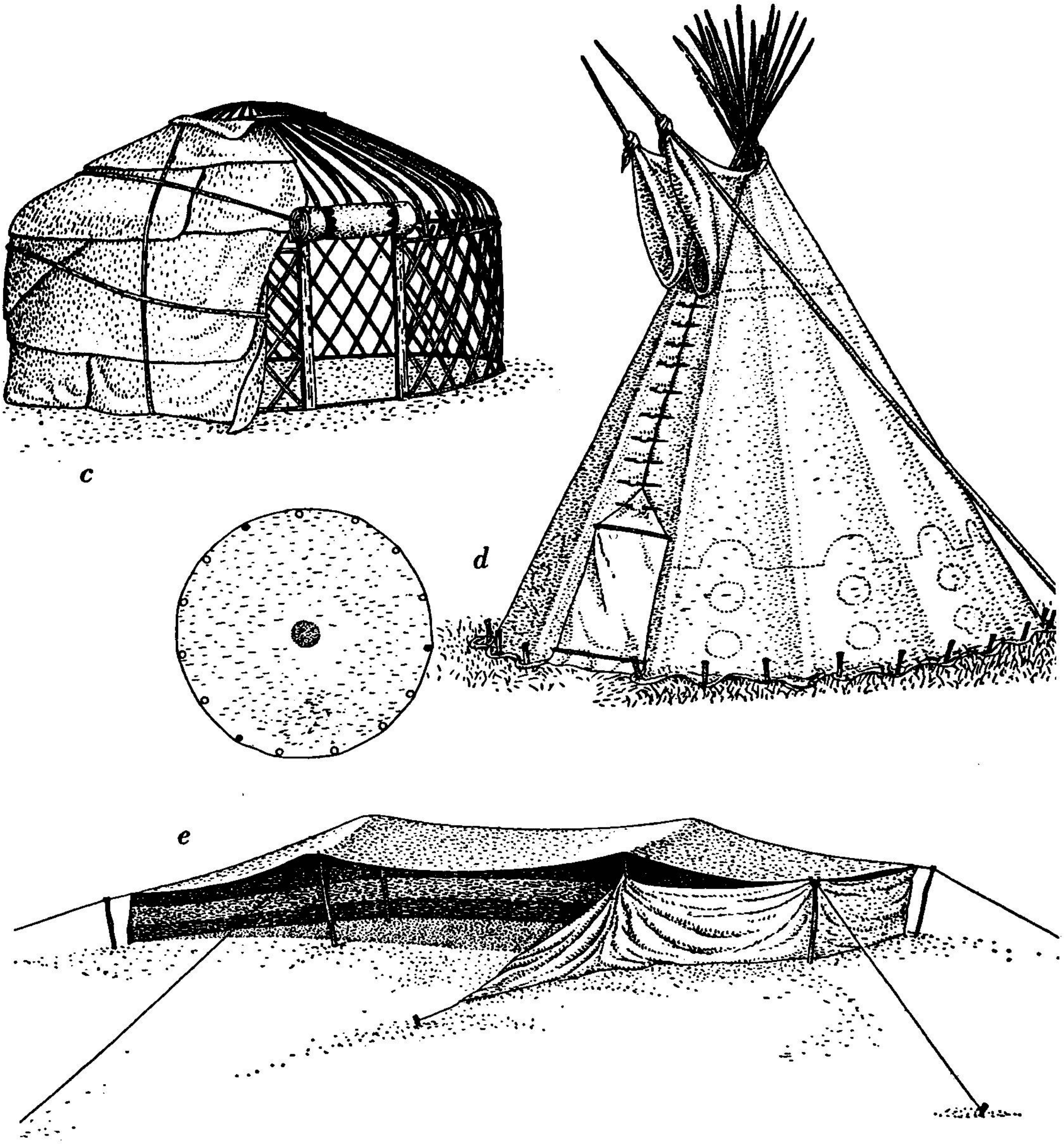
IGLOO TEMPERATURES may run as much as 65 degrees Fahrenheit higher than external air temperatures. The heat source: a few oil lamps and a few Eskimo bodies. Outside temperature is typical winter range.



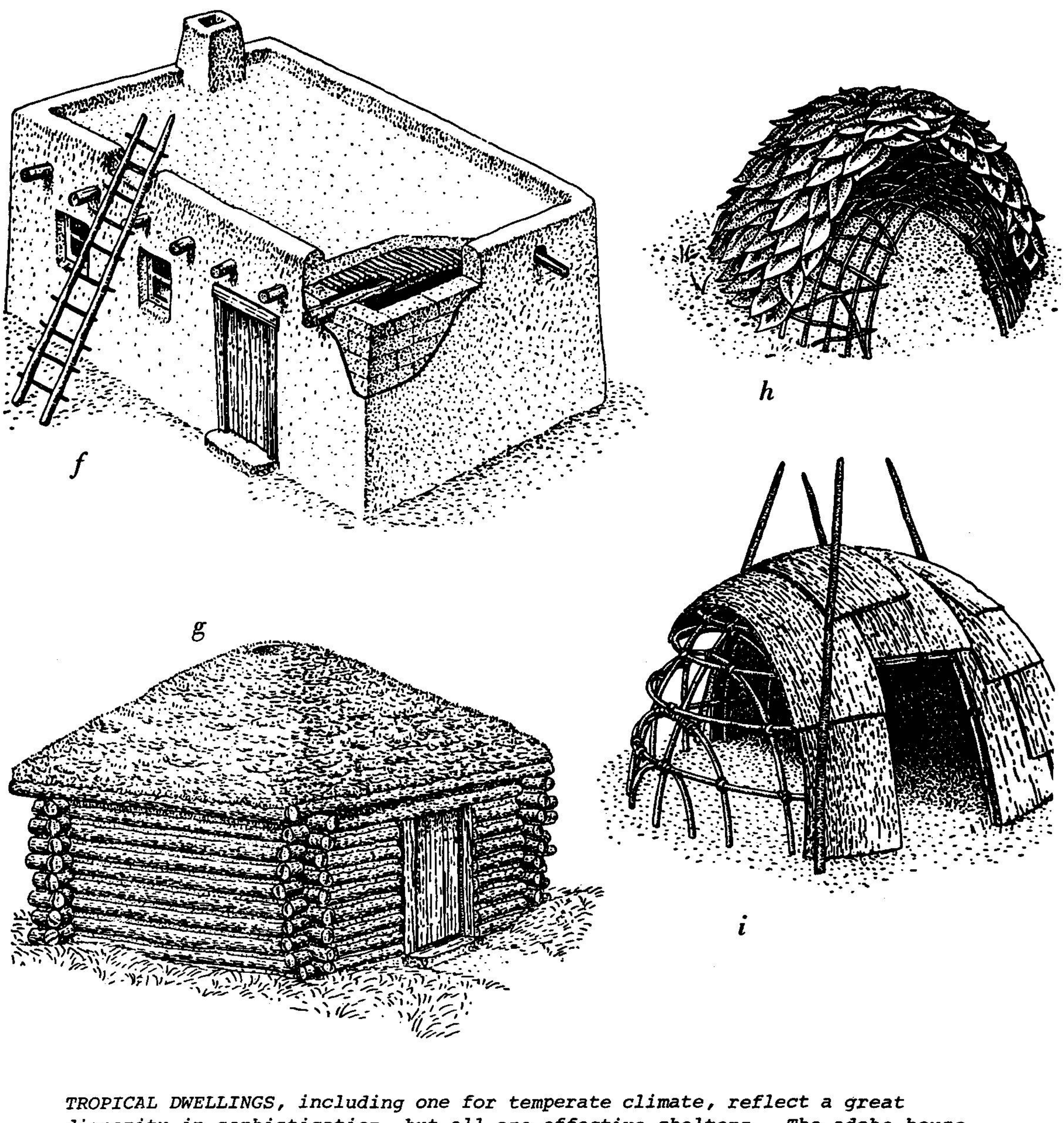
ADOBE HOUSE TEMPERATURES compare favorably with those obtainable in modern air-conditioned homes. Moreover, the solar heat trapped by the roof slab in the daytime keeps the interior warm through the chill night.



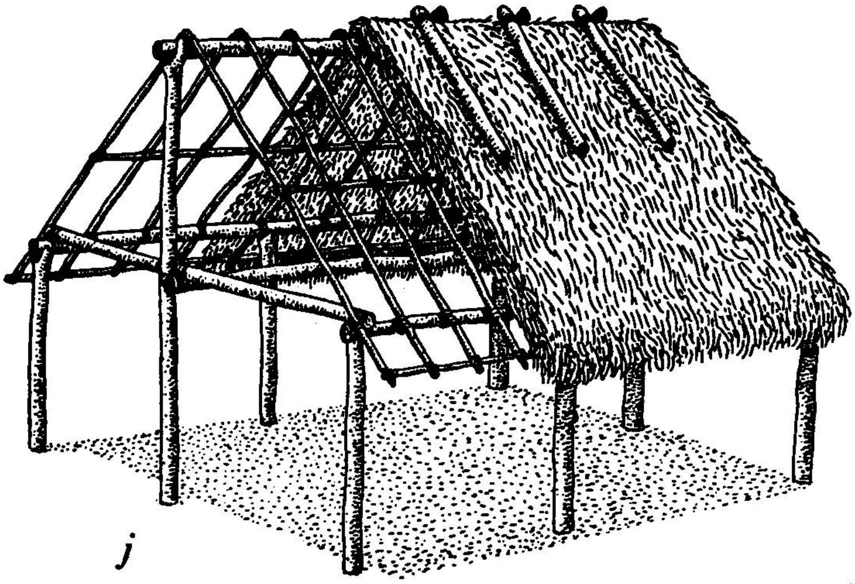
PRIMITIVE DWELLINGS, viewed as engineering structures, extract remarkably high performance from commonplace materials. Eskimo igloo (a) is built from snow blocks 18 inches thick that have insulating value equivalent to two inches of glass fibres. When lined with skins (detail drawing) the temperature of the interior can be raised to 40 degrees F without melting the dome. Summer house of Nunamiut Eskimos (b) follows igloo plan, but is made of sticks covered with slabs of turf.



The yurt, or Kazak tent (c), is among the most ingenious and weatherproof of the many types of demountable dwelling conceived by nomadic tribes. Its lightweight willow walls fold up like a child's safety gate. The covering is felt, sometimes two-layered with an air space between. The familiar Indian tepee (d) has a hide covering that can be closed weathertight or opened variably. Floor plan of tepee shows the three poles (solid circles) that are erected first. Bedouin tent (e), usually of woven goat hair, is primarily a sunshade, but, when required, must serve as a protective shield against sandstorms.



TROPICAL DWELLINGS, including one for temperate climate, reflect a great disparity in sophistication, but all are effective shelters. The adobe house (f) of Indians of the South West is built of baked mud bricks with a smooth mud-plaster exterior. The massive roof is ideally designed to absorb the midday heat. The Navajo hogan (g) is usually much cruder, consisting of mud daubed on a rough wooden frame. (The one illustrated is neater than most.) The simple hut (h) of the Banbuti Pygmies (northeastern Congo) is a woven frame of twigs covered with large leaves. Since it is protected by the deep shade of the forest it does not need massive heat-absorbing walls and roof. The Chippewa hut (i) closely resembles the Pygmy but except that it is covered with birch bark.



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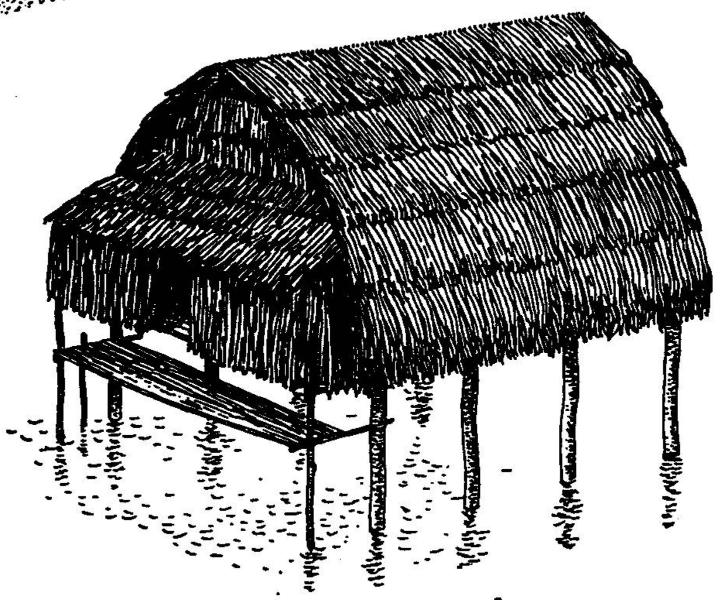

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k

The Seminole Indian house (j) anticipates the open, airy structures so admired by today's civilised Florida dwellers. In the Lake Chad region of Africa the local tribes build a cylindrical adobe hut (k) with a conical thatched roof. This roof, like that of the stilt house (l) of the Admiralty Islands off New Guinea, is most effective in shedding rain. In World War II the Pacific troops found such roofs much drier than a tent.

I

Mathematical models of form and energy use

Modèles mathématiques pour la forme d'une structure et l'utilisation de l'énergie

Mathematische Modelle für die Formgebung und Energienutzung

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SUMMARY
This paper argues that generalised conceptions of form are of fundamental importance in architectural design. The effective design of energy-conserving buildings requires a clear understanding of the relationship between form and energy use. The paper presents a survey of approaches to representing this relationship mathematically and discusses the influence which mathematical models have had upon the development of approaches to energy-conserving building design.

RESUME
L'article insiste sur l'importance essentielle du choix de la forme d'une structure dans le projet architectural. La conception efficace d'un bâtiment consommant peu d'énergie requiert une parfaite compréhension de la relation entre la forme et l'utilisation de l'énergie. Différents modèles mathématiques sont passés en revue; il est fait mention de leurs influences sur le projet de bâtiments fiables consommateurs d'énergie.

ZUSAMMENFASSUNG
Der Beitrag soll klar machen, dass verallgemeinerte Formgebungskonzepte für den architektonischen Entwurf von fundamentaler Bedeutung sind. Die zweckmässige Planung und Projektierung energiesparender Gebäude setzt ein klares Verständnis der Beziehung Form—Energieverbrauch voraus. Der Artikel gibt einen Ueberblick über verschiedene mathematische Methoden zur Erfassung dieses Zusammenwirkens und diskutiert den Einfluss, den mathematische Modelle auf die Entwicklung energiesparender Projekte von Gebäuden gehabt haben.

INTRODUCTION

The dictionary [1] defines form as, among other things, shape, outline, general appearance, type, order, arrangement, structure and established custom. Architects use the word in each and all of these meanings, sometimes with precision, as in the cases of order, arrangement or structure, and sometimes in an imprecise, but often potent, sense as with outline and general appearance. My dictionary's reference to established custom is particularly apt in architectural usage since there is evidence that much design derives from commonly held notions of what a building should be - a type or, more precisely, a stereotype [2]. These exist as generalised solutions to 'standard' problems and are used by many designers to inform the development of their specific designs. Inevitably they are subject to a process of re-evaluation, adaptation and change, but this only serves to confirm their utility not to challenge it. Form is therefore vitally important to an architect. In this paper the emphasis will be upon the references to shape and type, with the latter's connotation of established custom, in order to discuss the rôle and influence of mathematical modelling in the study of energy use in buildings.

MODELLING ENERGY USE

It is less than ten years since energy conservation became a major concern in building design. The first question which this raised in the minds of architects was, not surprisingly, "what shape is an energy conserving building?" In these few years a good deal of progress has been made towards finding an answer, or rather answers since there is no single, simple answer. Much of this work has made use of mathematical modelling techniques. In fact without some kind of quantitative analysis of a proposal it would be difficult for it to have much credibility. Perhaps this is the first time in the history of architecture that mathematics have been central to a major development.

Buildings use energy primarily in the process of environmental control - in providing a comfortable internal environment no matter what external conditions may exist. The problem of energy-conserving design thus becomes one of reducing the amount of energy used in heating, cooling, ventilating and lighting. All have some representation of the external climate, some definition of the internal conditions to be achieved and a means of describing the building itself.

Numerous large-scale computer models now exist which, in one way or another, meet this specification. One of the very first - predating the energy crisis - was developed at Cambridge in the late 1960's [3]. Many subsequent models have incorporated improved representations of the physics of energy flow, but it serves to give a picture of the general characteristics of models of this type.

The external climate was described in the following terms:

Table 1. Description of the external environment.

A. Thermal
   1. External air temperatures at hourly intervals for cloudy and clear days, winter and summer.
   2. Solar azimuth, hourly intervals, winter and summer solstices.
   3. Solar altitude, hourly intervals, winter and summer solstices.
   4. Direct and scattered solar radiation values.

B. Natural illumination
   Whole sky illumination, hourly intervals, winter and summer solstices.

C. Noise
External noise levels.

In this model the internal temperature of the building was found using the 'Admittance Method" [4] which calculates the dynamic response of a building to inputs of energy as a series of deviations from a daily mean condition.

$$\left(\frac{Qf}{A}\right) = \frac{Q'f}{A} + \left(\frac{\tilde{Q}f}{A}\right) \tag{1}$$

Where $\frac{Q'f}{A} = U(t'_{eo} - t'_{ei})$ (1a)

$$\left(\frac{\tilde{Q}f}{A}\right) = U(t_{eo} - t'_{eo}) \tag{1b}$$

Where $\left(\frac{Qf}{A}\right)$ = heat flow into space at time $\theta + \phi$ (W)

$\frac{Q'f}{A}$ = mean heat flow into space (W)

$\left(\frac{\tilde{Q}f}{A}\right)$ = deviation from the mean heat flow at time $\theta + \phi$ (W)

ϕ = time lag (hours)
t'_{eo} = daily mean sol-air temperature (^{o}C)

t'_{ei} = inside air temperature (^{o}C)

f = decrement factor

The values of ϕ and f are derived from the thermal properties of the building fabric. Further terms are added to the basic equation to calculate the effect of direct solar gain through windows and the effects of ventilation. In addition the effects of the heat gain due to the occupants of the building and to the use of articicial lighting are included. The latter is, where appropriate, "switched" on or off by making reference to the amount of available daylight.

Conventionally, daylight levels in a building are expressed in terms of the Daylight Factor. This is defined as, "The ratio of the illumination inside the building to that outside." [5]. It is assumed that the sky is overcast and has a luminance distribution where:

$$B_\theta = B_z = \frac{1 + 2\sin\theta}{3} \tag{2}$$

Where B_θ = luminance at altitude θ

B_z = luminance at zenith

The calculation of daylight factor assumes three components:
Sky component (SC)
Externally reflected component (ERC)
Internally reflected component (IRC)

The sky component for the sky luminance defined above is given by Hopkinson [6] as:

$$SC = \frac{3}{7\pi} \int_{\theta N_1}^{\theta N_1} \int_{\phi_2}^{\phi_2} \frac{\tan\theta_N . \sec^2\theta_N . \sec^2\phi}{(\sec^2\theta_N + \tan^2\phi)} + \frac{2\tan^2\theta_N . \sec^2\theta . \sec^2\phi}{(\sec^2\theta_N + \tan^2\theta^{5/2})} d\theta_N d\phi \tag{3}$$

Where θ = the angle of elevation of the visible patch of sky.
ϕ = its azimuthal angle.

The externally reflected component is usually taken to be a proportion of the sky component obstructed and the internally reflected component is found by an equation based upon the split-flux principle [7]

$$IRC = \frac{0.85W}{A(1-R)} (CR_{fW} + 5R_{cW})\% \tag{4}$$

Where
W = glazed area of window. (m^2)
A = total surface area of room. (m^2)
R = average reflectance of all surfaces.
C = a function of the sky luminance distribution and the obstruction angle.
R_{fW} = average reflectance of the floor and parts of the walls below the mid-height of the window, excluding the window wall.
R_{cW} = average reflectance of the ceiling and parts of the walls above the mid-height of the window, excluding the window wall.

When the daylight factor has been calculated for a room it can be converted to a series of estimates of absolute illumination by multiplying it by hourly values of whole sky illumination. It is then possible to estimate whether artificial lighting would be in use.

A model of this kind, operating within a comprehensive description of a building's form, construction and details, can be used to carry-out very detailed analyses of energy flows. The effects of overall shape and overshadowing by neighbouring buildings can be evaluated, as can the consequences of changing such details as the size, shape and position of windows and of shading devices.

A great deal of work has been done to explore ranges of possibilities and to attempt to establish ground rules for design. To give an example the Cambridge model was used to study four simple alternative arrangements of a fixed amount of floor space (Figure 1).

These studies [8], which went into considerable detail produced the following data on the relationship between form and energy use.

Table 2 Comparison of peak and 24-hour cooling loads for fully glazed facades - Btu/h

No of storeys	Peak load	24-hour load
2	1,084,000 (317)	14,200,000 (4160)
4	1,501,000 (439)	18,900,000 (5537)
5	1,721,000 (504)	21,400,000 (6270)
10	2,792,000 (818)	33,700,000 (9874)
*10	2,227,000 (652)	26,700,000 (7823)

* This case has long axis east-west
Figures in parenthesis are in kilowatts

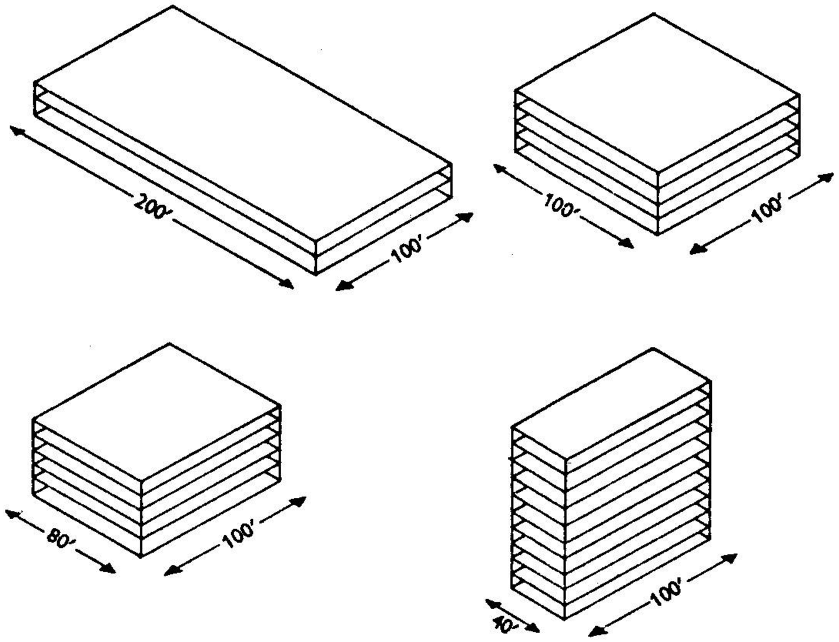


Figure 1

The clear lesson of this study is that energy consumption for summer cooling is much lower in a low, compact form than in a high-rise alternative, even allowing for the fact that the low building would use an amount of energy in artificial lighting, whereas the tall form would allow for full natural lighting in summertime. These results, and those from other, similar studies led to the deep-plan building being enthusiastically taken-up as an answer to the question of the shape of the energy-conserving building and, thus, to its rapid establishment as a design stereotype for many kinds of building.

Following this a number of mathematical models were developed which specifically aimed to aid the design of buildings of this type. These took many forms, some simple and some complex. Two contrasted examples will be described. The first is a simple model in which the simultaneous heat losses and gains in a building are related through the concept of the thermal balance point, that is the temperature at which gains equal losses. The basis of the analysis is the simple, steady-state heat loss equation:

$$Q_f = UA(t_i - t_o) \qquad (5)$$

Where:

Q_f	= rate of heat transfer	(w)
U	= thermal transmittance of material	($w/m^2 {}^oC$)
A	= area of element	(m^2)
t_i	= temperature inside building	(^oC)
t_o	= temperature outside building	(^oC)

In any building there will be heat gains from 'internal' sources such as people, artificial lighting and machinery. In addition there will be some contribution from solar gain. In the case of a deep-plan building it is reasonable to assume a high heat input from artificial lighting and that the solar gains will constitute only a relatively small proportion of the total heat gain, and that more of it will occur in summer than in winter. On these assumptions it is possible to plot a graph in which these gains are related to outdoor temperature (Figure 2).

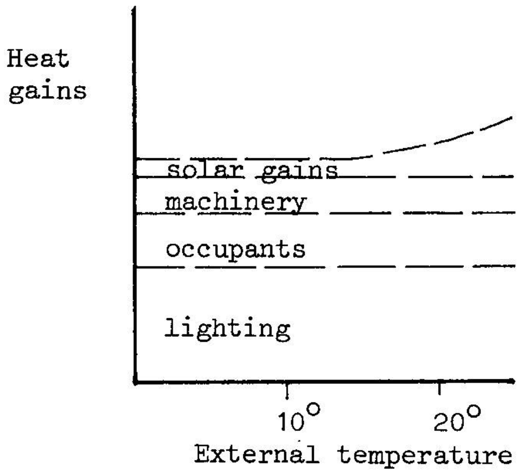


Figure 2

Using the steady-state equation it is then possible to calculate the heat loss from the building as a function of the internal-external temperature difference and to superimpose this upon the graph (Figure 3).

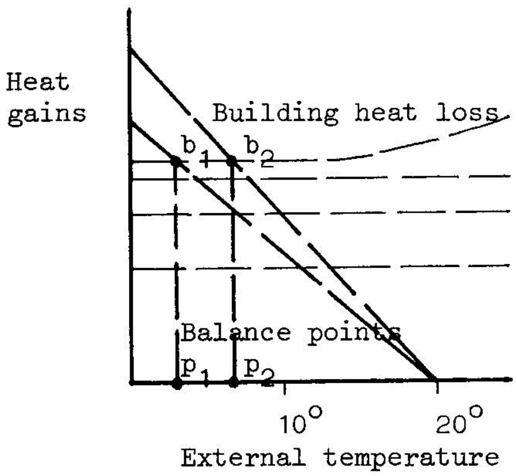


Figure 3

The slope of this curve is a function of the thermal efficiency of the building envelope. The greater its efficiency, expressed in heat loss per unit temperature difference, the lower the balance point. If this is pushed down to a low level, say 0°C, it is apparent that the building will not be likely to need any direct space heating in a temperate climate like that of Britain. This brings savings in the capital cost of plant in an air-conditioned building. Cooling will be required for a good proportion of the year whenever the outdoor temperature is significantly above the balance point. In its application this model confirms the advantages of the compact, deep-plan form in energy conservation, when compared with a form, such as a tower which arranges the same floor area within an envelope of greater area. In both cases it is assumed that the building will have a cooling plant.

The properties of the compact form have been investigated in great detail by Jones [9] using a complex model in which the climatic energy flow through the building envelope is broken-down into six elemental flux values representing the four walls, the roof and natural infiltration of air.

$$C = F_1 + F_2 + F_3 + F_4 + F_5 + F_6 \qquad (6)$$

For a wall of a given orientation

$$F_1 = znX_1Q_1 \qquad (7)$$

Where: $$Q_1 = T_{W1}(1 - A_{g1}) + T_{g1}A_{g1} + S_{g1}A_{g1} \qquad (8)$$

z = floor-to-floor height (m)
n = number of storeys
X = length of facade (m)
T_{w1} = mean specific energy flow rate in any hour through wall 1 (w/m^2)
T_{g1} = mean specific energy flow rate during the occupied or unoccupied period arising from air-to-air transmission and long-wave radiation exchange through the sindow glass of wall 1 (w/m^2)
A_{g1} = glazed fraction of wall 1
S_{g1} = mean specific air-conditioning load (heat gain) in any hour arising from direct and diffuse solar radiation through the window glass of wall 1 (w/m^2)

Similar equations are used to evàluate the flux flowing through the roof and that due to infiltration. All of the equations are solved for each hour of a typical day for each month of the year. The basic physics is similar to that of the Cambridge model outlined above, with a number of refinements, specifically to deal with the effect upon available solar radiation of cloud cover and the use of a statistical model of outdoor temperature. The energy flows through the individual elements are summed over the whole year and thus, an estimate is made of the total annual energy demand of the building.

Using this model Jones has examined in detail the relationship between built form, construction and energy use in air-conditioned buildings. His results confirm the general conclusions of earlier work, but in some respects offer a new degree of refinement. On the question of building shape he concludes that the best forms are those with the minimum ratio of surface area to floor area. Circular or square buildings are suggested as 'theoretically' preferable, and large buildings rather than small. The amount of glazing in the walls is shown to have a major influence upon energy use and the effect of glazing areas upon form is clearly illustrated in the comparison between the forms at Figure 4.

The models described all serve to develop an understanding of the relationship between form and energy use in buildings which use their external envelope to reduce the impact of the external climate upon the internal environment. In most cases these buildings make use of air-conditioning and some permanent artificial lighting. It is, however, possible to approach the question of energy-conserving design from a different standpoint in which the external environment is 'filtered' rather than excluded by the building envelope in an attempt to select those elements which are beneficial and to exclude those which are undesirable [10]. Such buildings are inherently different to those discussed so far and it is necessary to adopt a different approach to modelling their energy performance.

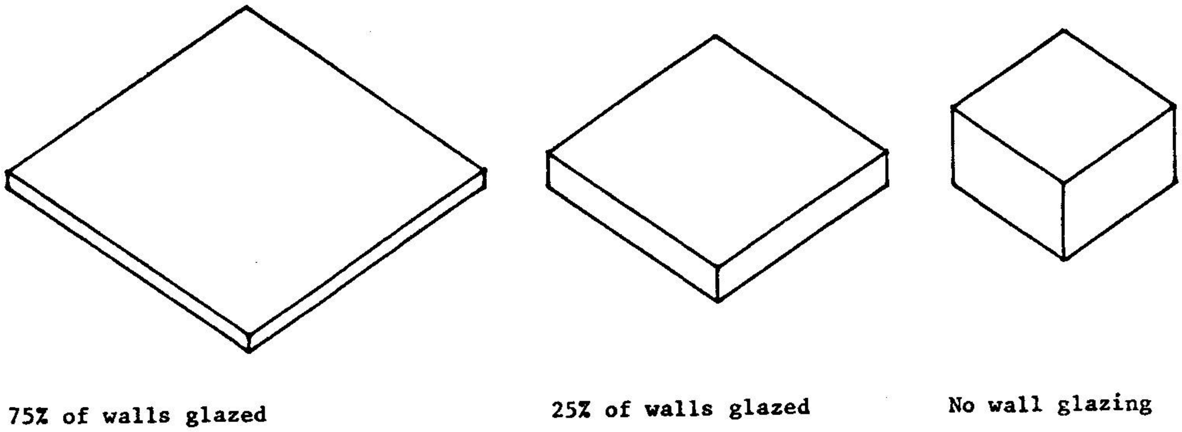


Figure 4

In each case the gross floor area is 25400m^2. The consequences of increasing the glazed area is to modify the form to reduce the overall wall area.

One of the most appropriate approaches to modelling buildings in which direct solar radiation is accepted as a primary, desirable input into the energy system is the thermal network. Davies [11] has presented a clear outline of the basic theory in which the separate effects of enclosure geometry and surface emissivity are distinghished. A simple representation of a cubic room takes the form shown at Figure 5.

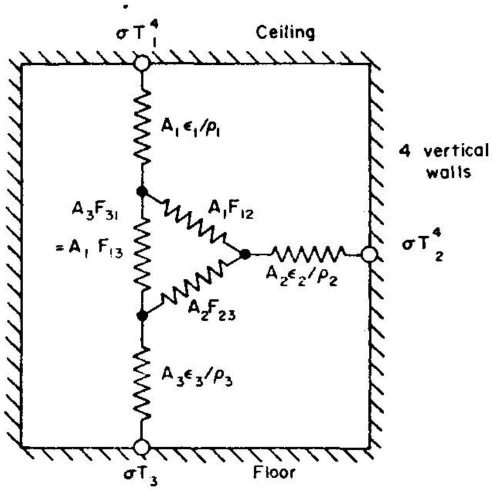
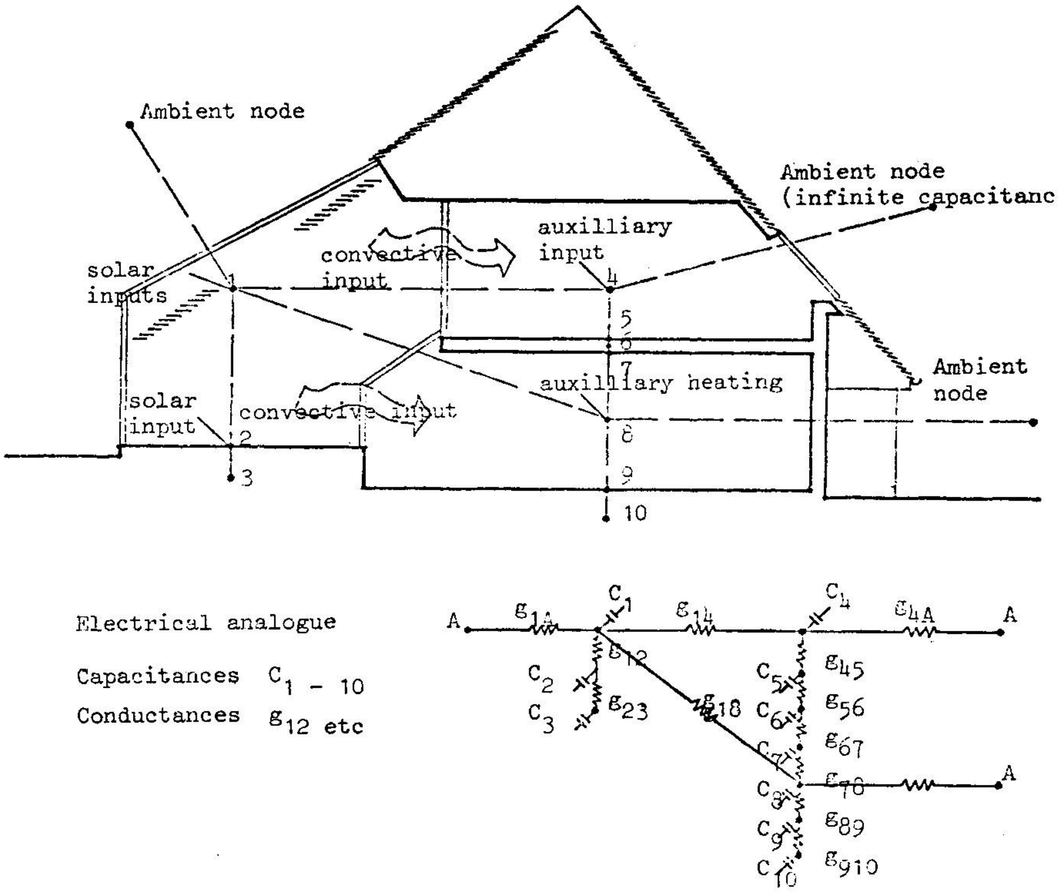


Figure 5 Thermal circuit illustrating radiant exchanges between a ceiling at T_1 with walls at a uniform temperature T_2 and the floor at T_3

A similar approach has been adopted by Baker [12] in work at Cambridge in studying the energy performance of school designs in which passive solar gain is exploited. In this model a network of capacitances and conductances is explicitly derived from the building configuration (Figure 6)



This is thence translated into a set of equations and evaluated for any given values derived from the constructional details of the building. In the particular case illustrated [13] the form and properties of the building clearly contradict the conclusions suggested by the models described above. The analysis has shown, however, that a design of this type achieves an energy performance which is more than comparable with that offered by a compact, minimally glazed form of similar floor area.

CONCLUSION

This paper has briefly reviewed the development of mathematical models for the study of the relationship between built form and energy use. By the use of models of many kinds a body of information is quickly accumulating through which this complex relationship may be understood by designers. On the evidence of much of the work it appears that the full complexity of the problem is best explored by the development of models which aim to address specific issues. As the examples illustrated above indicate, there is no unique answer to the question of the shape of an energy-conserving building. It depends crucially upon the assumptions which are made about the building and its environmental systems at the very outset. The problem of an air-conditioned building is quite different to that of a passive solar building, and this difference should also be reflected in the models which are used to study them. It is gratifying to note that, in this field, architectural science has managed to avoid the trap of determinism which has, arguably, compromised its acceptance in the past. We have a spirit of inventive inquiry in which mathematical models are playing a central rôle.

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I

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 $\Delta\Theta i = 4^oC$ and allowing a temperature drop of 6^oC through the surface film of the insulation but 20^oC 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^oC 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 $t=t$

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

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

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 $t=\tau$

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

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

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

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

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

Note that the rate of cooling or heating

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

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

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

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

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

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

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

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

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 = Θ) 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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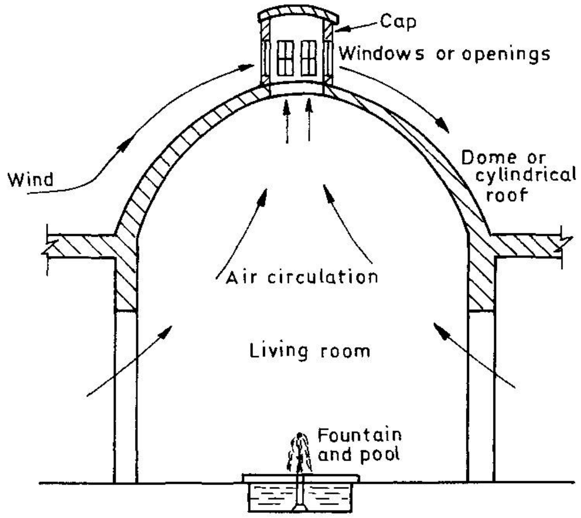


Figure 1. The air circulation pattern in a room with a curved roof (12)

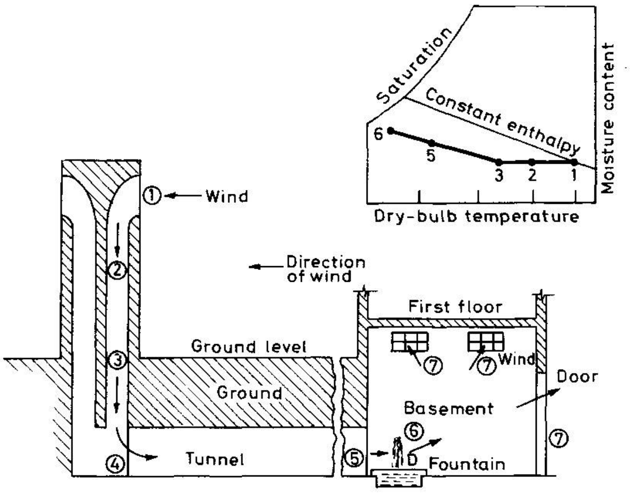


Figure 2(a) The cross-section of a wind tower connected to the basement by a 50-m-long moist underground tunnel (12)

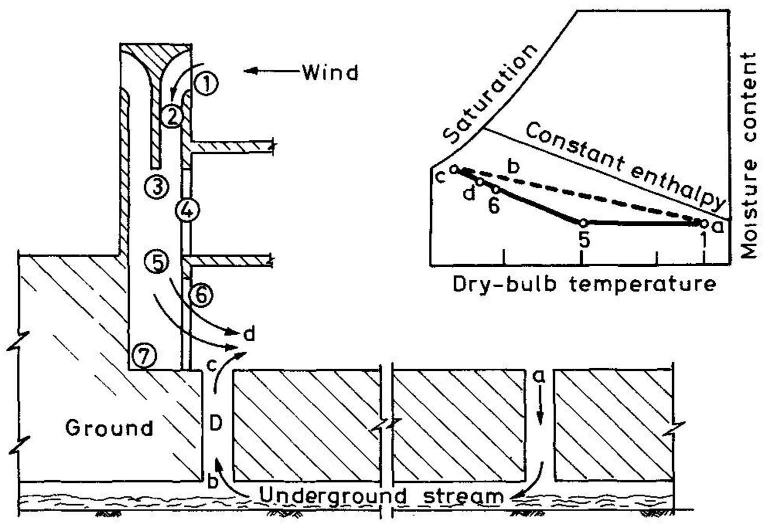
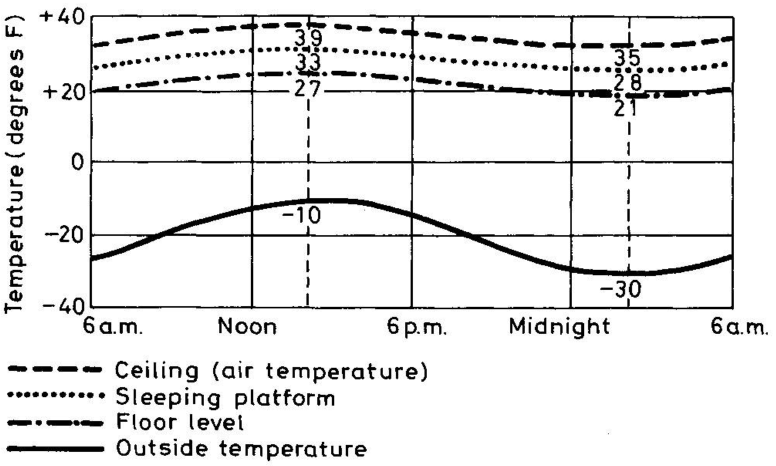
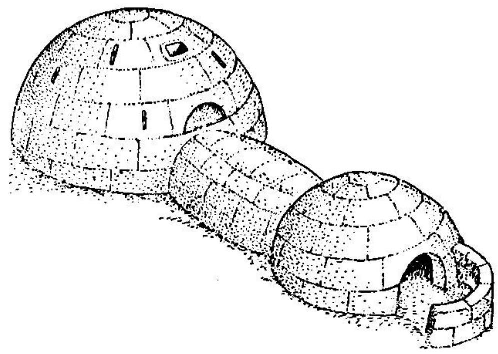
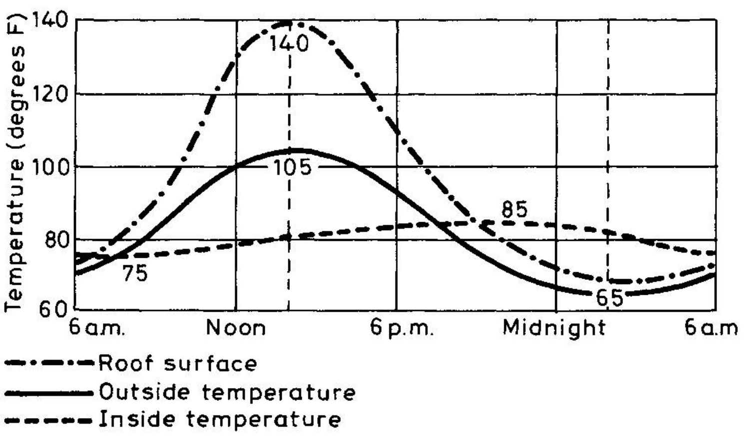


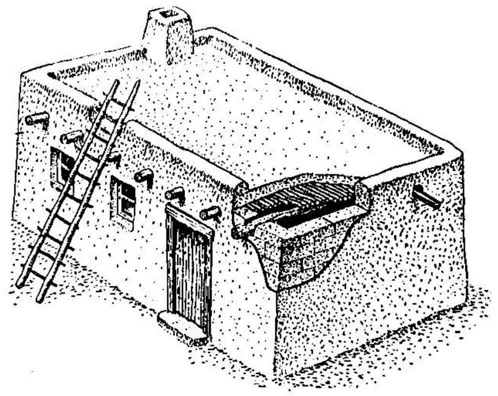
Figure 2(b) The cross-section of a wind tower used in conjunction with an underground stream (12)





(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)

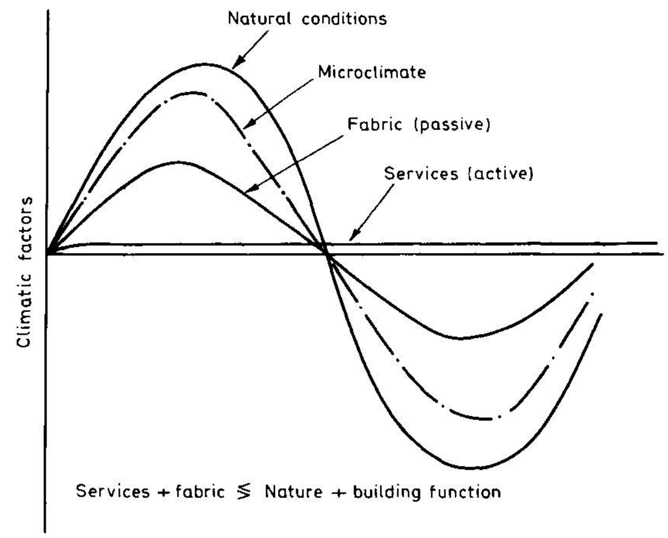
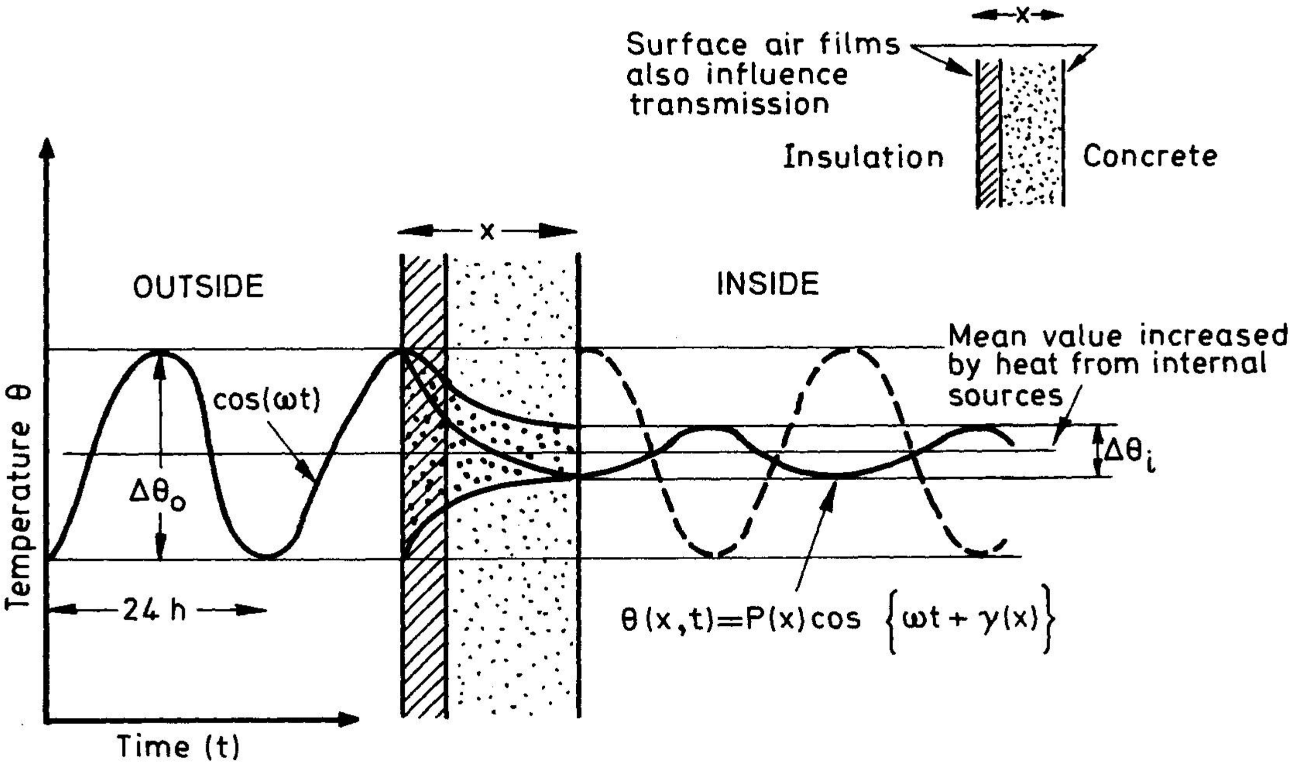


Figure 4. Environmental control



$P(x)$, $\gamma(x)$ are thermal properties of the construction

$\cos(\omega t)$ is climate function

Decrement factor $f = \dfrac{\Delta\theta_i}{\Delta\theta_o}$

Figure 5 (a) Effect of structure on temperature damping

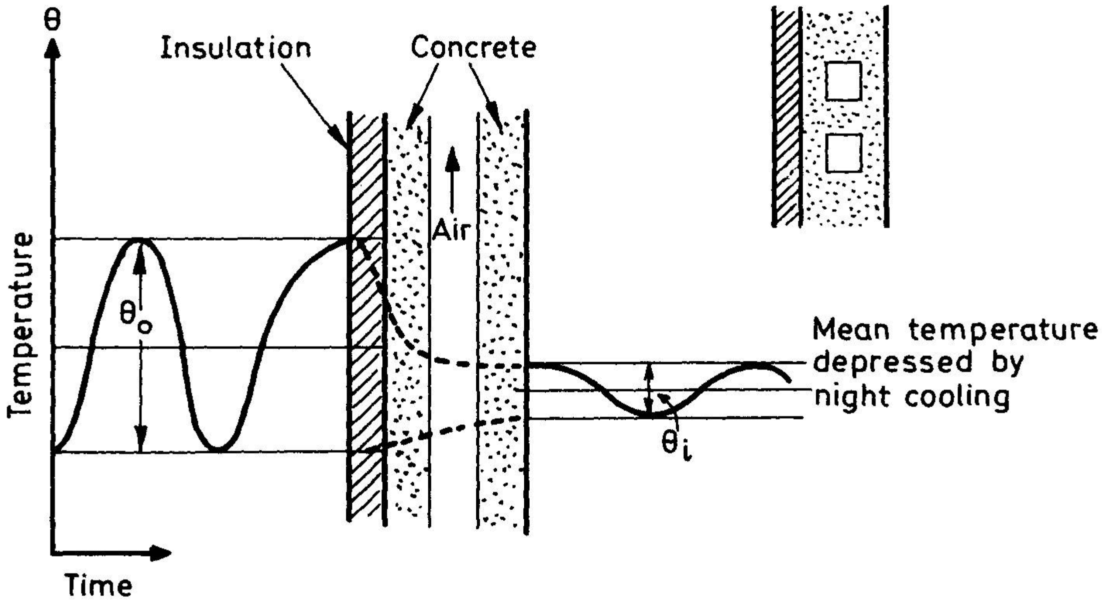
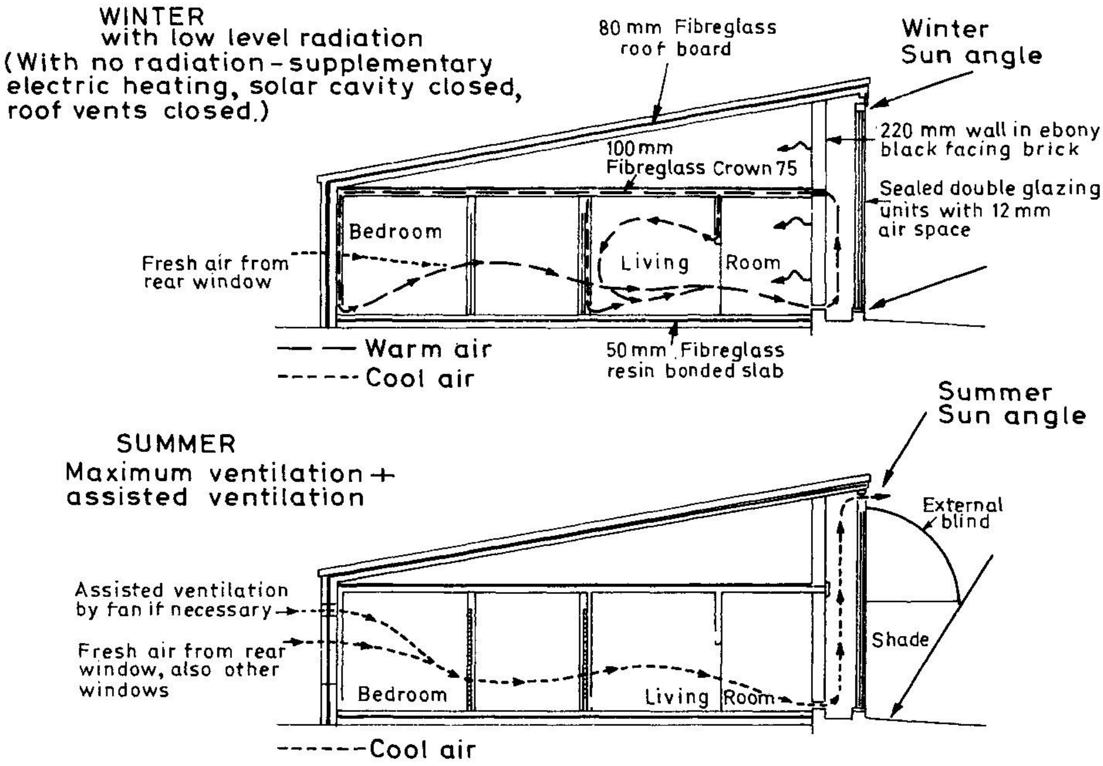
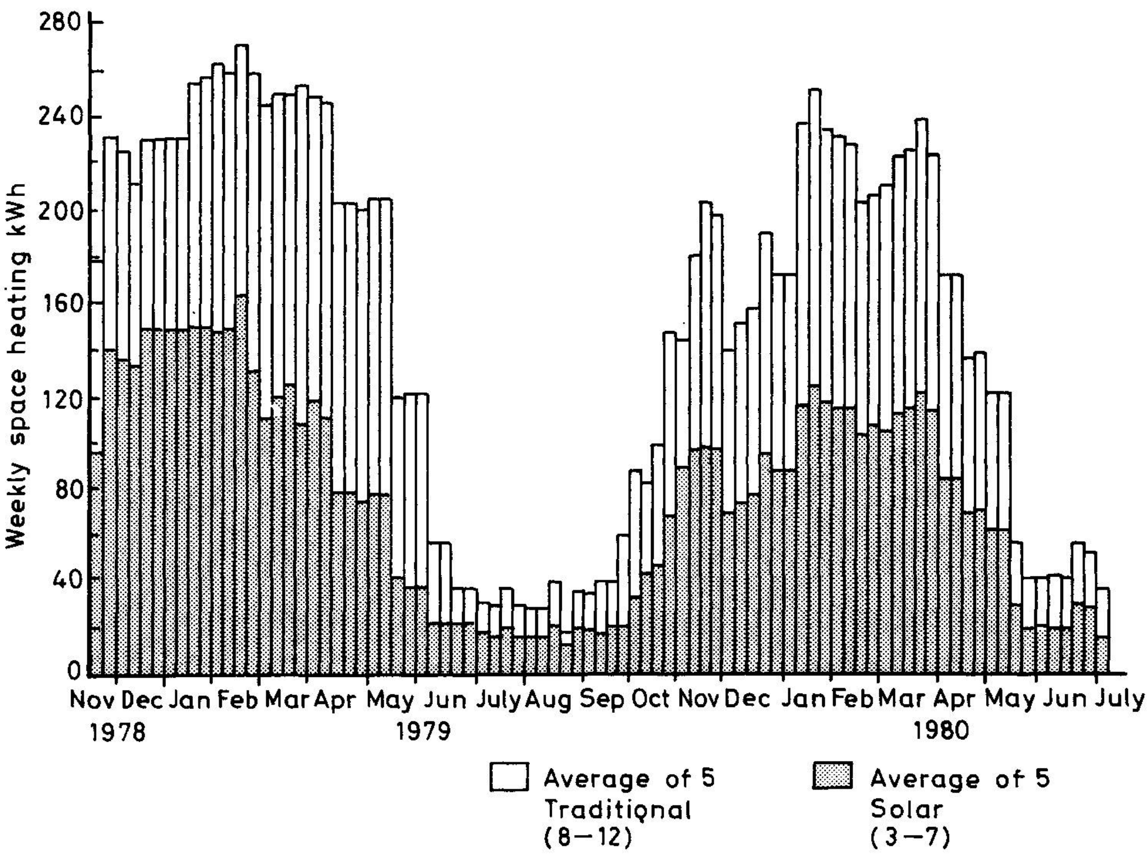


Figure 5(b) Effect of night cooling using hollow block ventilated structures

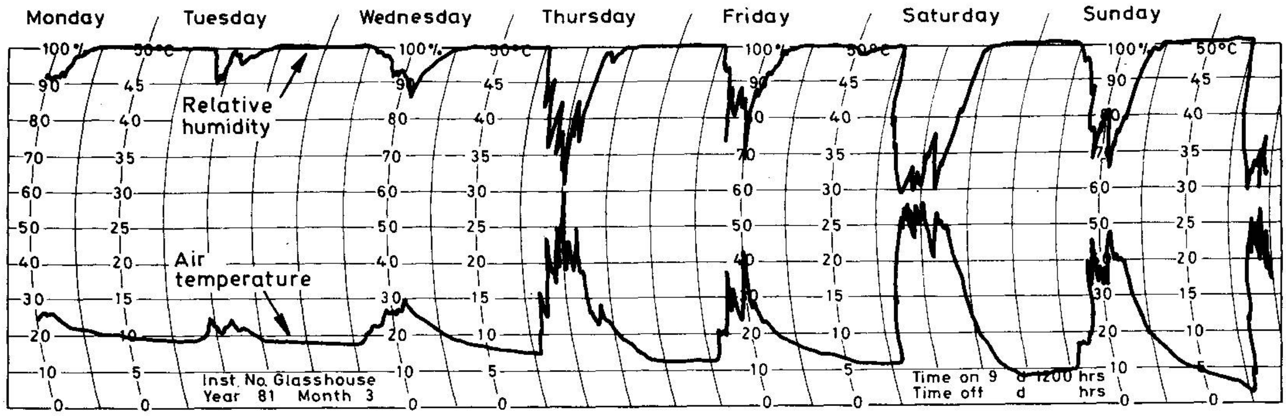


(a) Acorn Close, Bebington: Heating and ventilation systems using Trombe wall

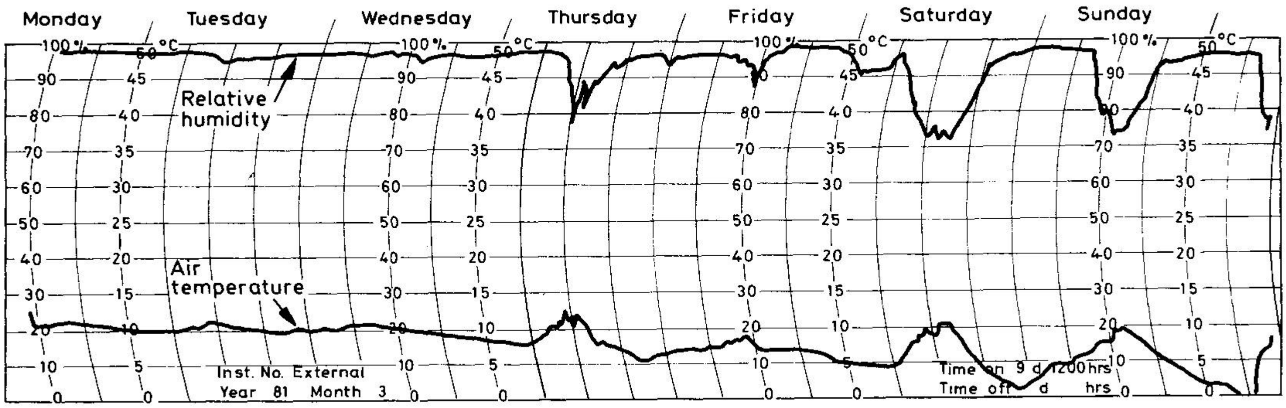


(b) Bebington houses weekly heating consumption (kWh)

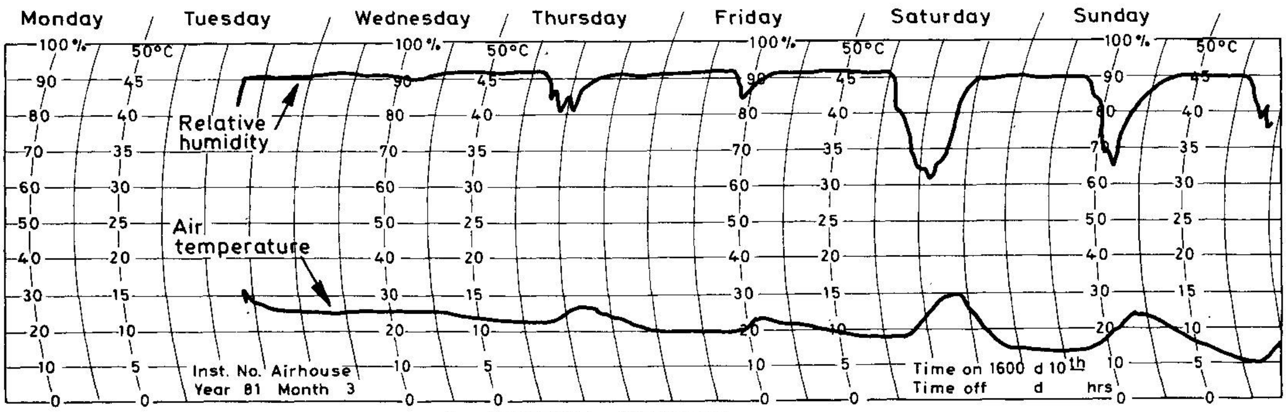
Figure 6. Performance of houses using Trombe wall (11)



A INTERNAL GLASSHOUSE

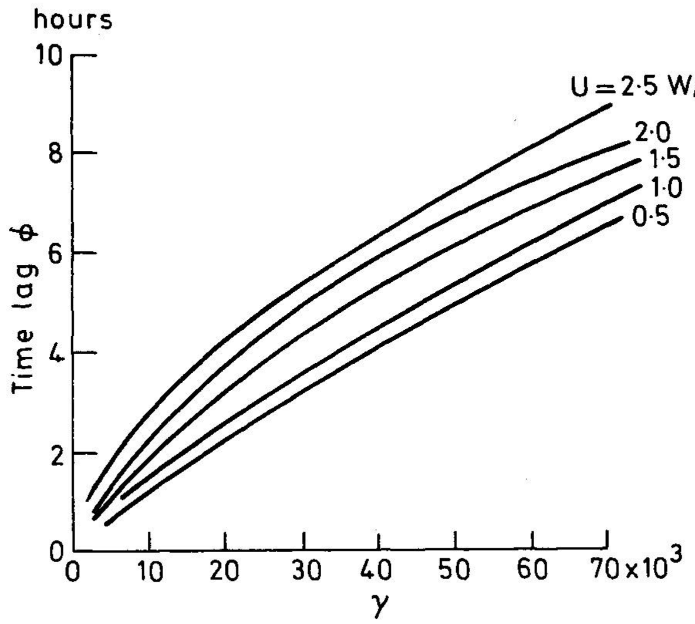


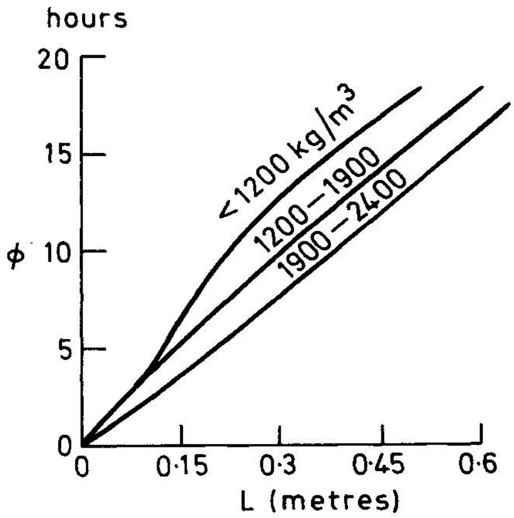
B EXTERNAL AMBIENT

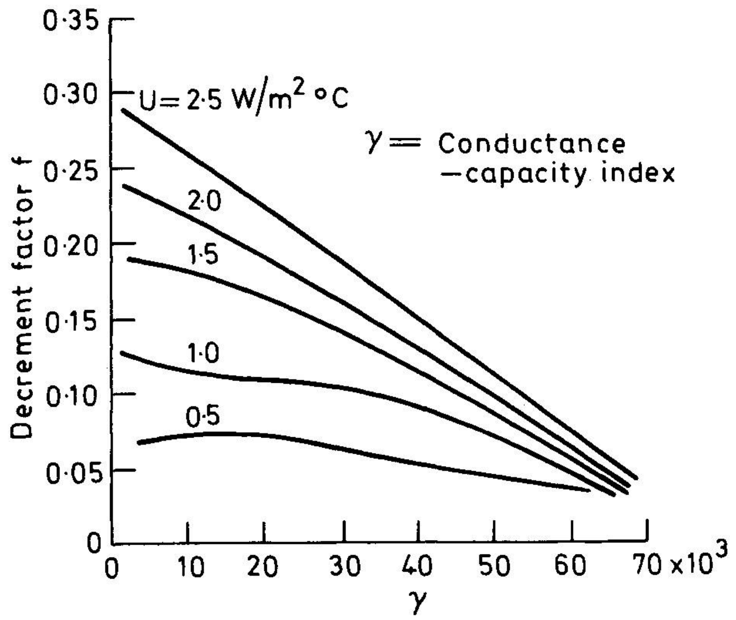


C INTERNAL AIRHOUSE

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







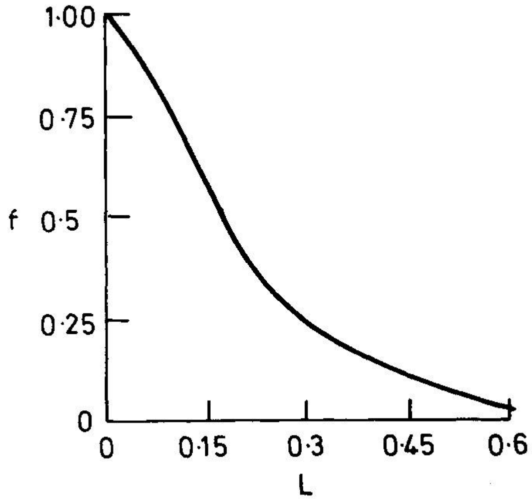


Figure 8 (a) Relationship between conductance—capacity index, decrement factor and time lag for different materials

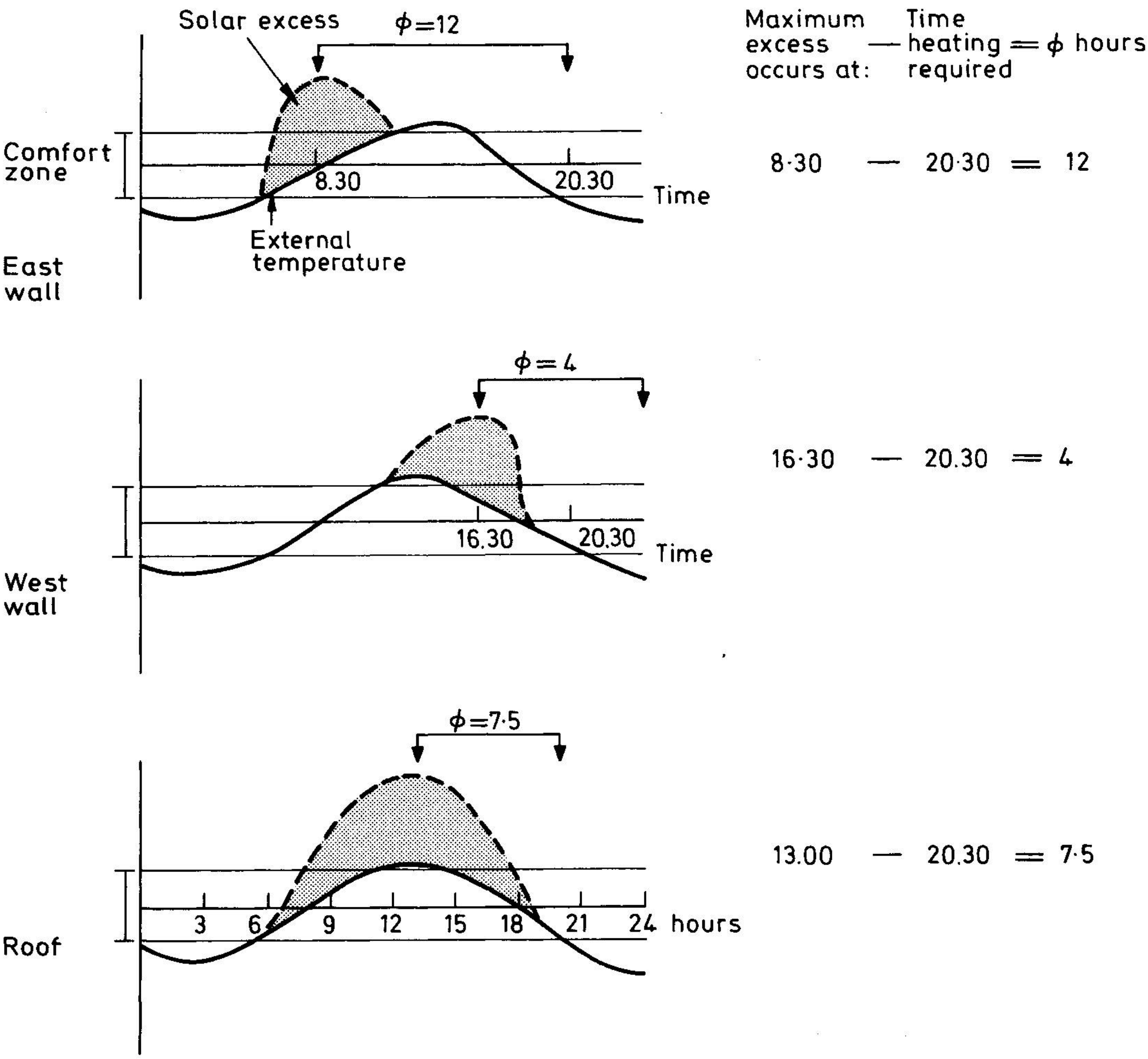


Figure 8(b) Solar gain, time lag and heating requirements

I

Trends and development of building materials

Evolution des matériaux de construction

Die Entwicklung der Baustoffe

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SUMMARY
This paper gives some fragmentaric aspects on the development of building materials against the background of trends in building industry, raw materials supply, waste products utilization and environmental influences. The aspects mentioned are of major interest today and will be of still increasing interest in the future.

RESUME
Quelques aspects fragmentaires illustrent l'évolution des matériaux de construction par rapport à l'industrie de la construction, aux ressources en matières premières, à l'utilisation des déchets et aux influences de l'environnement. L'importance de ces questions s'accroitra encore à l'avenir.

ZUSAMMENFASSUNG
Es wird über Teilaspekte der Entwicklung von Baustoffen berichtet, welche von der Bauindustrie, den Rohmaterialquellen, der Wiederverwendung von Abfällen sowie der Umwelt beeinflusst werden. Diesen Aspekten kommt grosse Bedeutung zu, und sie werden in Zukunft noch an Bedeutung gewinnen.

The building industry in the industrialized countries is of a size which gives it a significant and direct influence on the entire economy of the society. Its character is to serve essential, human requirements - good housing and working environmental conditions - and political considerations and decisions will therefore strongly influence the conditions and realizing of the building activities.

In many countries the industrial and economical development during the 60:ies caused an extensive increase in the production of dwellings. The large number of equally aged buildings has today formed the base for an increasing market for repair and rebuilding. This is in my opinion an interesting field of development - also from a material point of view - as modified ways of living and new requirements of the consumers will lead to modifications of the existing buildings.

The production of building materials - the building material industry - is representing a large part or approximately half of the total building costs. Some characteristics of this industry is that the character and size of its products is varying over a wide range. The classical materials for construction purposes - steel, concrete, brick and wood - is included but also finishing and furnishing materials such as wall and floor coverings, carpenting and supply system components.

Taking into account the importance of the building materials it is of obvious interest to make attempts to judge the development and conditions of the building material industry. In this paper will therefore be discussed some factors which are reasonable to assume will be of importance to the future development. Stress is put on a discussion of the synthetic, polymeric materials - the plastics - which today are used to a great extent in building.

Furthermore is discussed the development and the possibilities of further development of the existing material categories, specially the mineral-based materials. These do in my opinion represent extraordinary interesting fields of development, specially as far as raw materials supply and energy shortage is concerned. In this connection is briefly mentioned the possibilities of the composite materials. Finally some comments are made on the environmental impact on the building materials. Firstly, however, some essential factors in the general trends of building is discussed.

Building weights

The traditional building in Sweden as well as in other developed countries using concrete, brick and steel as dominating material can be described as a "heavy" way of building. The weights of the buildings were high and the principles and design of foundation constructions were fitted to this way of building.

Increased requirements - for instance concerning heating economy - lead to a development of the building components towards specified function in different respects and the new high-effective insulating materials - e.g. mineral wool - as well as light-weight material saving good bearing structures formed a natural part of this development. One interesting concequence is spotlighted by fig. 1 in which the total weights of the buildings is shown. The values indicate that the wheight per sq.meter dwelling area is reduced by ca 50 % during the period 1925-72. For buildings for industrial purposes this trend is still more pronounced and the concept "leight weight building" is today well established. High utilization of the materials in combination with moderate requirements on service life time has lead to extremely low building weights and to a drastic re-thinking as far as foundation design is concerned. However, it must be stressed that this development has not been without problems and an increased sensitivity to damage - e.g. to fire - for these buildings has lead to requirements from the insurance companies and others for research activities in the relevant fields.

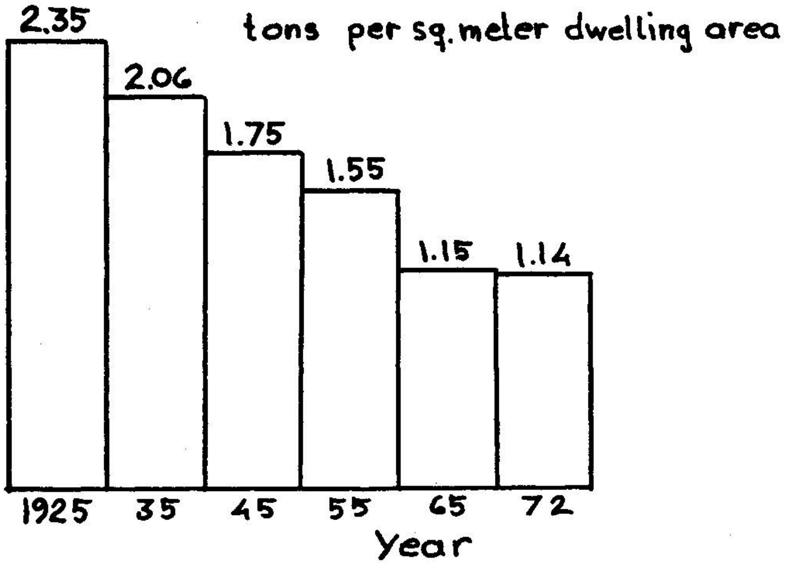


Fig.1 The development of building weights in Sweden during the period 1925 - 1972

It seems to be obvious that a continued development can give us buildings with a level of performance that was beyond reallity in the past probably, however, in combination with a reduction of the service life time. A qualified, scientific analysis of the service life time concept is therefore an unconditional requirement if the possibilities of this building shall be fully utilized.

Today's materials - further development

In general it can be stated that the building industry is creating products of high service life time and intended to satisfy primary, human requirements. It is therefore natural that the tendency to radically new thinking and changes as far as building materials and design are concerned is fairly small. As a consequence the large groups of materials which are today dominating the market (wood, concrete, light-weight concrete, brick, steel) are well known since long ago. These properties have been continously improved up to a level where further, essential developments will need a large i put of time and money , (However, there are probably large and interesting possibilities for the development of new products as well as of processes for production.

In some cases the today's level of material properties is constituted by several requirements some of which are contradictory. One example is the leight weight concrete of different kinds (steam cured or light weight aggregate concrete) where an increase of the strength will be combined with a reduced thermal conductivity. As the material is normally used both for load bearing and heat insulating purposes the two properties must be balanced against each other.

Energy aspects

The development during the last years has emphasised the importance of the energy aspects in building design, construction and maintenance. As far as building materials are concerned two main aspects can be separated. Firstly, materials must be given such properties that they can be used for keeping the energy consumption of the building during its normal service at an acceptable level. Secondly, the energy consumption for the production of the materials must be kept under observation.

Concerning the energy consumption of the building the heating energy forms the dominating part in many countries, e.g. in northern Europe and North America. The heat insulating properties is therefore of primary importance. However, also other properties which directly or indirectly will influence the heat insulating ability of the building components must be taken into account. This can be examplified by moisture properties, strength and deformation properties and by the durability of the materials. It can be mentioned in this connection that the developments of the insulating materials have been brought so far that essential reductions of the heating energy by increasing the insulating capability of the materials are hardly possible. Disturbances occuring from lack of workmanship and similar influences will have far greater effect to the behaviour of the component than a marginal reduction of the conductivity of the material.

The manufacturing process of the materials is in most cases more or less energy consuming. Relatively accurate information is available about this consumption for different materials and some rough figures are listed below.

Steel	27	MJ/kg
Aluminium	113	"
Brick	4	"
Concrete	2,4	"
Wood	0,7	"
Plastics	48	"

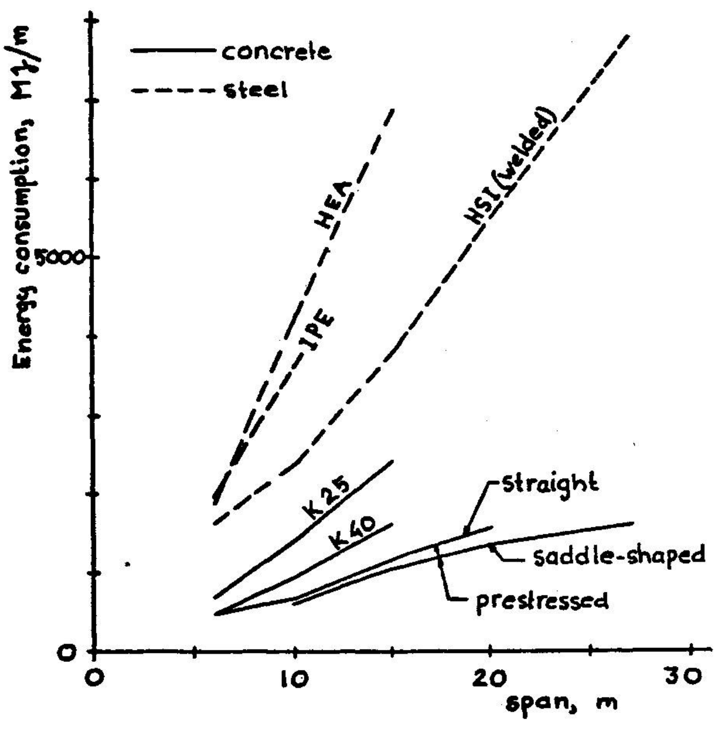


Fig.2

Energy consumption for simply supported beams of concrete and steel.

The problem is to put these figures in relation to the performance of the materials. Many attempts in this direction have been made. One example is given by fig. 2 in which the energy consumption for a simply supported beam is given at different span, load bearing capacity and choice of material /Beijer, 1975/.

Composite materials

The development of so called composites is often the result of the necessity to combine the characteristic properties of different types of materials. Examples of composite materials can be taken from the traditional materials, e.g. concrete, combining stone aggregate with a matrix of cement parte. Depending on the ratio between the mixing components the properties of the concrete - specially the strength - can be varied within fairly wide limits. Some of the main disadvantages of concrete are the high density and the high thermal conductivity. These disadvantages can to some extent be compensated by using other aggregate materials and during the last years many types of light weight aggregates have been used. These materials can consist of e.g. natural porous minerals, expanded clay or flyash from heating plants.

The use of "concrete" with porous aggregate was known already to the ancient Romans. In Italy many vulcanic materials - such as pumice stone or lava - was used as aggregate. Many buildings of this kind are still standing and the Pantheon in Rome (errected in its present form about 120 AD) is probably one of the most famous examples (fig. 3)

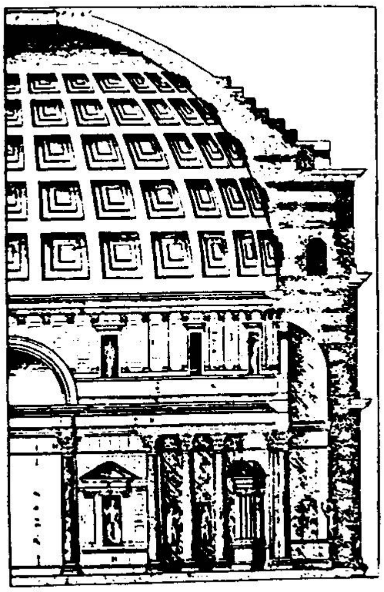


Fig.3

Pantheon in Rome. The dome was errected around 70 AD.

In early 19:ies some waste products from industrial processes were used in England for this purpose. Many coal-fired power plants produced a type of light porous slag clinker which could be used for the manufacturing of heat insulating blocks.

The next step after having used natural materials was to develop industrially produced light weight aggregates. In the US the first furnace for expanded, sintered clay was put into service in 1917 and about ten years later (1928) a corresponding production of granulated slag started. In Europe a production of this type was not started until the 1930:ies.

The porous structure gives the light weight aggregate concrete a reasonably good insulating capability. In many parts of the world however, these materials are also used for load bearing structures. In such cases the aggregate density is normally chosen higher than for insulation purposes. In fig. 4 is shown a relation between compressive strength and gross density for light weight aggregate concrete at varying water-air/cement ratio, aggregate density and the content of non-purpose sand filler /Skarendahl, 1973/.

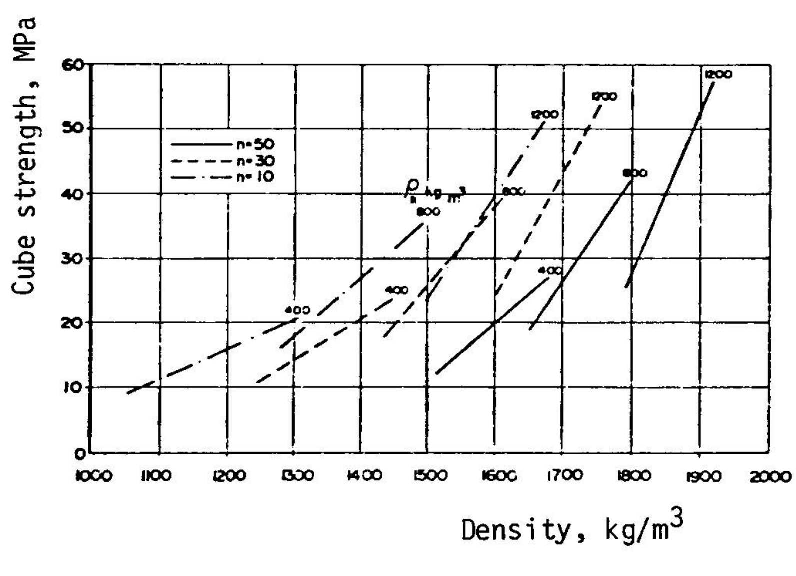


Fig. 4 Relation between strength and density for light weight aggregate concrete.

One further disadvantage of normal concrete as well as light weight concrete is the capillarity and other moisture-related properties. The water content in all hyproscopic materials will significantly influence almost all essential properties, in most cases so that the material deteriorates when the moisture content increases. It has been shown that small additives can change the concrete from a hydrophil to a hydrophob material and drastically improve the properties in this respect /Berge, 1978/.

Normal concrete is characterised by low tensile strength as composed to the compressive strength. In the classical design of concrete structures the tensile strength is therefore neglected. (However, when analysing the shear stresses and deformations of the structure the effect of the tensile strength must be taken into account). The ductility of the material is low and the type of fracture in non-reinforced concrete is normally characterised as brittle. One interesting and promising method to neutralize this disadvantage is represented by the use of fibre reinforced concrete. The influence on the properties of a fibre reinforcement is shown in fig. 5 in which the relation between elongation and tensile stress (in bending) for test beams of non-reinforced and fibre reinforced (2 % by volume) cement mortar is given /Krenchel, 1978/. In fig. 6 is shown load-deflection curves for cement mortar test beams with varying content of steel fibers. It is obvious that even small contents of fibers can essentially improve the material /Lankard, 1972/.

Polymeric materials (plastics)

The polymeric materials are extensively used in modern buildings in many applications e.g. for wall and floor coverings, points and glue and for furnishing. This group of materials is characterized by great flexibility and the properties can be varied within wide limits. These advantages together with manufacturing methods which are well suitable for mass production has added to the building materials market a great number of products with properties quite different from these of the traditional materials. Resistance to moisture and cleaning agents are only some of the advantages which can be achieved with plastic materials.

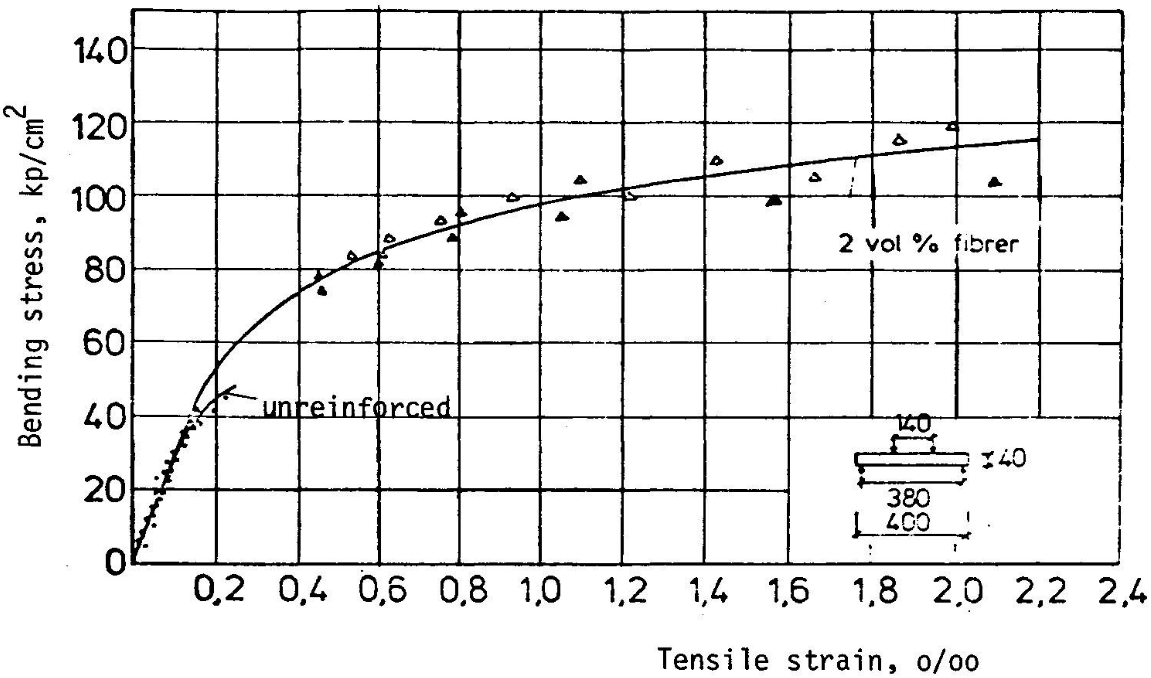


Fig. 5 The tensile stress in bending as a function of the bending strain on the tension side in the case of bending of non-reinforced and steel fibre reinforced mortar beams.

Fig. 5.

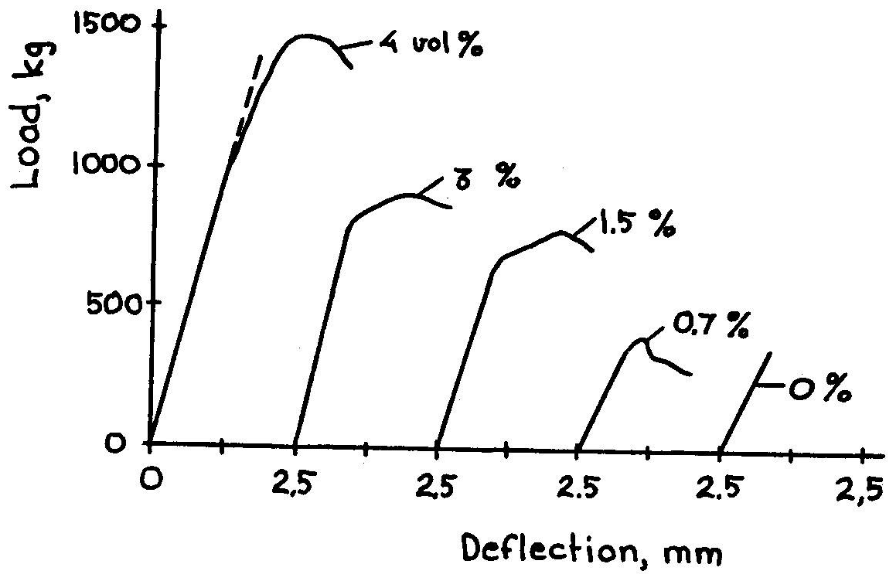


Fig. 6 Load-deflection curves for test beams of cement mortar with steel fibre content of 0 - 4 % (by volume)

In spite of this some factors can be stated which constitutes fairly strict limits for the use of plastics in building and consequently for further expansion. Primarily, three such factors can be separated.

The raw material supply will probably cause problems in the near future. Most plastic processes use petroleum products as raw material and the present situation in this field makes it obvious that the costs will increase and the use for building purposes will be reduced for the benefit of other applications - such as machine and tool industry - were the level of refinement is higher and where consequently the price of the raw material is of minor importance.

The use of plastics in building is relatively young and the rapid - almost explosive - development has taken place during the last two decades. The picture of the materials as far as changes of the properties during the life cycle of a building is therefore not quite clear and the durability of materials is therefore a scientific area where the uncertainity today is large. It is, however, quite clear that the properties of the commonly used building plastics change significally during the time periods relevant to building. A qualified analysis of these effects - e.g. based on a service life time analysis - is today lacking.

The third set of problems which may break the expanding use of plastics in building is connected to the specific fire technical properties of these materials.

It is obvious that the fi e behaviour of modern building plastics cause major problems. These can be summarized under the following headlines.

a) High heat value - most plastics have calorific values of the same magnitude as oil, which means approximately twice the value for wood.

b) Heavy smoke production - the plastics produce large amount of smoke with high optical density.

c) Toxicity and corrosion - the materials do in some cases develop highly toxic on corrosive products of combustion. The most common example is represented by the hydrochloric acid produced at thermal decomposition of PVC.

d) Low thermal stability - large deformations when heated, formation of drops etc. may - for same plastic materials - create certain risks.

A special problem in this connection is the lack of relevant fire test methods. The existing methods were normally developed for testing traditional materials and have often turned out to give irrelevant results when testing plastics. Development of new methods is at present going on within the work of ISO (International Organization for Standardization).

Waste products' utilization

The raw material situation for the building materials industry is so far favourable with the exception of specific sectors (cf the previous section). However, increasing costs make alternative raw material sources interesting.

A general tendency in the modern, industrialized society is to utilize all rescources available as far as possible. The question of reusing industrial waste products forms a very interesting field of development in this connection. As an example can be taken some parts of the mineral processing industry which produces large volumes of waste products. These volumes represent considerable costs occuring from crushing, grinding and transports. These waste products could be used - and have been used in some cases - for building material purposes with good success.

One basic disadvantage of the natural minerals is that there tensile strength is normally low compared to the compressive strength due to unregularities in the structure of the material. One way to avoid this disadvantage is to crush the material - a process which is already done for many waste products - and to rebind the material e.g. with cement paste with or without hydro-thermal curing.

Research and development work in this field is going on in Sweden and abroad. Main attention has hitherto been paid to the $CaO - SiO_2 - H_2O$ combination as the binding mechanism in leight weight concrete is of this type. During the last years encourageing results have been reported from steam curing of Al_2O_3 and of the $MgO - SiO_2 - H_2O$ complex. Due to practically unlimited raw material stock of suitable Mg - minerals the latter is of special swedish interest.

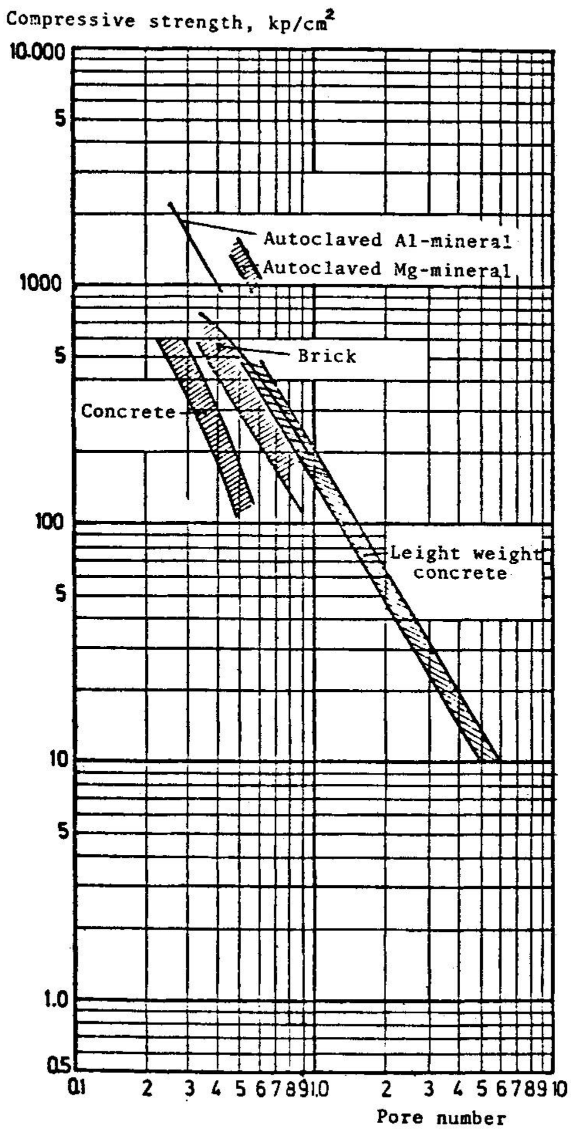


Fig. 7

Relation between pore number and compressive strength for some building materials and for experimental, autoclaved materials based on Aluminum and Magnesium minerals.

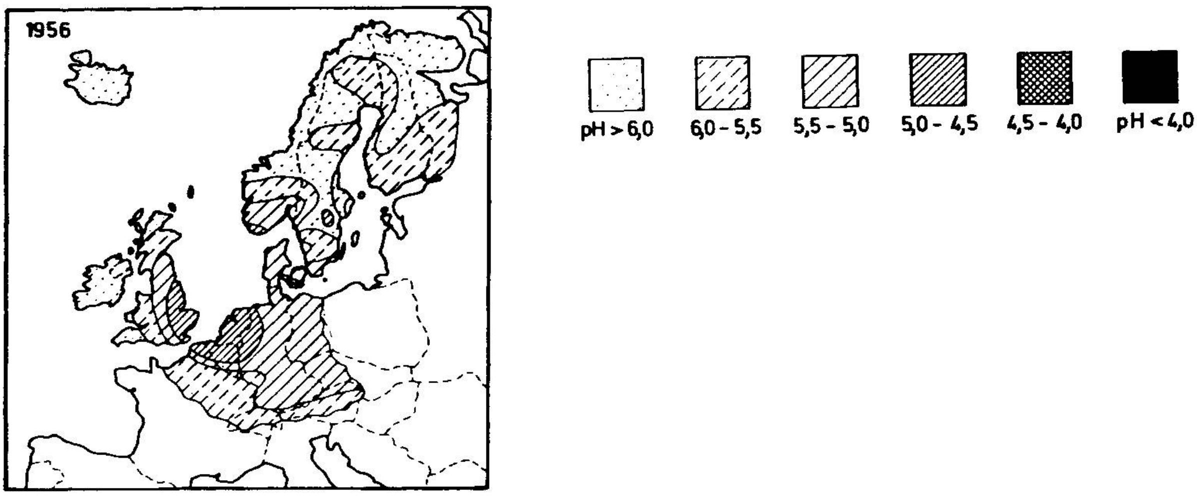
In fig. 7 is shown some examples on the relation between pore number and compressive strength for some materials included in swedish investigations /Kihlstedt, 1974/.

Environmental influences

All building materials are exposed to environmental influences of different kinds which may deteriorate the material. Most of them are well known and can be listed under the following headlines:

- Chemical (acid and alkalies)
- Electro-chemical (rust)
- Physical (effects of freezing water)
- Biological (micro organisms, fungi)

As a consequence of extensive polution of acid products - e.g. SO_2 - the environment of the industrialized parts of the world is getting increasingly aggressive. This is illustrated by fig. 8 in which the pH-value of the european rainfall is shown.



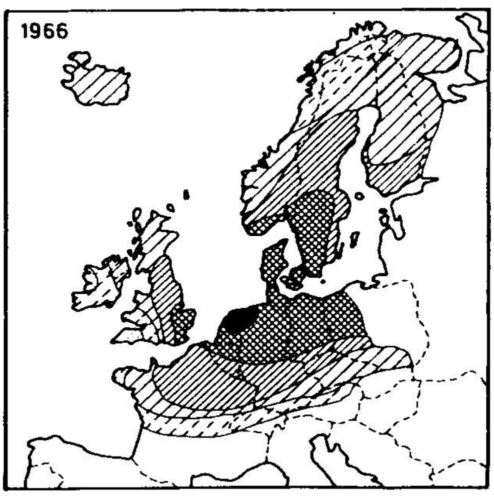


Fig. 8

Average pH-values (over one year) of the european rainfall.

It is easily understood that these low pH-values create a much more deteriorating climat for almost all materials than is the case in other parts of the world. One example is given in fig. 9 where the intensity of rusting is shown for test specimens in different environments.

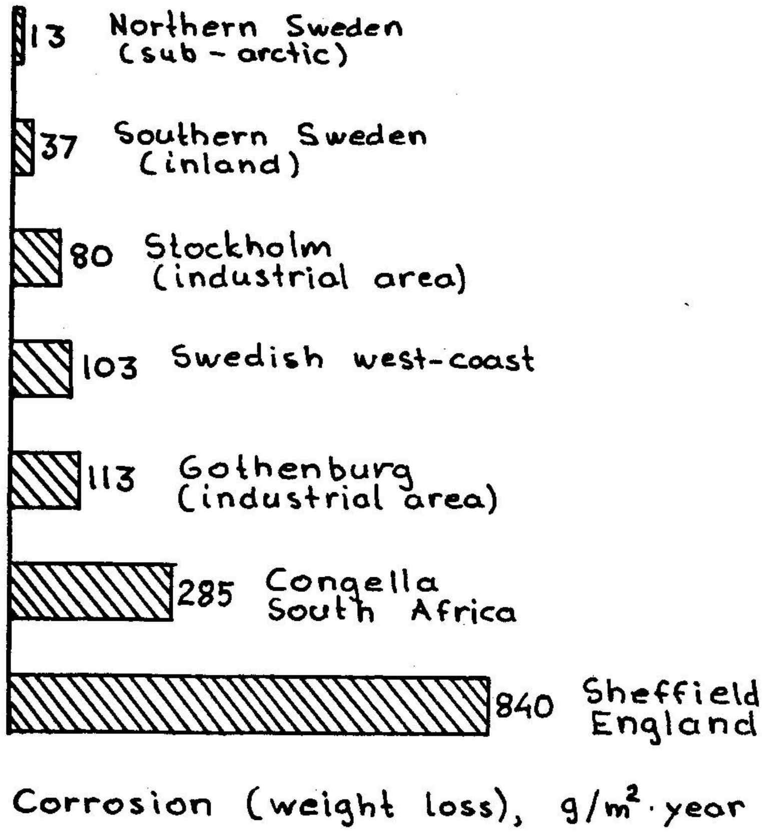


Fig. 9

Measured values of the corrosion (weight loss) for steel test specimens in different environments

In this paper have been given some fragmentaric aspects on the development of building materials against the background of trends i in building industry, raw materials supply, waste products utilization and environmental influences. Due to space restrictions essential and interesting parts of the subject have been deleted. However, I am convinced that the aspects which are mentioned in the paper are of major interest today and will be of still increasing interest in the future.

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I

Energy conservation—who is concerned?

Conservation de l'énergie — Qui Concerne-t-elle?

Energiesparen — Wessen Aufgabe?

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SUMMARY
Energy conservation is both, a necessity and an opportunity. However, many different obstacles impede a quick breakthrough. The highly desirable progress has primarily to rely on the efficiency of the price mechanism. It should be supplemented by proper information and — as a last resort only — by government interventions. Of the four possible steps to energy conservation — avoiding obvious waste of energy, rational use of energy, (governmentally) forced savings and self restraint — the rational use of energy which relies mainly on the price mechanism, seems to be the most promising. Professional engineers, architects and economists have to play a major role in promoting it.

RESUME
La conservation de l'énergie est aussi bein une nécessite qu'une chance. Toutefois, différents obstacles s'opposent à un développment rapide. Le progrés hautement désirable doit en premier lieu reposer sur l'efficacité du mécanisme des prix. Il doit être complété par une information judicieuse et — en dernier ressort seulement — par des interventions gouvernementales. Des quatre étappes possibles vers la conservation de l'énergie — éviter des dilapidations flagrantes, utilisation rationnelle, restrictions forcés (par état), restrictions voluntaires — l'utilisation rationnelle de l'énergie, qui repose essentiellement sur le mécanisme des prix, semble la plus prometteuse. Des ingénieurs, architects et économistes ont un rôle décisif à jouer dans sa promotion.

ZUSAMMENFASSUNG
Energiesparen ist sowohl eine Notwendigkeit als auch eine Chance. Verschiedene Hindernisse stehen indessen einem schnellen Durchbruch entgegen. Der höchst wünschbare Fortschritt sollte in erster Linie auf die Wirksamkeit des Preismechanismus abgestützt werden. Er sollte ergänzt werden durch geeingnete Information und — aber nur als ultima ratio — durch staatliche Massnahmen. Von den vier Stufen zum Energiesparen — Vermeidung von offensichtlicher Energieverschwendung, rationelle Energienutzung, (staatlich) verordnetes Energiesparen und freiwilliger Konsumverzicht — erscheint die rationelle Energienutzung, welche im Prinzip auf dem Preismechanismus beruht, am vielversprechendsten. Ingenieuren, Architekten und Oekonomen fällt bei ihrer Förderung eine entscheidende Rolle zu.

1. THE CHALLENGE OF THE PRESENT ENERGY SITUATION

Energy is likely to remain one of the most-discussed topics for many years ahead because the range of problems it brings, is enormous. One has to recognize that, worldwide, the energy problem is basically an oil problem. Oil is by far the most important form of energy. It provides 46 % (1978) of the total world energy consumption. Including natural gas, with its share of 19 %, the hydrocarbons represent two thirds of the total world energy supply (Ref. 9, p. 111). However , this highly valuable source of energy is - as everybody knows - not renewable and hence finite. According to the findings of the World Energy Conference in Munich (1980), the production of conventional oil is at or near its all time maximum level (Ref. 2, p. 4). Due partly to this fact, and partly to political reasons, it has become very expensive in the last decade. Besides being expensive and scarce, it constitutes a political and economic risk of highest concern for most of the oil-importing countries. These considerations concerning the supply side already provide a good many reasons to wish that the world economy should do with less oil.

But how does the demand side appear? Industrialized countries such as the OECD members want to maintain or even increase their economic growth rates. But nowhere in the world has it been proved that a substantial economic growth can be obtained without increased energy input, not to speak of the developing countries, where per-capita consumption of energy amounts to approximately a seventeenth of the amount of that of the OECD-countries (Ref. 2, p. 2). These are the countries most-seriously affected by the oil and energy crisis. Their standard of living is very low and the need to catch up is enormous. And if, in addition, their fast-growing population is taken into account, their energy demand turns out to be tremendous. It is, therefore, not surprising that most world energy scenarios expect that the global energy demand will increase in the next four to five decades by a factor of three to four (Ref. 5, p. 171; Ref. 4, p. 31/32). If these levels of energy production cannot be reached, it will become very likely that the economic growth rates, which were assumed for these scenarios, also cannot be achieved. Economic growth will then be curtailed by insufficient physical availability of energy and that means depression, unemployment and extending the phase of misery in the poor countries.

With respect to this serious background of the demand and supply situation of energy it is evident that there are two energy strategies which form the main options for all countries throughout the world:

- the first one is substitution of oil (or hydrocarbons in general) by other forms of energy such as coal, nuclear, hydro, unconventional oil and all kinds of new energies.
- the second, and not less important, strategy is the one that has to be dealt with in more detail - energy conservation.

2. POTENTIAL AND ADVANTAGES OF ENERGY CONSERVATION

Energy conservation means a reduction of energy consumption, be it in relative or in absolute terms. A reduction in relative terms can be defined as a decreased ratio between used energy and unit of activity. This definition is identical with improved energy efficiency. A better energy efficiency does not necessarily lead to reduced energy consumption in absolute terms. The answer depends on the question whether the respective activity is increasing faster than energy efficiency. But in any case, improved energy efficiency leads to a lower level of total energy consumption than otherwise would have been obtained. Under "ceteris paribus" conditions, a reduction in absolute terms is always obtained.

The proposed definition of energy conservation - namely reduction of energy consumption in relative or absolute terms - clearly demonstrates that energy conservation can also be obtained without improved energy efficiency, simply by a reduction of the denominator, e.g. the requested comfort, consumption or the economic activity in general. Whereas the first version - improved energy efficiency - means doing things better, the second one means, not doing things at all or at a lower quality (Ref. 2, p. 5).

If energy conservation is to be one of the most-important strategies of world-wide energy policies, its potential should be of a considerable magnitude. In fact, in most known energy scenarios of countries or enterprises, energy conservation plays a key role and the energy-conservation potential is very significant. According to a review of several studies, which has been prepared for the European Community (Ref. 7), the potential, which could be harnessed up to the year 2000 (based on oil prices before 1979), was estimated at:

- 20 - 25 % in transportation
- 15 - 35 % in industry
- up to 50 % in the residential and commercial sector

According to the Federal Energy Committee of Switzerland, it is possible to reduce energy consumption by 20 to 30 % compared with the reference case up to the year 2000 (Ref. 3, p. 22).

Even if energy conservation is limited to a contribution of about 20 percent within the next twenty years and even if progress cannot go on endlessly, due to the law of the diminishing returns, we have to be aware of the fact that within the next few decades there does not exist any single new form of energy with the same potential. Energy conservation has therefore rightly been called an "invisible resource" (Ref. 2). Unlike many other forms of energy, this invisible resource presents further advantages:

1. Being an "<u>indigenous</u>" resource, it eases the balance of payment problems of energy-importing countries and replaces imported energy by capital and indigenous skills and manpower.

2. It reduces the <u>risks</u> of a possible oil-supply disruption with very severe economic and political consequences.

3. Energy conservation enables - at least relatively - a lower level of energy consumption and affects therefore the environment to a much lesser extent. Energy conservation is so-to-say <u>clean.</u>

4. As energy prices have risen drastically in the last few years, energy conservation is in most cases also <u>economically</u> attractive.

5. Energy conservation is, in practice, a <u>renewable</u> resource, i.e. it is limited in extent but it does not rely on limited resources and its fruits can be

earned every year; it is renewable.

We can therefore conclude that energy conservation is not only a necessity from the point of view of the world energy supply and demand situation as pointed out at the beginning, but that it is also one of the most-attractive options for any energy policy; be it in developed or developing countries and even for oil exporting countries because, one day, their resources will also be depleted. Among all the possible and necessary energy-policy measures, energy conservation is by far the least-controversial one.

If energy conservation is the most-attractive option of energy policy, it is surprising that the results are rather modest - at least up to the present time. The figures of the OECD-countries (Ref. 6, p. 3) show that from 1973 to 1978 total energy consumption still increased by 1.3 % per year. This is, of course, a considerable progress if compared with the energy-growth rate of 5.2 % from 1960 to 1970. But the progress is, to a great extent, due to the reduced economic activity, which dropped from an annual GDP growth rate of 5 % to 2.6 % in the two respective periods. Thus, only about one and a half percent of the diminished energy growth rate can be attributed to improved energy efficiency. Apparently, we are still in a phase of little steps, painful details and tiny successes. Is that not astonishing for a period in which the oil crisis and the limits to growth were the most vigorously discussed topics?

3. THE DIFFICULTIES OF ENERGY CONSERVATION

An examination of the way energy conservation must be implemented soon identifies a great variety of factors which impede rapid and effective progress. Some of these factors are of a practical nature and some are more psychological.

3.1 Lack of Information and Awareness

Lack of public information, awareness and concern belong to this latter category. Human behaviour and attitudes cannot be changed if people do not have a clear understanding of the energy problem. Although progress in this matter would have substantial effects, this improvement is hard to achieve. For the man on the street, the energy problem is not his only problem. The energy issue is competing with other and possibly not less important ones, such as labour conditions, family questions, health, housing, hobbies, social security, cultural and lots of subjective topics, which reflect the complexity of our life.

3.2 Diffuse Appearance

Moreover, consumption of energy is often hidden from the eyes of the individual and diffuse in appearance. Turning off the lights, which saves very little energy, unfortunately appears as the most-obvious kind of saving energy. But when somebody opens a window to get fresh air, sits in a car and enjoys a beautiful landscape, eats deepfrozen food or drinks beer out of aluminium cans, he is rarely aware of the fact that he is indirectly consuming considerable amounts of energy. And even if he were willing to seriously save energy, he would be almost powerless in many respects. What can he do if he lives in a building which is badly insulated, if his route to his working place urges him to use an energy-consuming transportation vehicle or if he has to buy energy-intensive products? He is not totally powerless but energy conservation would need many little and non-spectacular actions, which are not very attractive.

Energy conservation is difficult, mainly because it is a very diffuse and not a concentrated matter.

3.3 Too Short Time Horizons

Another well-known difficulty is the time horizon perceived by consumers. Private as well as industrial users expect that investments are paid back in a well foreseeable future, e.g. in the next two to five years, regardless of the fact that the physical lifetime of the investment may be ten to twenty years. Although this attitude is not justified, it represents another real difficulty for energy conservation.

3.4 Important Role of Indirect Use of Energy

The more indirectly energy is used, the less is the chance that it can be saved explicitly by the final consumers. The relationships in this respect are quite impressive. In industrial countries, energy used as an intermediate good within the economy, accounts on the average for 60 % of total energy consumption. About 40 % only is used directly by households as consumptive energy (Ref. 1, p. 524). This does not mean that in the industrial sector energy conservation is neglected. On the contrary, the efforts in industry in favour of a rational use of energy are considerable. Nevertheless, the consumption patterns of private consumers are only indirectly influenced by energy-related arguments.

3.5 Institutional Impediments

Other impediments are of an institutional characteristic. The best example is the housing sector where the landlord is basically interested in low investment costs because he wants to compete with a low rent on the market. This excludes in general that much attention is paid to the question of energy conservation, e.g. insulation, optimal size of heating devices, etc.

3.6 Low Rate of Renewal in Energy Infrastructure

Energy is largely used in conjunction with durable capital goods such as houses factory equipment, vehicles, etc. An adjustment of the energy-related equipment to a new energy situation and prices requires, therefore, a massive change in the capital stock. This must reasonably be spread over a long period of time. Rising energy prices will undoubtly bring forward the economic threshold of replacement investments. This means a chance for an earlier adjustment to the new situation. However, it will be years before the adaptation will fully have taken place.

3.7 Complexity of Proper Calculation

Finally, we have to take into account that rational decisions on energy conservation are highly complex.

a) Theory

In general, this is a classical optimization problem which looks - al least for engineers and economists - rather simple. It can easily be illustrated by a simplified example of optimal insulation of a building by Figure 1.

There exist:

- fixed costs,
- insulation costs, which are roughly proportional to the insulation level, and
- energy costs, which decrease more or less hyperbolically.

By superposition of the three functions, the total cost curve is obtained, the minimum of which indicates the optimum insulation level. This is the theory.

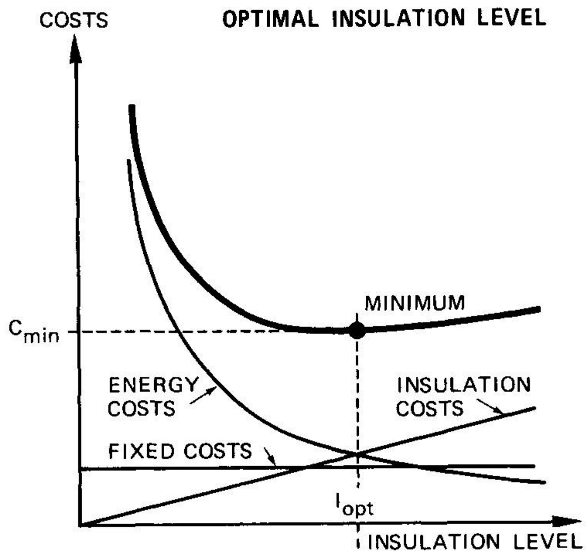

FIGURE 1

b) Estimating Parameters

In reality, some major problems have to be solved in order to make a proper calculation.

- One has to apply a reasonable interest rate level; (in correct relation to inflation)
- one must take into account the future maintenance costs of the building;
- one has to estimate the physical lifetime of insulation materials, of the building and of the heating installations;
- one has to argue about future energy prices and
- if one applies sophisticated calculation methods, one has to do all these cost-benefit considerations on the basis of a risk analysis.

c) Comprehensive Approach Needed

Even if all the calculations are properly done, the danger has to be faced that only a small fraction of the problem is treated with accuracy, that the bigger part of the problem remains in the dark and the question arises whether this accuracy is worthwhile. When considering material questions one has to ask what happens before the material is used and what happens after its useful lifetime. If a certain success in energy conservation in the context of space heating in a building is only obtained at the cost of a bigger energy input in preceding or succeeding processes, the result is very dubious. Figure 2 shows the whole complexity during the life circle of an industrial material (Ref. 11, p. 112). This demonstrates that a valid answer can only be obtained by extending the energy-balance calculations on the whole energy chain of a certain product. It often happens that the energetically bad reputation of some energy-intensive products like aluminium or plastics is not so bad after all. E.g., in the transport sector, the energy balance of aluminium may well be positive if the high energy content of the construction material is compared with the energy savings of the vehicle during its lifetime due to its lighter weight.

d) Human Factors

Not even the aforementioned level of knowledge is sufficient because the energy consumption of a certain system is not only determined by its hardware configuration but also by its use by human beings. If one looks at the energy-consumption determinants of a building, it is seen that insulation is an important, but by far not the only decisive factor. The total energy consumption depends on factors such as:

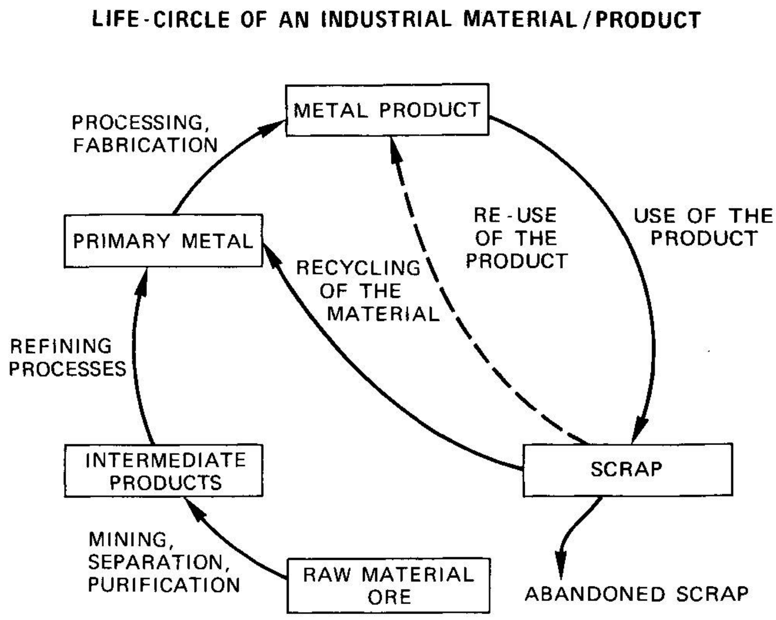

FIGURE 2

- climate (which cannot be influenced)
- dimensions of the building
- position and exposure of the building
- configuration of the building
- insulation, not only of walls but also of the roof, windows, doors and the ground floor
- sealing of joints
- efficiency of the heating system (dimensioning, layout, heat recovery)
- demand for comfort (temperature level, air-conditioning)
- behaviour of inhabitants

3.8 Conclusion

To sum up, it has to be recognised that many difficulties and impediments exist, which make progress in energy conservation very difficult. In view of all these difficulties, a good deal of optimism is required if one is not to give up. However, as has been pointed out, energy conservation is a necessity as well as a major opportunity.

4. AN EFFICIENT APPROACH IS NEEDED

In order to surmount all these obstacles in the interest of energy conservation, a strategy is needed, which is simple enough to be applied and effective enough to provide good results. First of all the strategy has to be efficient.

In this respect, the overriding role of the price mechanism has to be stressed. Its main advantage lies in two effects. First, the price mechanism automatically accumulates all energy inputs at the different levels of production. If this mechanism is not hindered, an investor does not have to worry about the energy balance of the whole energy chain of his products. The second advantage lies in the fact that all the decisions can be taken without any government interference or other administrative efforts. More than 200 years ago, Adam Smith called this phenomenon the "invisible hand". Now, it can be concluded that his "invisible hand" plays a most-decisive role in utilizing the "invisible resource" of energy.

One may object that in the costs of a product the energy price plays a minor or an even neglectable role. This may have been true for the years before 1973. However, it is no longer the case today as Figure 3 clearly shows. The nominal price of crude oil has since then increased by a factor of 20 and even in real terms by a considerable factor of 4 - 5. As far as future energy prices are concerned, it is better to err on the high side in making projections. If it could be assumed that the free market prices of energy reflected the real costs of energy, including all possible external costs, the decisions on the use of energy could well be based on a pure rational cost calculation, which indicates a certain solution giving minimum costs. This is justified because finally, energy conservation is not a goal in itself but a means to find the solution with the least costs. The consideration which has to be the starting point is as follows: The price mechanism is, as a first approach, the most-efficient and most-reliable allocation mechanism for the rational use of energy.

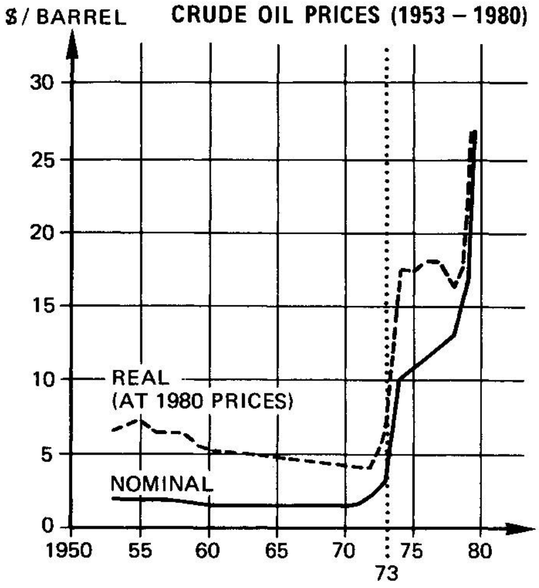

FIGURE 3

A minimum prerequisite in this respect is that energy prices are deregulated and that there should not be tax exemptions made for energy.

If there are - and there are indeed - imperfections within this mechanism, the efforts should be aimed at supplementing and not supplanting the market mechanism. On a first level, information and motivation should be improved in the education sector from primary schools up to universities, in the public sector for the man on the street and also in the industrial sector, from labourer to top manager. This information should demonstrate the widespread relevance of energy flow in our society and civilisation and give hints how to avoid unnecessary dependence on costly energy in the present and the future.

However, the response of the consumers to better information is still voluntary and government's energy policy may have to become more positive. The rationale for government intervention are cases where

(1) private markets <u>do</u> not work (or do not work well);
(2) private markets <u>can</u> not work; and
(3) private markets <u>should</u> not work (Ref. 8, p. 2)

For instance, environmental and ecological side effects of the use of energy cannot be taken into account by the market mechanism. In order to limit these effects to an acceptable level, the environmental costs could be internalised. The market mechanism could then work as before. As this internalization is very complicated and often controversial, the other alternative is, to set explicit standards for insulation or speed limits for cars, etc., which must not be violated. Even in this latter case, governments should only prescribe standards but not give instructions how they have to be obtained. This task can be fulfilled by the market.

Another deficiency of the market mechanism may be the already-mentioned conflict between tenants and landlords. Building codes with mandatory minimum thermal efficiency standards may then be reasonable. Unfortunately, their efficiency is limited to the fact that they can only be applied in the context of the construction of new buildings. For existing buildings, the occasion of renovation has to be awaited.

5. THE FOUR STEPS TO ENERGY CONSERVATION

These considerations of the question of how to strengthen the energy conservation efforts indicate that an efficient energy conservation policy should

- rely primarily on the price mechanism
- provide the necessary information for all kind of private or industrial, direct or indirect energy consumers
- and - if necessary - supplement the voluntary efforts of consumers by certain governmental measures.

If these guidelines are accepted, the energy conservation policy that can be recommended consists of four successive steps (a synopsis is given in Figure 4):

The four Steps to Energy Conservation

Figure 4

Step	Necessary Conditions	Who is concerned ?
1. Avoiding obvious waste of energy	• Avoidance of stupidity • Awareness • Information	• Individual consumer • Government
2. Rational use of energy	• Effective energy price signals • Proper calculations • Rational behaviour and energy management	• Investors • Building contractors ↑ (Engineers, Architects, Economists)
3. Forced savings (by legislation)	• Mandatory measures • Inhibitions	• Governments • Politicians
4. Self restraint	• Readiness to renounce on comfort and convenience • Insight, change of life style • Moralistic austerity appeals	• Individual consumer ↑ (Opinion leaders, Philosophers, Politicians)

- The first step is: avoiding obvious waste of energy. Everybody is able and encouraged to do this. There are plenty of examples for this case e.g., not to heat or to cool empty rooms or buildings, to reduce the almost tropical and unhealthy temperature levels of offices and private rooms, not to regulate the room temperature by opening windows but by turning off the radiator, not to let machines, appliances or cars operate which are not really used, etc.

  This very primitive stage can be achieved without loss of comfort. No basic change of behaviour and no investments are required. It needs only some information, awareness and concern about the energy situation. Although the contribution of this step cannot be quantified, it is obvious that considerable progress in this respect is possible. This step is, by the way, the most advantageous one, because no or only an insignificant effort induces a considerable result.

- The second step is based on the concept of rational use of energy. This is the major field of activity of professional engineers, architects and economists. Although, the decisions are taken by investors and building contractors they have to be informed and advised by specialists. Loss of comfort or convenience is not required at this stage either, however it needs substantial effort either of an intellectual nature and/or in terms of capital investment. This step is the art of finding the optimum relationship between energy input and the obtained result, as was pointed out by Figure 1.

  This approach shows that energy can, to a certain extent, be replaced by capital and know how. Today's tendency is evident: As energy costs increase drastically, it will prove, quite often, that the technical solutions of the past ten to twenty years can no longer be the solutions of today or tomorrow. Our buildings should no longer be conceived as a pure matter of statics and aesthetics but must also take account of energy requirements. They should not, as a critic pointed out recently, remain energy anihilation machines. A real revolution in building construction and architecture is needed. This revolution is not based on some nebulous and vague socio-revolutionary idea but on the hard fact that energy is no longer abundant and cheap.

  This step can be considered as the most promising one. Its potential is enormous and the improved energy efficiency is not the result of less comfort, or government regulations, but the result of rational behaviour within free-market conditions. The better it works the less are the chances that government has to step in or that energy prices will rise faster then they have already.

- The third step of accelerating the process of energy conservation is forced savings. As already pointed out market mechanisms are sometimes not as perfect as desirable. Consumers may sometimes not be as well informed as proposed in step one, and will possibly not behave as rationally as the pure "homo oeconomicus" of step two would suggest. In these cases, a supplementing of the market forces by mandatory measures by governments may have to be taken into consideration. In the transportation sector, for example, it may be reasonable to introduce speed limits instead of leaving the decision on the maximum speed up to the individual driver. Price signals obviously do not work well in this case.

  Another example of imperfect market mechanism is the already mentioned sector of rented houses, where the interest of the landlord lies in low construction costs, whereas the tenant is interested in low total costs, including the costs of energy for heating and warm water. Mandatory insulation standards may in this case be an acceptable and efficient solution.

An even more extreme measure in the category of forced savings would be an absolute inhibition of certain forms of energy use. People could by such measures be forced to restrain from purely luxury energy consumption like heating of private swimming pools or outdoor heating.

It is obvious that these measures should be only a last resort for governments. There prevails the danger that these measures are arbitrary, that they create inefficient bureaucratic paper work and it is almost certain that they would not be popular to the public. Although mandatory measures may sometimes be psychologically helpful and acceptable, their range is limited. In normal situations their effect should not be overestimated. Experience shows that, by and large, the market mechanism provides better results than a multitude of government interventions (Ref. 10, p. 11). One should, therefore, always compare the possible deficiencies of the market mechanism with the possible deficiencies of mandatory measures.

The fourth degree of energy conservation could be called self restraint, in contrast to step three which was called forced saving. Like the first step (avoiding obvious waste of energy) it appeals to the energy consumer's free will. However, at this stage, the possibility of renouncing on comfort is no longer excluded. Renouncing on pleasant room temperatures (heating and air-conditioning), walking instead of driving, manual work instead of using all kinds of appliances in kitchen, house and garden are also considered as possible alternatives to energy consumption. Another indirect way of reducing energy consumption would also be to consume less energy-intensive products and services. Clearly questions of our life style, of personal behaviour as well as fundamental questions of our civilisation are involved. Is personal and collective happiness any longer positively correlated with the amount of consumed goods, the flow of services and, hence, energy consumption? Can we afford an energy consumption level which is nearly twenty times higher than the one in developing countries? These are important and justified questions indeed. However, the answer cannot be given by engineers and economists. It has, if ever these ideas are to be convincing, to be the result of a change in the public attitude, which in itself could be the result of the efforts of all the philosophical, ethical, moral and political authorities to reduce energy consumption, not only by increasing efficiency but also by diminishing the consumption demand in broad terms. It would, of course, be one of the most effective steps to energy conservation if people would decide to consume less.

Although one cannot be too optimistic with respect to the possibility of voluntary energy savings, one has to bear in mind that a wise self restraint is much more easily to be accepted than a situation in which a forced restriction turns out to be the only possibility.

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