History of climatic influences in building design

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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 rubble 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.

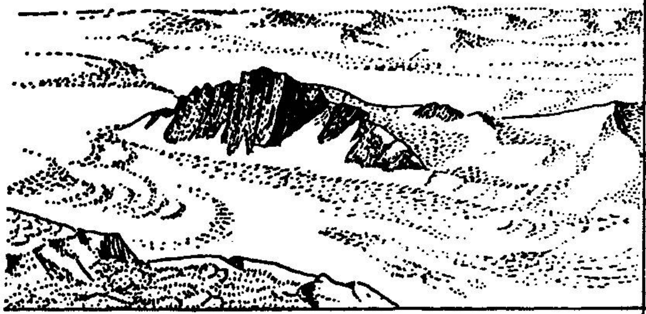
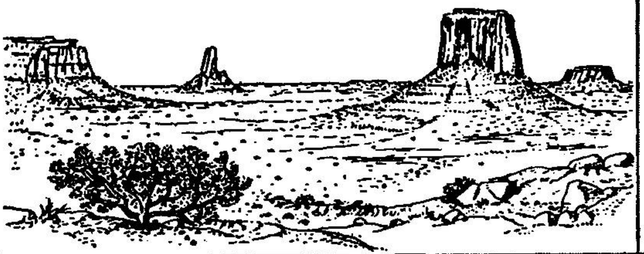
Naturally many other forces beyond the purely climatic are at work in shaping primitive architecture. The culture and means of subsistence will determine whether the shelter be permanent, mobile, seasonal or purely temporary. If the culture is a hunting one, like that of the Indians who once inhabited 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.

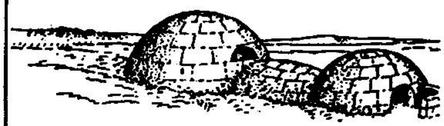
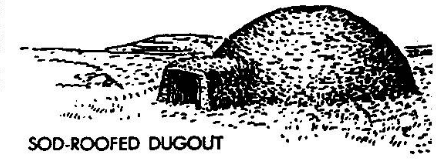
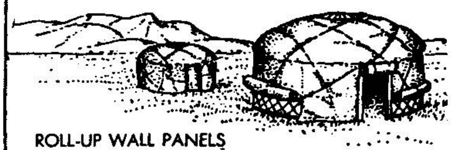
Contemporary US architecture would be greatly enriched, esthetically as well as operationally, by a sober analysis of its primitive traditions. Nor would it be stretching things to include in these traditions the simple but excellent architecture of the early white settlers who, in many respects, were 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.

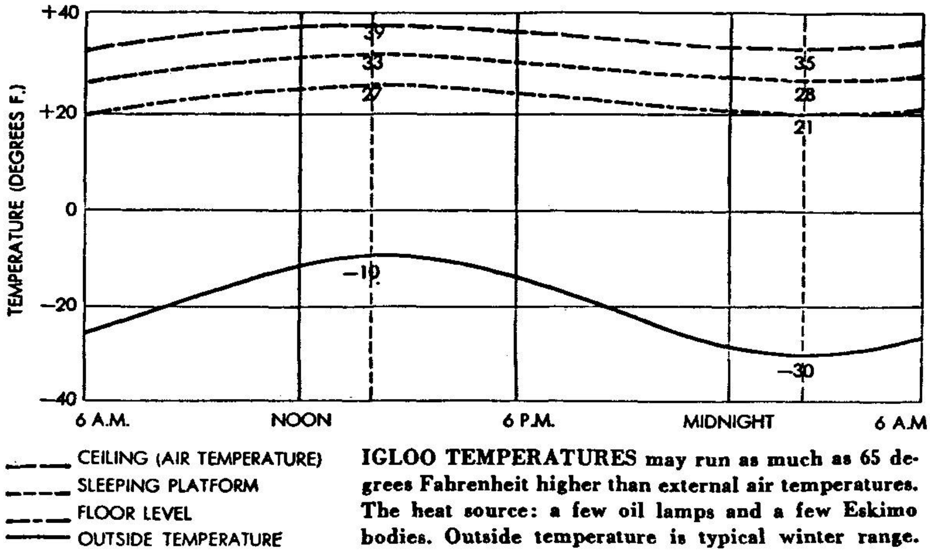
REFERENCE

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

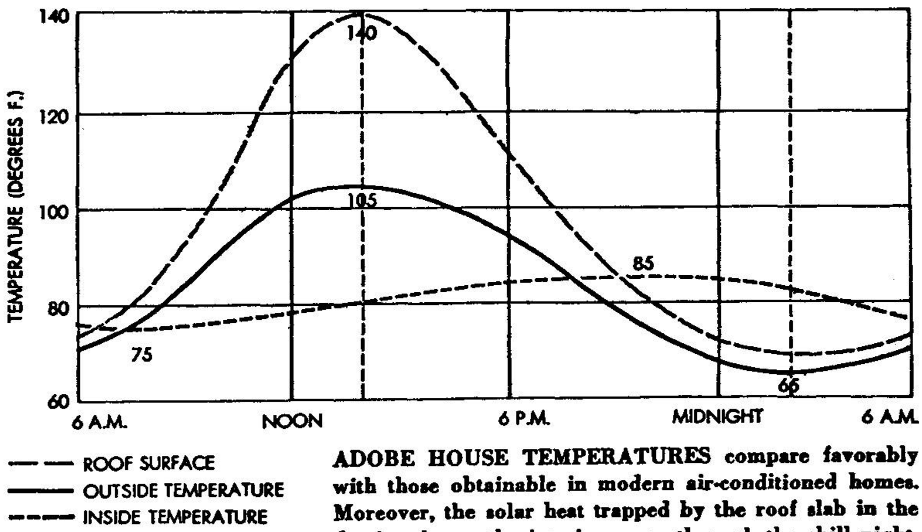
CLIMATE	THERMAL CHARACTERISTICS
ARCTIC AND SUBARCTIC 	WINTER INTENSE, CONTINUOUS COLD LITTLE SOLAR LIGHT OR HEAT HIGH WINDS SUMMER MODERATE TEMPERATURES INTENSE SOLAR RADIATION
CONTINENTAL STEPPE 	WINTER INTENSE, CONTINUOUS COLD NEGLIGIBLE SOLAR HEAT HIGH WINDS SUMMER LONG, WARM DAYS COLD NIGHTS
DESERT 	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.

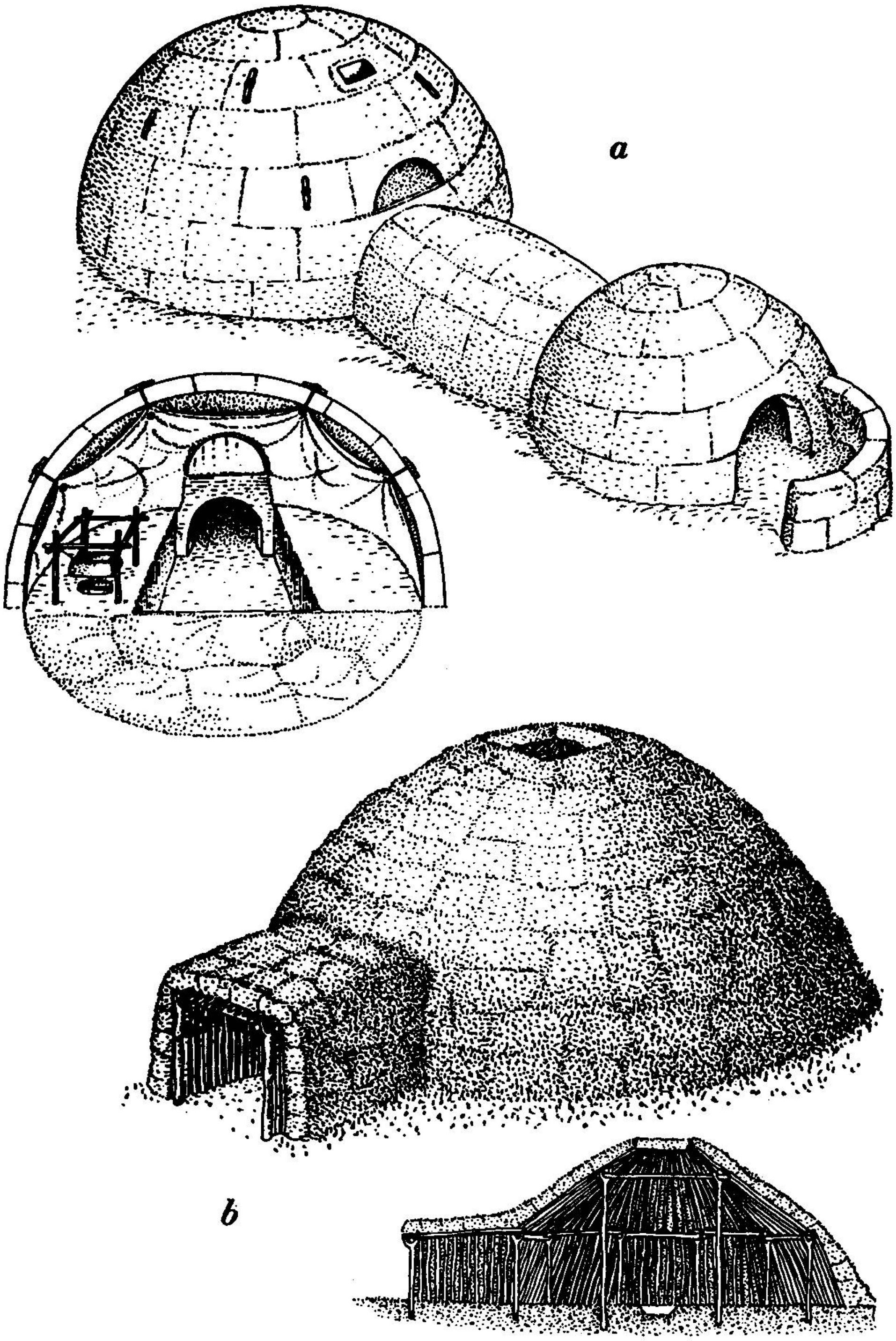
REQUIRED ARCHITECTURAL RESPONSE	RAW MATERIALS AVAILABLE	TYPE OF TENANCY	STRUCTURAL SYSTEM EVOLVED
LOW HEAT CAPACITY WALLS AND ROOF MINIMUM SURFACE, MAXIMUM STABILITY	SNOW	SEASONAL (HUNTING)	 SNOWDOME, ICE-AND FUR-LINED
HIGH HEAT CAPACITY ROOF AND WALLS	TURF, EARTH, DRIFTWOOD	SEASONAL (HUNTING-FISHING)	 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



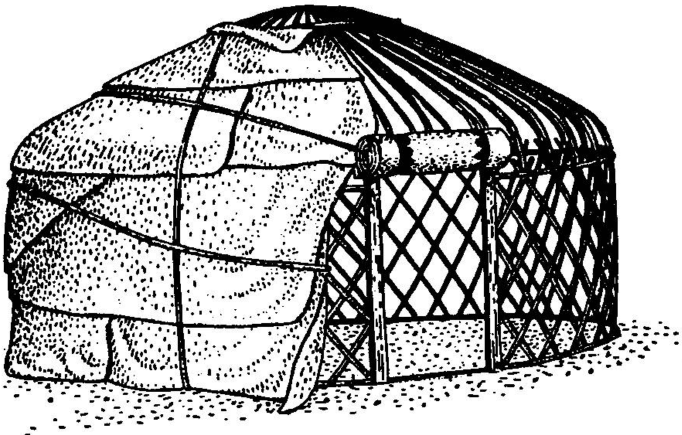
IGLOO TEMPERATURES may run as much as 65 degrees Fahrenheit higher than external air temperatures. The heat source: a few oil lamps and a few Eskimo bodies. Outside temperature is typical winter range.



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.



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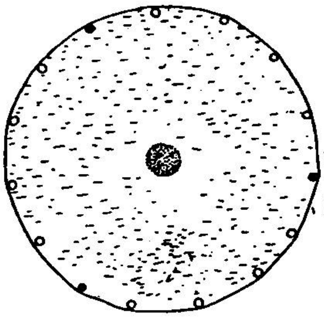

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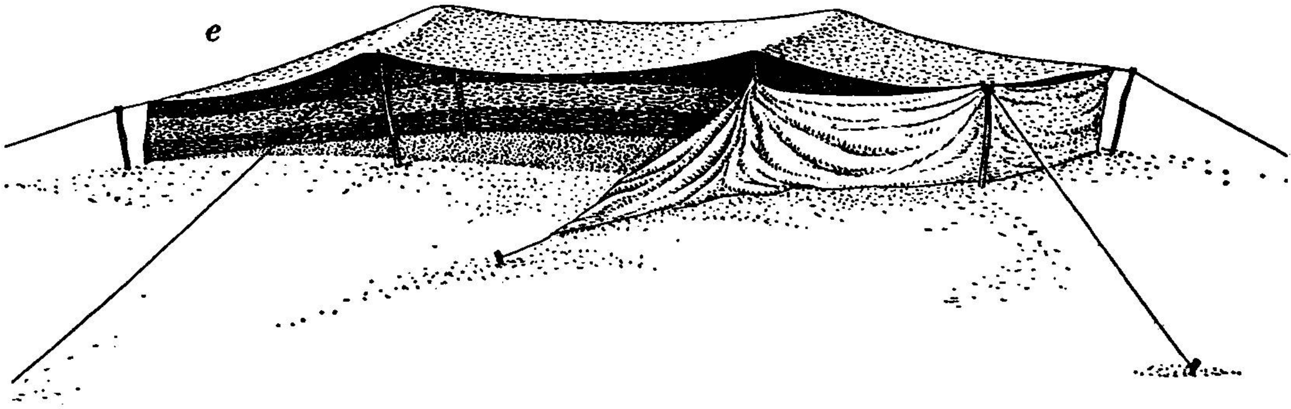
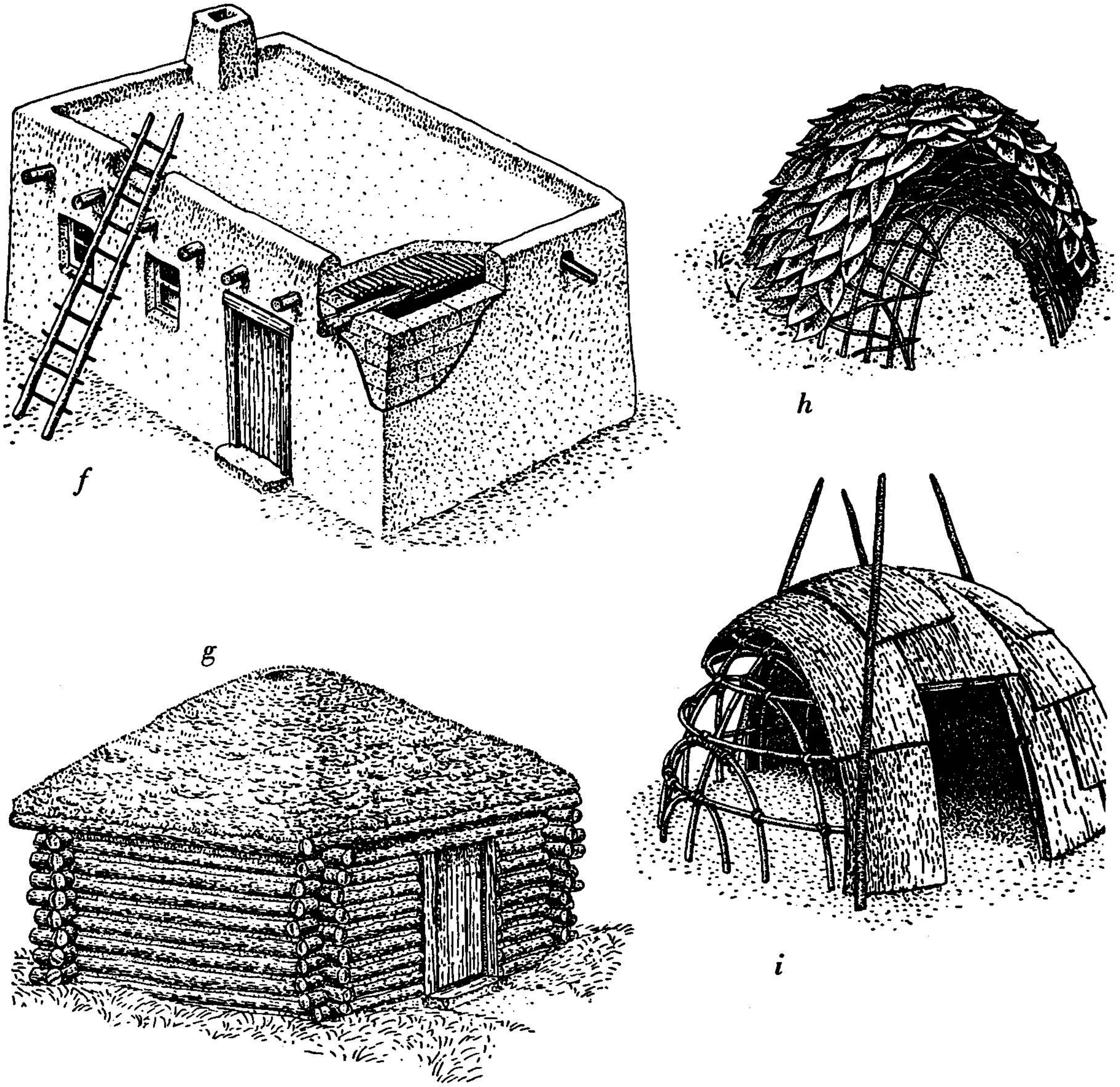
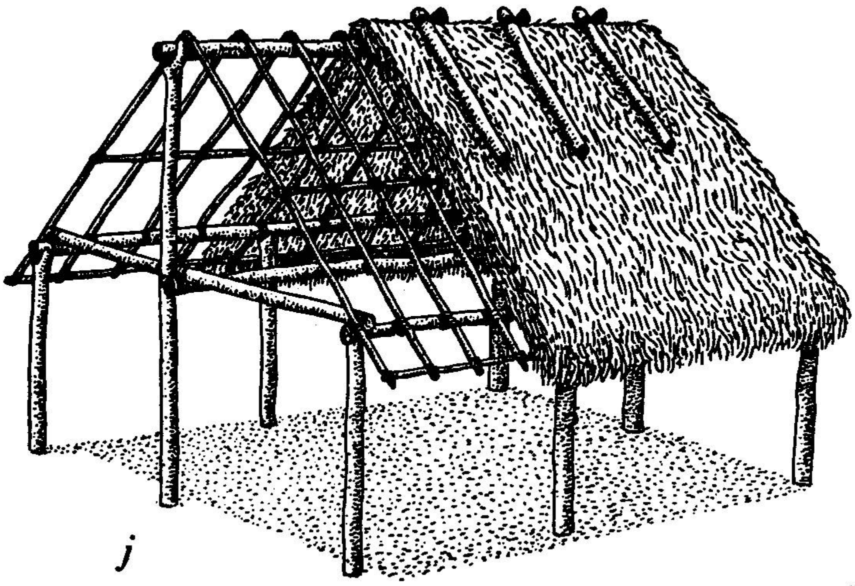


The yurt, or Kazak tent (c), is among the most ingenious and weatherproof of the many types of demountable dwelling conceived by nomadic tribes. Its lightweight willow walls fold up like a child's safety gate. The covering is felt, sometimes two-layered with an air space between. The familiar Indian 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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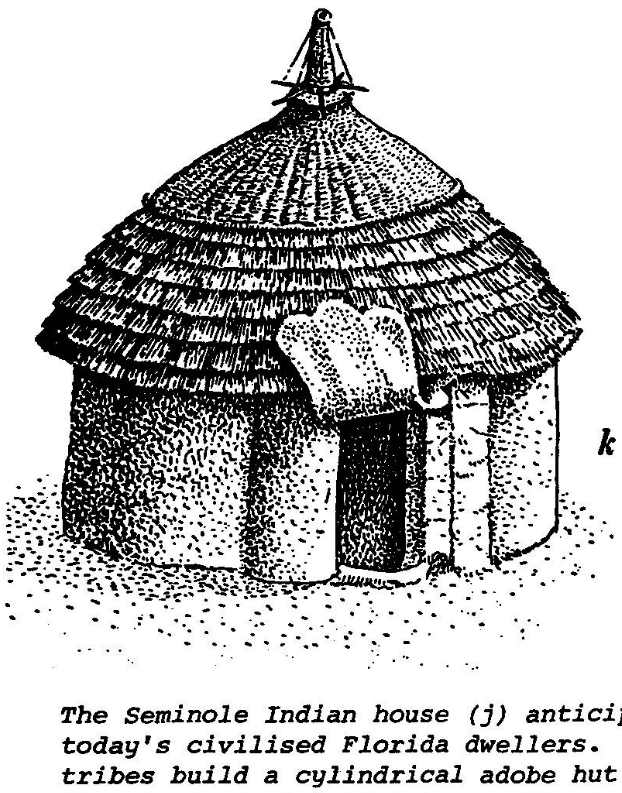

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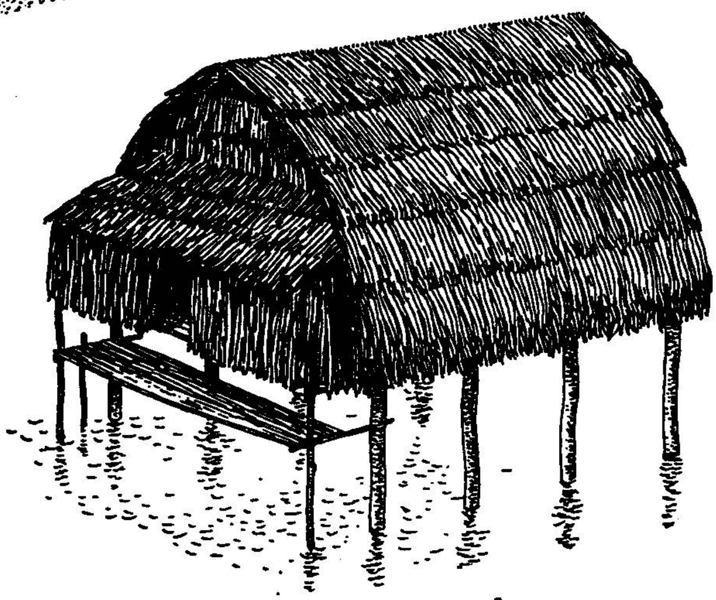

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The Seminole Indian house (j) anticipates the open, airy structures so admired by today's civilised Florida dwellers. In the Lake Chad region of Africa the local tribes build a cylindrical adobe hut (k) with a conical thatched roof. This roof, like 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.