The use of daylight as a substitute for electric lighting in desert regions

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ABSTRACT
This paper reviews the use of daylight as a light source in desert regions and outlines existing and potential techniques for harnessing this resource. Amounts of daylight in desert latitudes are considerable but despite this a major proportion of installed electric load in buildings in desert regions is used for electric lighting. Some of the traditional approaches to the problem in a number of desert areas are reviewed. Recent developments in technology of lighting systems and materials which may offer opportunities to make greater use of the daylight resource are described. Case studies of some modern approaches to the predominantly naturally lighted buildings demonstrate that daylight has potential to reduce energy consumption in desert areas and to contribute to a sustainable environment

KEYWORDS
Daylight, electric lighting, desert regions, arid regions, energy

INTRODUCTION
This paper reviews the use of daylight as a light source in desert regions and outlines some existing and potential techniques for harnessing this resource. Amounts of daylight in desert latitudes are considerable but despite the amount of this natural resource available a major proportion of installed electric load in buildings in desert regions is used for electric lighting. This is clearly an issue for designers of sustainable environments. The main architectural design constraint in desert latitudes is exclusion of heat gain and this has traditionally shaped the form, layout, structure and construction of buildings. For example the intense solar radiation and high temperature swings that are characteristic of dry continental climates favours deep plan massive construction but efficient daylight utilisation requires limited depth using conventional vertical glazing methods. The problem of getting daylight deep into buildings may be solved in temperate latitudes using roof-lights – a technique that is impossible to use in areas of high solar radiation.

This paper reviews some of the traditional approaches to the problem in a number of desert areas world-wide and describes some successful techniques. Building codes relating to daylight in a number of desert areas are outlined. Recent developments in technology of lighting systems and materials may offer opportunities to make greater use of the daylight resource. Materials such as chromogenic glazing that are commonly incorporated into 'smart glazing' systems, widely used in temperate latitudes, may have some application in desert latitudes. Systems such as light pipes offer the means to transmit natural light deep into buildings after prior removal of solar heat, thus offering a low heat gain solution to daylight usage. Similarly a variety of prismatic glazing materials are available whose solar rejection properties at specific sun angles may enable skylight to be used as a light source. Case studies of some modern approaches to the predominantly naturally lighted buildings demonstrate that daylight has major potential to reduce energy consumption in desert areas and to contribute to a sustainable environment.

AVAILABILITY OF DAYLIGHT IN DESERT LATITUDES
Desert regions worldwide are located between 15-32 degrees north or south of the equator. The desert areas among this range are characterised by the dominance of hot and dry climate which

have high annual temperature with large daily variation, very hot days in summer and cool in winter, low rainfall, very strong solar radiation and ground glare. (Evans 1979) Humidity can be considered as a problem in some desert latitudes where sea and water surfaces are adjacent.

The abundance of solar radiation in such regions ensures that daylight is available but the magnitude of daylight available to designers for a given location is less certain. Little reliable measured daylight data is published for desert regions. The International Daylight Measurement Programme for example has 52 measurement stations world-wide mainly located in temperate regions in Europe, Japan and North America – the proposal to site a station in a desert area (Alice Springs in Australia) failed because of lack of funds. (Dumortier 1999) An alternative method of obtaining daylight data for design is to use illuminance models based on either locally recorded or calculated climatic data or using generic data for the characteristic type of local sky (Robbins 1986). Where none of the above methods are applicable estimates of available daylight can be made from total radiation measurements, which are routinely made at climatic station or airports. This is possible using values of the luminous efficacy of daylight, which was derived from simultaneous measurements of illuminance and radiation (Littlefair 1988). Clear and overcast skies vary little in luminous efficacy with solar altitude and a value of 110 lumens/watt for both types of sky can be assumed.

In desert latitudes the available daylight shown in Table 1 ranges from about 30000lux to 70000 depending on latitude, season, time of the day, altitude, sky and atmospheric conditions. This amount of daylight can potentially provide sufficient illumination to light the variety of tasks in most types of building interior. The availability of daylight is affected by any atmosphere obstructions such as humidity, dust of other particles contained in the atmosphere. The typical clear sky luminance in desert areas is of the order of 2000 cd/sq.m. - light dust in the sky may increase this to 10000 cd/sq.m. whilst heavy dust may reduce it to 500 cd/sq.m.

MONTH	LATITUDES			
	17°	21°	25°	29°
Jan	39200	36100	32100	28300
Feb	45100	42600	39100	35800
Mar	52400	50500	48100	45700
Apr	57500	57000	56200	55200
May	59900	60800	61300	61300
June	60500	62200	63300	63900
July	60300	61800	62600	63000
Aug	59000	59300	59200	58800
Sep	55300	54000	52400	50700
Oct	48900	46700	43600	40800
Nov	41800	38900	35000	31600
Dec	37700	34400	30500	26700

Table 1: Availability of direct daylight (global illuminance) for selected desert latitudes on horizontal surfaces (lux)

The main design constraint for buildings in desert latitudes is exclusion of heat gain and this has traditionally shaped the form, layout, structure and construction of buildings. This results in small openings which may allow a view of the high altitudes rather than the horizon (to reduce glare for haze on the horizon and ground) but which are in all cases protected from direct solar radiation. Thus despite the abundance of daylight outside the amount of light reaching an interior can be insufficient to provide a level of working illuminance without supplementary electric lighting.

CONSUMPTION OF ELECTRICITY IN DESERT REGIONS

Electricity consumption in the desert regions such as Saudi Arabia and other Gulf States is very high. The building sector in these regions consume the majority of electrical power output e.g. Saudi Arabia 70%, UAE 90%, Bahrain 80%, Oman 95%, Qatar 80% and Kuwait 70%. The rest is consumed by industrial and agricultural sectors (Al Nagem, 1998). It should be remembered that electricity generation has an efficiency of the order of 30%, the remaining 70% being wasted and it is unlikely that any major improvements will be achieved in the short term.
The use of electricity in buildings of desert regions is mainly devoted to lighting and air-conditioning. On a hot day the need to reduce high internal temperatures by air-conditioning requires additional electrical load. The use of electric lighting increases cooling load since in conventional mechanically conditioned buildings, each watt of electric lighting load requires one-half to one watt of air-conditioning (Millet et al, 1981). Therefore, the use of daylight is desirable in order to reduce electrical consumption both for lighting and cooling. The use of daylight in buildings provides a pleasant environment due to factors such as improved light colour and light modelling, and the provision of view out leads to a general sense of well being.

TRADITIONAL APPROACH TO DAYLIGHT IN DESERT AREAS

Traditionally daylight was considered in the planning and design of cities and houses in the desert regions. Planning considerations of daylight are manifested in different ways such as shape, size and heights of building, landscape of open spaces, treatments of external surfaces such as pavements and streets, and painting of the buildings facades. Shapes and layout of buildings have a significant effect on the distribution of daylight (Boyer, 1981).
Courtyards, terraces (Kharejah), light-wells (Minwar), and different types of windows, are the main elements which in particular affect the daylight provision in desert houses. Such design elements affect the provision of daylight whether by toplighting or sidelighting methods.
One example of traditional designs is the Hedjazi house which is built in the west of Saudi Arabia (Latitude 22 Deg North) and other surrounding areas. Jomah has analysed the Hedjazi house in the cities of Makkah, Jeddah and Al-Madinah and described some of the elements which can be considered as toplighting methods for provision of daylight in the interiors (Jomah, 1992). Some of those elements are: open-court (Housh), light-well (minwar) and skylight (jila). According to its availability the provision of daylight in traditional designs is controlled using different methods. Therefore techniques exist to adjust the relationship between control and provision of daylight and the other design requirements such as thermal comfort, view and ventilation. Rowshan and Mashrabiah (Figure 1) are one such technique where windows are designed for specific performance. The Rowshan window could be considered as a basic element of maintaining shade on the wide apertures of the Hedjazi house, controlling natural illumination and at the same time maintaining a passage of natural airflow through the spaces between the slats of the *Rowshan* sashes.

Other example of traditional designs in the desert is the courtyard house (Figure 2) which can be found in many areas of the world and mostly is predominant in most of desert regions such as Iraq, Egypt, Yemen, Spain, Arabia etc. and it employs similar principles. It creates internal micro climatic conditions providing comfort, security, privacy and protection from glare and sand storms. The courtyard acts as light well and ventilation shaft bringing in cooler air at night. When it is provided with greenery and water and is shaded, it acts as a cooling well and actually modifies the microclimate by lowering ground temperatures and radiation and by evaporation (Rapoport, 1969). In courtyard houses, external openings are different from the internal ones facing onto the courtyard . It is usual that most of the external openings are small and few in number to lessen the impact of the outside heat, radiation and glare on inside spaces. The north elevation of building is the most suitable one for openings because not subjected to excessive heat and has no direct radiation as other elevations. Therefore, natural illumination from north windows are most preferable as it is indirect, sufficient, constant, balanced and comfortable in such luminous environments. Therefore, other elevations from east, west and south have few or no openings. To substitute the loss of external openings over the elevations, the courtyard and the internal openings looking towards it, are used because of the climatic extremes of hot dry climates. Because of the need for ventilation the few, small openings that exist are high on the walls on the ground floors which admit little heat and dust and prevent ground glare. A larger number of wider openings are located on the first and second floors.

NEW TECHNOLOGIES FOR DAYLIGHT

A number of new glazing and daylight systems which have been developed in recent years for directing daylight into buildings have a number of characteristics that make them potentially very valuable for use in desert latitudes. The first class of device – advanced glazing systems - are high-performance glazing and reflecting systems for otherwise conventional windows which offer spectral and/or angular selectivity, intended to improve illumination quantity and quality while reducing solar radiant heat gain to improve human comfort and energy conservation. Advanced glazing systems may include a variety of attachments such as shades, blinds, screens, fixed and movable louvres, or mirrored surfaces for re-directing daylight entering conventional glazing apertures. They may also include glazing types such as those containing electrochromic layers. The use of holographic material for this purpose is still in the research stage. The second class of devices – advanced daylight systems - are intended for “core daylighting”, the process of introducing daylight into the core spaces of buildings, spaces distant from the building envelope, or other locations where conventional daylighting apertures cannot be located. They are mainly based on “light pipe” technology which has been developed for many applications (Ayers and Carter 1995). Because of their complexity the performance of both types of device are difficult to predict for desert locations. Some of the features of these devices that are of potential use for desert applications are examined.

Advanced glazing systems have incident angle-dependent optical properties and make use of a number of techniques to control admission of direct beam and diffuse sky light into a building, including vertical and horizontal fixed louvers, both inside and outside the building, exterior shading screens, and operable interior and exterior louvered shades, shutters, and awnings (see Figure 3). The glazing materials used exhibit strong spectral selectivity. This works as follows. Only a limited portion of the solar spectrum contains visible light and all the rest, including infrared and ultraviolet, is invisible to the eye and hence not capable of producing illumination. All portions of the solar spectrum, however, produce heat when absorbed by the building envelope. A strongly spectrally selective glazing can transmit adequate quantities of daylight illumination while rejecting much of the solar radiant heat gain. A disadvantage of these systems is that with the exception of spectrally selective glazing, determining the solar heat gain performance of complex systems is not a straightforward engineering process and thus reliable design data for specific locations is difficult.

Advanced daylighting systems consist of a daylight collector connected to a light transport system of mirrors and/or light pipes, and one or more terminal emitters, which serve the same purpose as luminares in electric lighting systems, but take light from the light transport system and deliver it to the occupied space. (Figure 4) Some core daylighting systems have either tracker or concentrator system to collect light (Figure 5), whilst others have a simple passive collector in which the degree of concentration is traded off with the angular acceptance or field of view of the collector (Figure 6). Passive collectors require reasonably large views of the sky, allowing direct beam sunlight to be collected without moving the concentrator. And these optical components are also used (in reverse) in emitters. At their most complex, some advanced daylighting systems can have sophisticated and expensive collection and concentration mirrors with arrangements for directing the concentrated sunlight into the transport system. These can involve light pipes or arrays of mirrors inside light housings, for directing the light around corners and over significant distances to the emitters. Inevitably the light losses in these systems are substantial but must be traded against the plentiful 'free' light source. The major problem with advanced daylight systems is that there are no reliable methods for prediction of their thermal properties and this is a major constraint in their use in desert areas. Some work has been undertaken on the steady state thermal performance of passive collector systems (mainly in the context of heat loss in temperate climates) but to the authors knowledge no work on the thermal performance of these devices under the conditions of intense solar radiation has been done. Some work on the light transmission properties of passive collection light pipe systems has established likely output for a limited range of sky conditions and pipe geometry and this research continues.

SOME MODERN APPROACHES- CASE STUDIES

It was argued earlier that one of the main reasons for small windows in traditional buildings in desert areas was to avoid heat gain. Research has shown that window size in hot and dry climates has a minor effect on the indoor air temperature as long as shading is provided. On the South-North orientation a horizontal shading device is sufficient because of the high altitude of the sun during the summer, but on the East-West façade vertical or lattice screen shading is required (see for example Al-Azzawai (1985), Rosenlund (1989)). Advances in design tools in recent years, notably software for building thermal analysis, have meant that these concepts have been widely applied in practice. The following case studies illustrate some of the principles.

Phoenix Central Library, Arizona, USA (Latitude 33 Deg North)

The 5-storey building is constructed in concrete and covered on the East/West facades by steel framed services zones covered in continuous copper sheet. Plan dimensions are approximately 80m by 50m and the building has a central atrium atrium that is the main circulation space. The North/South windows are 100% glazed to take advantage of mountain views (Figure 7). In order to withstand the Phoenix climate they are protected by horizontal louvres on the South and vertical 'sails' on the North, the latter to prevent ingress of mid summer sun. The South wall louvres are some 500mm wide and control via software the degree of solar penetration, some of which is allowed in mornings as a heat source. The atrium serves to bring daylight down to all five levels from an advanced daylight system at its top. Nine circular skylights house mirrors that automatically track to sun at the azimuth angle, their tilt angles being adjusted to reflect light vertically as much as 30m down. The skylights are glazed with an advanced glazing system that transmits visible light and absorbs infrared. Other skylights, constructed of the same material, are located over the roof and each contains a lens at ceiling level. These are made of laminated glass with layers of polyvinyl butyl that are tinted to appear sky blue and hence give the appearance of a pleasant view.

College of the Desert, Palm Desert, California, USA (Latitude 33 Deg North)

This library is an example of integrated daylighting apertures, low-emissivity glazing and shading devices that provide abundant natural light while protecting against direct beam penetration and solar heat gain into the spaces (Figure 8). The 4100 square-metre, single-story library is organised around a North/South vaulted circulation space that connects stack and reading areas. Shaded vertical glazing in high clerestories over the vaulted areas, punched windows adjacent to offices, and roof monitors over the reading carrels were included in the design to ensure ample illumination without solar heat penetration. Window size was minimised in the stack areas due to concerns about fading of printed material. Because of the range of apertures employed in the design, several shading devices—each appropriate to its orientation were adopted. These include on the west side of the library, a 4 metre-deep colonnade which spans the entire front side of the building, shading the windows that provide light into the ground floor offices and work areas. On the south side of the building a 3 metre painted metal sunshade covers the concourse and overhangs spaced every metre vertically from the bottom to the top of the aperture shade the south-facing vault clerestory. An arched tube steel sun louver, constructed of metal fins and mounted to follow the curving roof, extends out over the west and east side clerestories. Below the east-facing sun louver are three horizontal perforated metal sheets shading elements to shade the clerestory from the morning sun. A vertical perforated metal sheet mounted directly in front of the glazing minimises summer sun penetration through the north-facing glass in the vault clerestory. The double-pane clear advanced glazing units incorporating a clear low-emissivity coating that allowed light transmission with full colour rendition, while providing resistance to heat gain. The electric lighting system uses fluorescent lamps with electronic ballasts in the offices and reading/stack areas that are dimmable as supplementary natural light is available

CONCLUSIONS

This paper has examined the contribution of daylight to the debate on building sustainability in desert areas. Despite abundant daylight there has been a reluctance among building designers to exploit this resource and correspondingly the electrical load due to lighting represents a major proportion of the total. Traditional buildings in desert areas are characteristically of high thermal mass with small apertures to prevent heat gain and glare and to offer privacy to their occupants. Issues of sustainability were clearly understood, if only implicitly, by their designers and builders. The various new techniques described offer lighting solutions that could be considered to be improvements on those that went before and additionally may be incorporated into building forms and methods of construction that differ radically from those traditionally used. This paper should not be read, however, as a universal endorsement of their use. Any consideration of sustainable development needs to consider all of the energy and environmental issues. At a simple level an environmental system such as lighting has an influence on other services – notably mechanical – and also on the structure due to for apertures. Other issues include the amount of embodied energy incorporated in the new devices and the sustainability implications of repair and maintenance of these sophisticated devices located in a harsh climate.

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