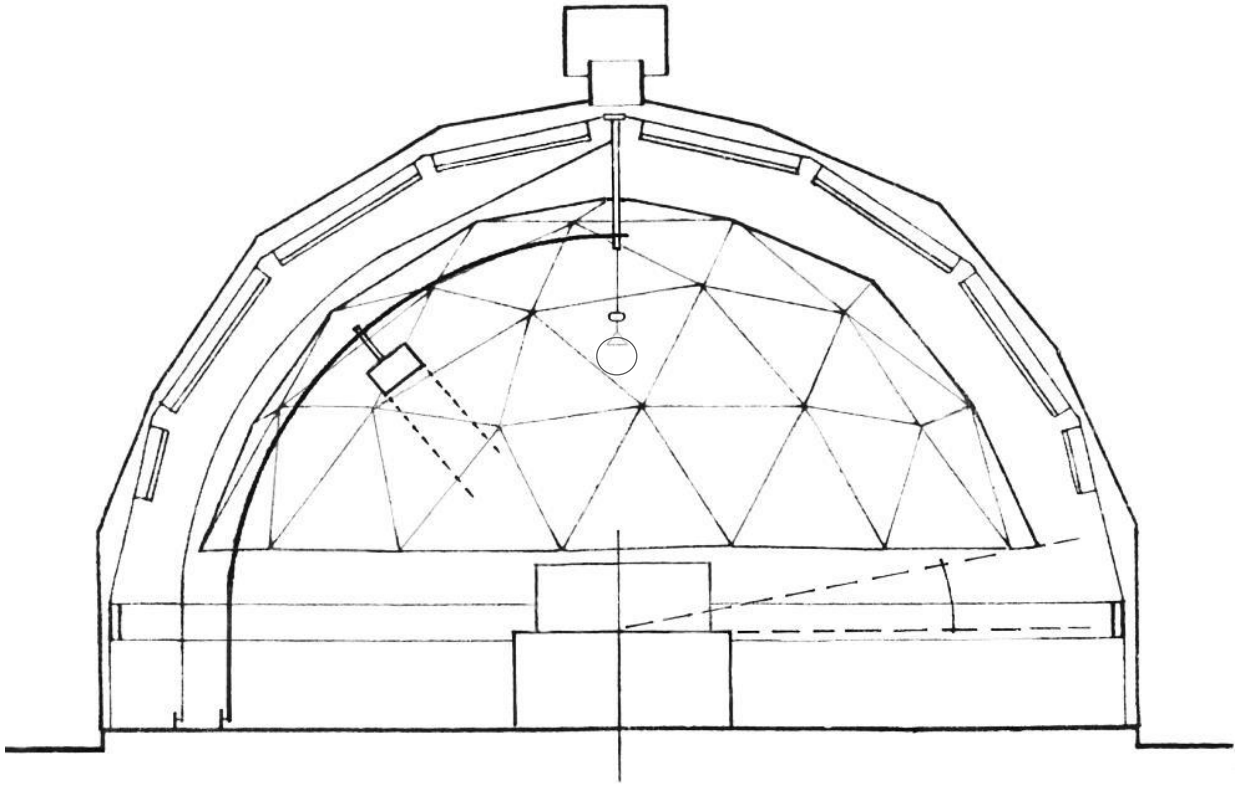
daylighting by design

1. Artificial skies for building design -
past, present and future

2. Some early examples of the use of an artificial sky



David Croghan

Cambridge UK July 2015 version 1.5

daylighting by design

This booklet comprises two papers:

1. 'Artificial Skies for building design – past, present and future'.
   The development of artificial skies for building design is outlined up to 1962, when the author completed a sky of novel design – a transilluminated hemidome - at Cambridge U.K. Subsequent sky designs up to present date are examined and the design for a future 'ideal' sky is postulated.
2. 'Some early examples of the use of an artificial sky'.
   Photometric daylighting studies at building design stage carried out by the author between 1958 and 1970 and not previously published are reported in full.

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the author

David Croghan (DC) studied at the Cambridge University School of Architecture (CUSA) from 1953, gaining a Bachelor of Arts (BA) degree in 1956 and the Diploma in Architecture (DipArch) in 1958. The titular degree of Master of Arts (MA) followed in 1960 and in the same year he qualified for registration as an architect and elected an Associate of the Royal Institute of British Architects (ARIBA). From 1958 DC undertook post-graduate research at Cambridge, in 1963 submitting a successful thesis for the degree of Doctor of Philosophy (PhD).

Between 1962 and 1970 DC was variously director of the CUSA Daylight Research Group and lecturer in Building Science and Construction at the CUSA and in Building at the CU Department of Land Economy. A number of technical papers were published and also he engaged in daylighting design consultancy.

From 1965 DC was a principal in private architectural practice, initially on his own account, later with partners Raymond Hooper and Glanfyll Lewis (as Anglian Architects) and finally solely with Dr Lewis (as Croghan Lewis Associates). RH and GL had their offices in Waltham Abbey, Essex, whereas DC's was always in Cambridge. In 1970 DC left academia to concentrate on practice work that embraced a wide range of building types from military installations to Cambridge colleges, and also DC engaged in consultancy in energy conservation and as an expert witness in 'right to light' and building failure legal cases.

DC was elected Fellow of the Royal Society of Arts (FRSA) in 1990 and became a Member of the Academy of Experts (MAE) in 1994. He qualified for his state pension in 1998 and ever since has been attempting to retire.

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paper 1

Artificial skies for building design: past, present and future

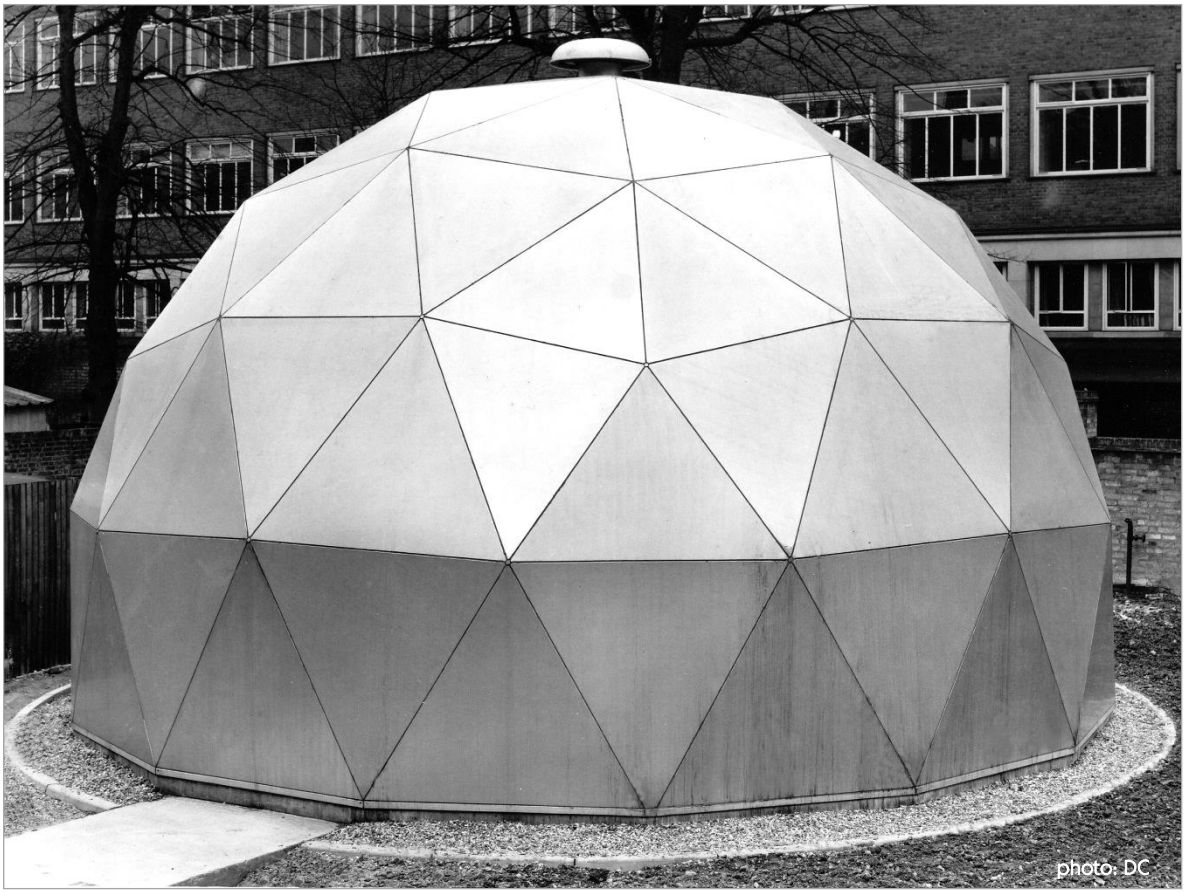
a personal view

Artificial skies have been in use in various forms since about 1914 by architects and lighting engineers seeking to simulate known and stable sky luminance distributions by which model buildings could be tested for interior daylighting by photometry and/or subjective visual appraisal.

The author (DC) came to this field as an architecture PhD student in 1958 and moved away in 1970 to pursue a career in general architectural practice. During his 12 years of active involvement in daylighting studies, DC became closely familiar with developments and was pleased to be able to make his own contributions.

DC takes 1962 as his reference year and records that the 'Skydome' that he designed in 1959 was completed that year at the Cambridge University School of Architecture (CUSA), adding a third generic type of artificial sky – the 'transilluminated dome' – to the pre-existing two types: the 'opaque reflecting dome' and the 'mirror-lined box'. He observes that further developments took nearly 40 years to appear and names these respectively the 'polka-dot sky' and the 'CGI sky'. It is held that these latter two were not necessarily advances. He notes the subsequent re-appearance of the transilluminated domical sky and welcomes the adoption, in one recent but relatively small example of this type, of light emitting diode (LED) luminaires in fully addressable, diffusing modules assembled in zones to form a near-hemispherical surface with the potential for controlled, smoothly-graded variable luminance: the 'LED sky'.

DC, who adheres to testing physical models in artificial skies in preference to the more limited calculation techniques or digital computer simulations, contemplates a future where there may be only a few such LED skies in fully developed form, for they would involve building to larger size and at greater expense than hitherto to reduce to insignificance the often quite small errors at present inherent in the model study technique. He offers an outline description of such a device.



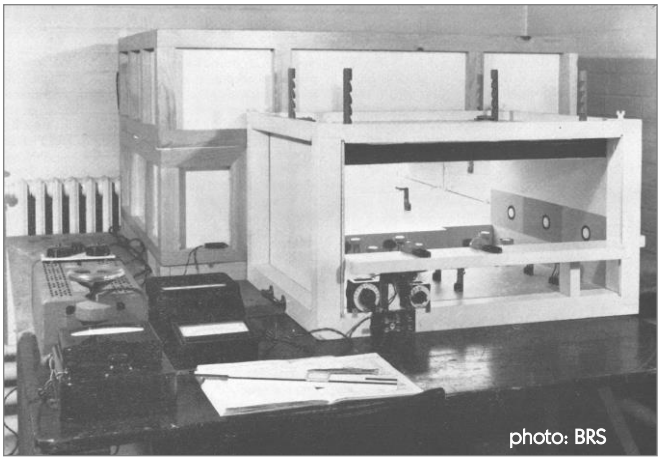
The Cambridge University School of Architecture (CUSA) 'Skydome' built in 1962

This artificial sky is notable for having been designed from first principles with little constraint other than the size of the garden area in which it was set, and in consequence it served for many years. With seed capital from the Nuffield Foundation Division for Architectural Studies, most of the cost was met by industrial sponsors.



The CUSA Skydome in use in 1965 by a team of Greater London Council (GLC) architects setting up a model of a school for testing. This illustrates the generous floor space available and freedom from inter-reflections in this type of 'sky'.

(1) the state of the art of 'artificial skies' prior to 1962:



Left: the UK Building Research Station's Mk.1 'artificial sky' of 1954, a mirror-lined box measuring 1.2m x 0.9 m x 0.6m with integral light source above a diffusing 'Perspex' panel.
[RG Hopkinson & J Longmore 1954]

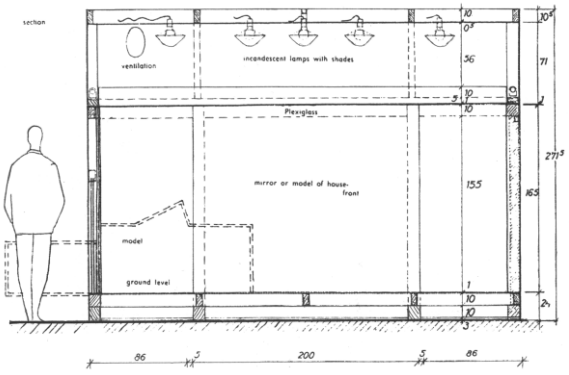
This was the only 'sky' in use in the UK when DC was first involved in the study of daylighting in model buildings at the CUSA in 1957.

In the foreground 'daylighting' conditions are being tested with numerous measuring photocells in a model room (with its back wall removed).
In March 1959 this sky was loaned to the CUSA for the use of DC who soon found it too small for studies of anything more elaborate than single side-lit model rooms with limited external obstruction, emphasizing the need at Cambridge for a much larger device.

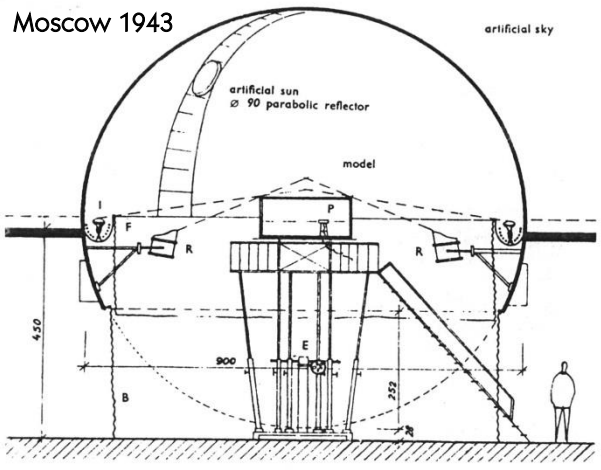
In 1961 BRS built a 'Mk.2' measuring 1.8m x 1.5m x 0.6m.

The 'state of the art' of artificial skies internationally at the time the author designed the CUSA 'Skydome' is well-summarized by R Kittler writing in 1959. He usefully categorizes and details artificial skies that had been used since 1914 and observes that "model measurement on extensive buildings with top plus side-lit interiors" requires "domes at least 5 to 10 metres in diameter." He notes five then currently in use:
(1) a hemispherical dome of 9m Ø of 1943-52 in Moscow by NM Gusev *et al.*, (2) a hemi-ellipsoidal dome 6.5m Ø of 1948 in Stockholm by G Pleijel, (3) a flattened dome 7.3m Ø of 1952 in Sydney, Australia by RO Phillips *et al.*, (4) a 5m Ø hemispherical dome of 1955 in Warsaw by T Oleszynski *et al.*, and (5) a 5.8m Ø hemi-ellipsoidal dome of 1955 in Texas by EE Vesey *et al.*
Of these R Kittler illustrates (1) & (5) and also his own 1957 3.6m x 3.6m x 1.65m (effective height) octagonal mirror-box sky.
[R Kittler 1959]

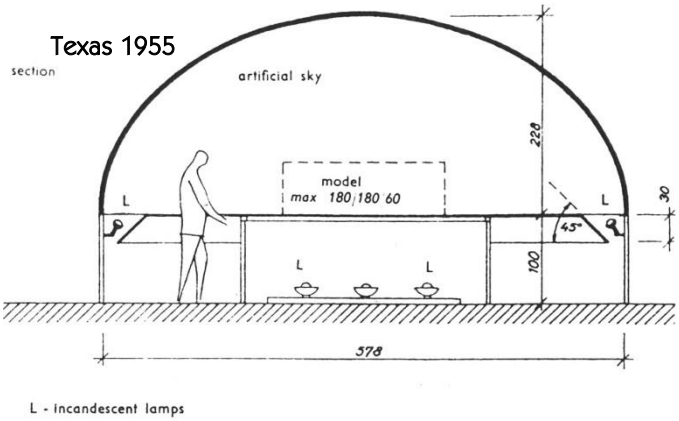
Below: section of R Kittler's 1957 mirror-lined box sky at the Slovak Academy of Sciences, Bratislava, Czechoslovakia. Designed on the same principle as that at the BRS, but unlike the Mk.2, its effective wall height of 1.65m enabled testing of roof-lit models. Also it was hexagonal in plan.
Both followed the 'mirror box' sky design established by G Pleijel of Stockholm in 1941.



Bratislava 1957



sectional drawings of 'skies' from R Kittler [1959]



Left: section of NM Gusev's 9m Ø hemispherical sky of 1943 at the Moscow Academy of Building & Architecture. This and (above) EE Vesey's 5.3m Ø hemi-ellipsoidal sky of 1955 at the Texas Engineering Experimental Station are both reflecting domes and illustrate the problem of obstructed floors that typically arises in this type of 'skydome' due to the necessary location of the lamps.

the upshot is that before 1962 there were only two types of artificial sky:
'mirror-lined box' and 'reflecting dome'

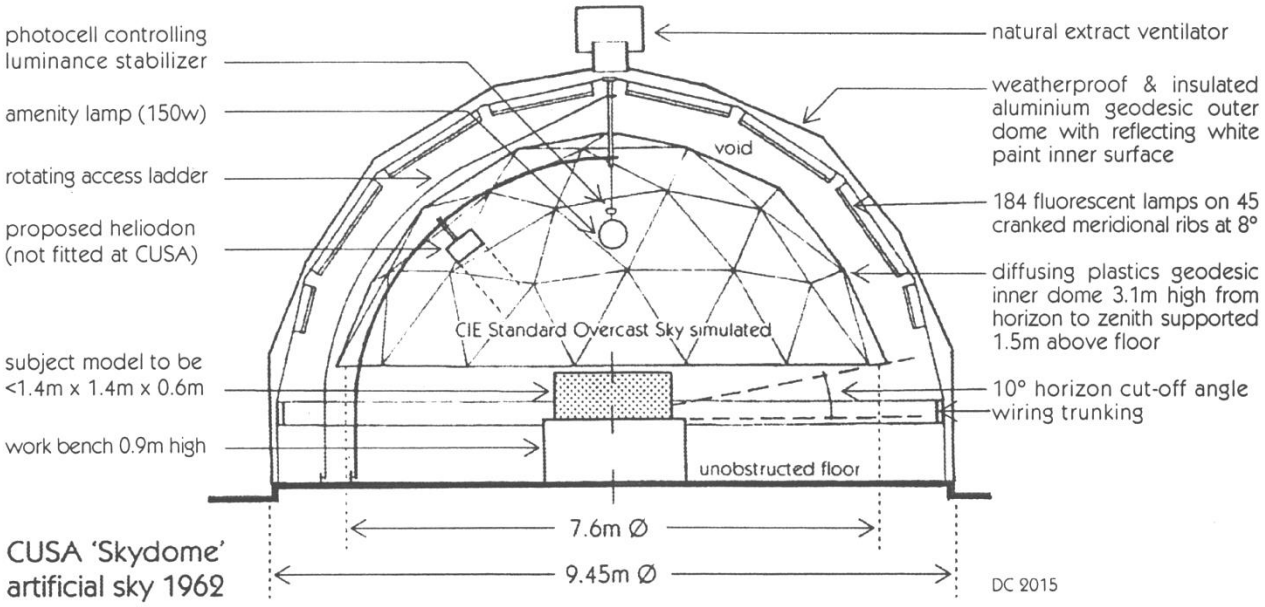
(2) in 1962 an additional type of artificial sky appears.....

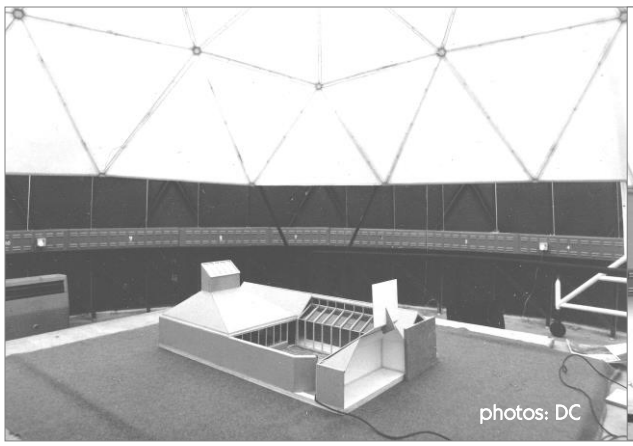


Designed in 1959 and completed in June 1962, the CUSA Skydome represented a new type of artificial sky: the transilluminated dome, a hybrid that adopted the diffused, direct lighting of the mirror-box sky with the conceptually clear representation of the sky vault of the opaque reflecting dome type. Whereas the latter's lamps are placed around the periphery at or below horizon level and directed to reflect off the dome's surface – often much restricting useable floor space – those in the Skydome were set above an inner translucent dome, leaving the floor clear. The transilluminated dome, like the mirror-lined box sky, could readily be designed to the luminance distribution of the CIE Standard (non-uniform) Overcast Sky. This could prove difficult in the case of the domed sky as its zenith, the part most distant from the lamps, requires to be 3x brighter than its horizon. While the mirror-lined box sky remained the most popular – being by far the least expensive – its multiple inter-reflections, while essential to its functioning, present a considerable problem in the representation of correct external obstructions and render it less than satisfactory as a teaching environment.

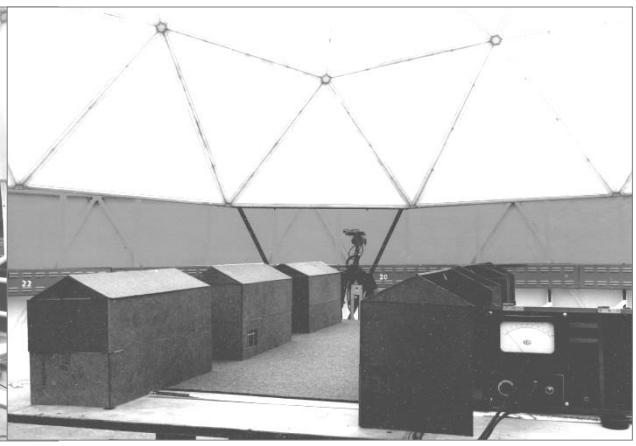
Further description of the CUSA Skydome is to be found in D Croghan [1963, 1964a, 1964b & 1964c]

It will be seen that DC concurred with R Kittler's views on the optimum size of artificial skies and determined the 'Skydome' at 7.6m Ø.



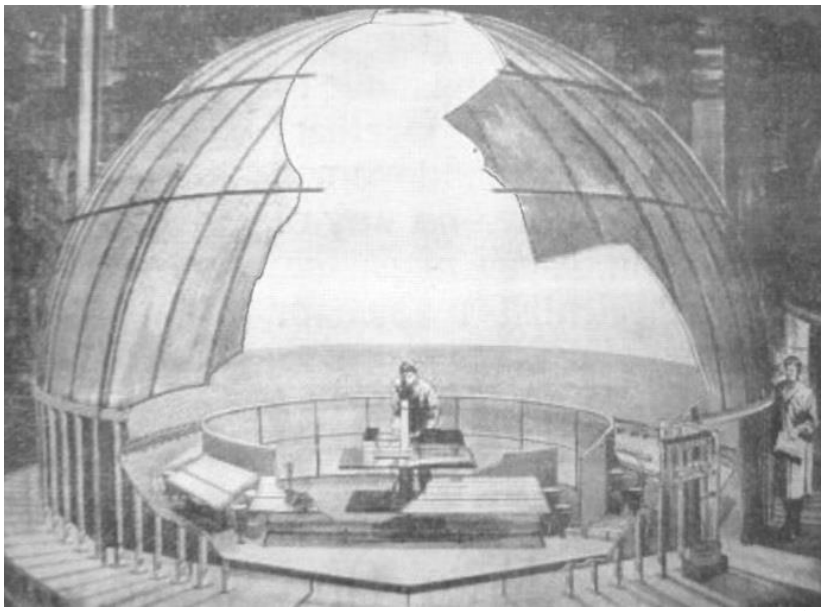


A school design set for testing.



Terraced houses set for testing.

(3) also representing the state of the art in 1962:



from the *New Scientist* of 4/10/1962

A new reflecting domical artificial sky contemporary with the CUSA Skydome.

Drawing of the domical artificial sky installed by the glass company Pilkington Bros at St Helens, UK in 1962: a 6.1m Ø reflecting dome that well-illustrates the drawback of a periphery and/or floor much obstructed by very hot lamps and their screens and enclosures.

In the *New Scientist* of 31/10/1963, Pilkington Bros advertised for a lighting engineer to provide a consulting service to architects based on their new dome facility. DC applied for the post having been without regular stipend since the end of his 3-year PhD research grant in 10/1961, his 'overrun' period of work to complete and commission the CUSA sky being unfunded. DC's application was successful, but in the event he did not take up the post that would have involved abandoning the superior equipment in Cambridge. Eventually funding for research employing the Skydome was secured from 10/1964 under a BRS/SRC External Research Contract, believed to be the first awarded to a university arts faculty. This supported the CUSA Daylighting Research Group consisting of a director (DC), an architect researcher and a PhD student.

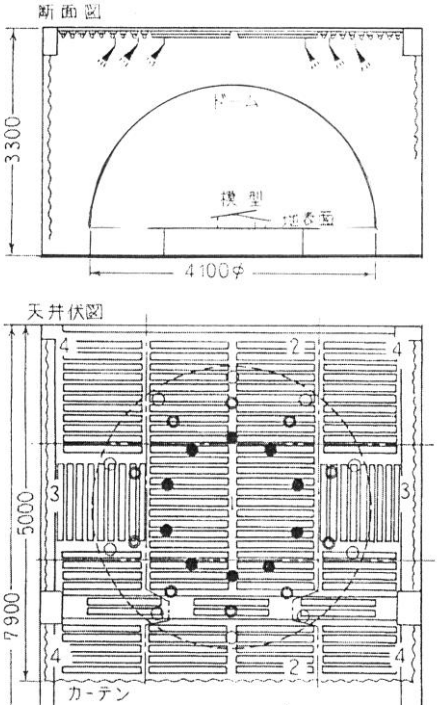
Below: at work in 1966 in the BRS MK.3 'walk-in' mirror-box sky measuring 4.9m x 4.9m x 1.9 m high. This was planned in 1962/63 and operational in 1964.

This photograph well-illustrates the problem of inter-reflections that arise with this type of mirror-lined sky and which make it difficult to set up accurately scaled and sited model external obstructions: an obstruction correctly set up in one plane is automatically replicated to infinity on all sides of the subject model, as indeed is the model itself and any operative.



(4) so what happened after 1962 and when?

A full codification of artificial skies built after 1962 remains to be undertaken (most usefully in the form of diagrams and tabulated details adopted, as above, by R Kittler in1959), but it is clear that all three types then extant – (1) the mirror-lined box, (2) the reflecting dome and (3) the transilluminated dome – continue to the present day, and that these were joined – but not before 1999 – by two further types: first (4) a quasi-dome formed from arrays of unshielded lamps that DC terms the 'polka-dot sky' and then (5) a virtual sky simulator based on a segmental – or less – version of the latter with model and camera under computer control generating images: the 'CGI sky'. Later, from about 2006, the transilluminated dome was re-introduced for remedial purposes, namely to hide and diffuse the lamps of the 'polka-dot sky' so that once again architects could make direct assessments of their buildings.

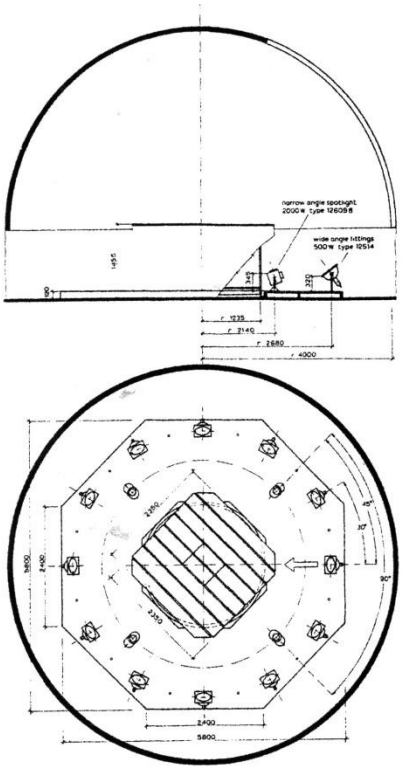


Section and ceiling plan of the 4.1m Ø hemispherical transilluminated sky constructed at the Building Research Institute, Tokyo in 1966.
from M Innui *et al.* [1967]

The transilluminated dome type having well-diffused and evenly graded luminance distribution as adopted by the CUSA 'Skydome' was never widely replicated due to its size, relative complexity and consequent high cost. The original served well for some 16 years in both teaching and research, and could have been in use today had there been the will and funds for restoration and re-lamping to simulate additional types of sky luminance condition. In its day it was unassailable in its provision of working space and in its simulation of the 1955 CIE Standard (non-uniform) Overcast Sky, the norm for north European latitudes and the condition to which both other types of 'sky' also aspired throughout the 1960s and 1970s. Today the aim is to simulate, in addition, at least a 'uniform overcast sky' and a 'clear blue sky'. Many claim to simulate sky and sun conditions for any hour of any day at any place.

An early partial replication of the CUSA transilluminated dome concept was assembled in 1966 in Tokyo at the Building Research Institute (after staff visited the CUSA Skydome). Here a grp diffusing dome of 4.1 m Ø was set on 0.4m steel legs within an existing rectangular room of 7.9m x 5.5m with its 3.3m high ceiling covered with lamps, many of which were at some distance from the dome. Side walls and windows were covered with reflective white curtains. As at Cambridge, this sky was designed to simulate the CIE Standard Overcast Sky [M Inui *et al.* 1967].

Elsewhere stalwarts continued with reflecting domes, the most flexible being that built in 1973 (and still extant) at the Institute of Construction and Architecture of the Slovak Academy of Sciences in Bratislava [R Kittler 1974]. This is of 8m Ø and fully 'tuneable' to uniform and non-uniform overcast skies, the latter both as the CIE Standard Overcast Sky with dark ground and horizon/zenith luminance distribution of 1:3 and also as the local variant: snow covered ground characterized by a luminance ratio of 1:2. Another significant dome of this type, of 7.32m Ø, was built by M Navvab *et al.* in 1981 at the Laurence Berkeley Laboratory (LBL), California. This was designed to simulate a uniform sky, an overcast sky and several clear-sky luminance distributions [S Selkowitz 1981].



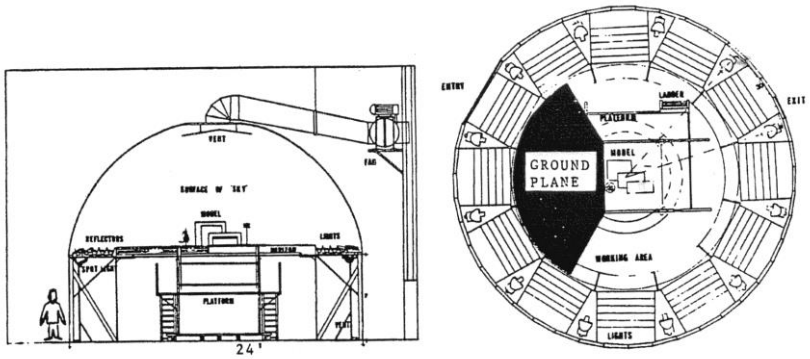


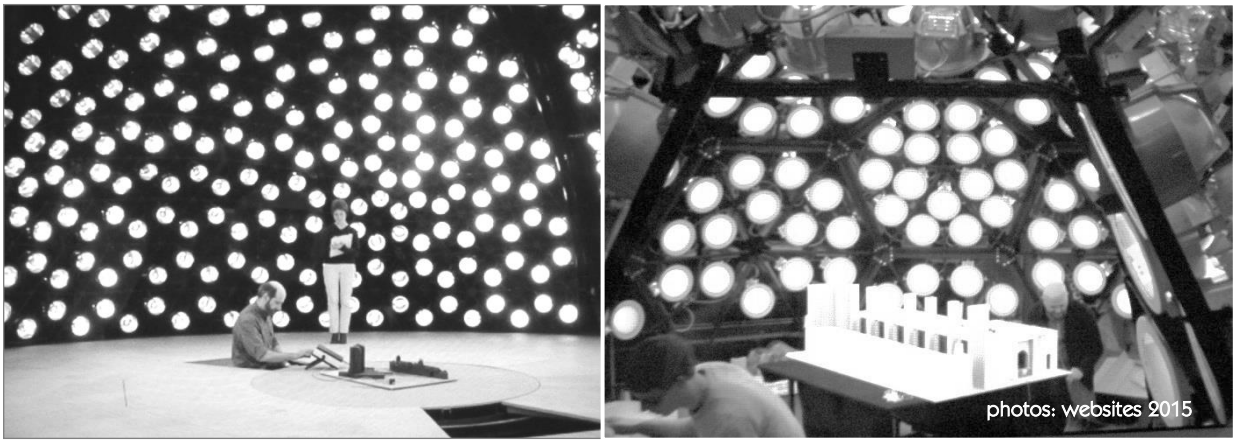
Fig. 1. Plan and Section of LBL sky simulator.

Above: the 7.32m Ø skydome of 1981 at the LBL, California by M Navvab *et al.* The dome element is provided by a standard metal dome manufactured as the top of a grain silo. This is set over a 2.1m high cylindrical plywood wall.
[S Selkowitz 1981]
Left: plan and section of the 8m Ø skydome of 1973 at Bratislava by R Kittler. This is formed from gypsum plaster on metal mesh with a tubular steel frame, the whole suspended from its laboratory roof "like a huge white chandelier."
[R Kittler 1974]
Both these qualify as 'variable luminance artificial skies' (VLASs).

....the polka-dot artificial sky appears....

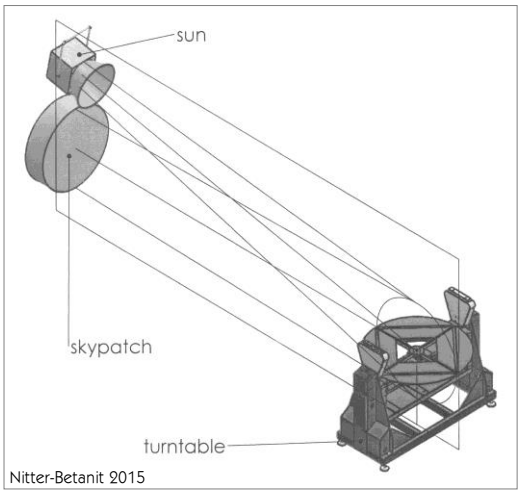
In the 1980s physical models largely were superseded by mathematical models, an event not unconnected with the proliferation of the personal computer and the digital mind-sets these engendered. Calculation techniques remain and continue to be developed (with the essential validation help of artificial skies), typically – it would seem - by engineers and physicists seeking PhD topics.

At this same time in the 1980s, though many schools of architecture turned away from building science in response to the rise of post-modern and deconstructivist ideologies, artificial skies never entirely went away. Indeed there was resurgence in the 1990s after P Tregenza [1987] defined a mathematical model of a sky vault sub-divided into 145 light patches or sectors in 8 equal altitude bands that could be represented by circular reflector lamps in closely-packed arrays mounted on an open hemispherical frame, typically of geodesic form. From their resulting patterned appearance – one of circular luminous peaks set in dark background inter-spaces with total lack of diffusion and even luminance gradation – these may be termed 'polka-dot skies'. In these, computer control of the lamp arrays is claimed to simulate a full range of sky conditions. However, often their relatively small diameter exaggerates scale and horizon errors and their inherent surface patterning gives rise to significant parallax errors in model measurements [J Mardaljevic 2002]. In addition patches of halation – 'star effect' – arise that can make nonsense of photometry [K Mansy *et al.* 2005].



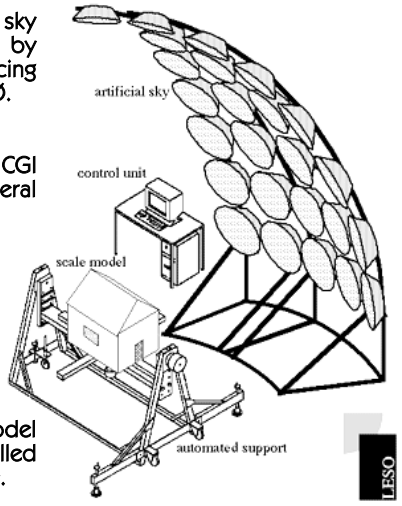
Above left: the 8m Ø 'polka-dot' domical sky with 640 lamps at the University of Wales, Cardiff (1999) and, on right, the six-sector, 270 lamp quasi-dome of 5.2m Ø at UCL Bartlett, London (2014). Another at UC Dublin is of 4m Ø with 145 lamps.

The Tregenza mathematical model, offering economy but too literally interpreted, appears to have readily seduced institutions seeking to build artificial skies. In consequence a whole rash of unsatisfactory 'polka-dot' skies was replicated by designers who mostly remain anonymous, with a dearth of published calibrations. The common and striking defect in these skies - strong surface patterning - has been partly overcome by a hybrid technique. Again relying on the Tregenza principle, a virtual dome is built by computer from an array of only 25 lamps in a one-sixth sector. With the addition of a 'sun' and with the subject model fitted with a special digital camera and set on a mechanized turntable, a digital image of daylight and sunlight light in or on a building for any time of day under any sky or sun condition can be digitally generated by multi-scanning. Subsequently P Tregenza [1989] varied his model to allow an array of 30 lamps on a single meridian or 'spotline' of a virtual 3.4m Ø hemisphere. This has been yet further extended to require but a single lamp to represent a patch of sky, with the model mounted on a fully rotating and tilting turntable. DC names these 'computer generated image (CGI) skies', though others prefer the terms 'virtual sky domes' (VSDs) or 'sky simulator domes' (SSDs).



Left: the 'Kiwi' single patch sky simulator (and heliodon) by Nitter-Betanit of Italy producing a virtual sky dome of 12m Ø.

Right: a 25 lamp segmental CGI sky simulator from the Federal Polytechnic of Lausanne.



In both the above, the model is set on a computer-controlled rotating and tilting turntable.

Though the above sky simulation approach was – and remains – relatively inexpensive and thus attractive, it is remote from the classical concept of an artificial skydome and – being more akin to calculation techniques – it is not further discussed in this paper. As an architect DC appreciates that, rather than rely on computer generated images, building designers often will prefer to make measurements and direct visual appraisals of daylighting in physical models under 'skies' clearly recognisable as such....

....and so it became necessary to 'de-spotify' the polka-dot hemispherical sky....

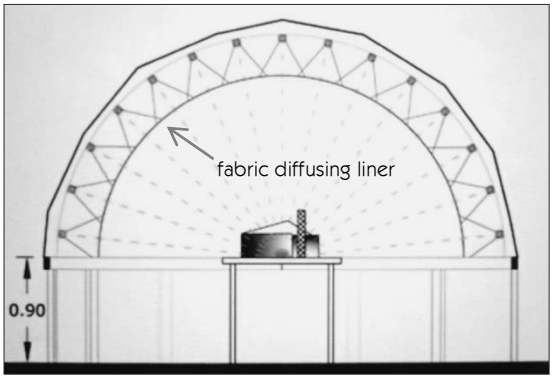
So between model with its photometers and the typically unshielded dome of glaring individual lamps in the 'polka dot sky', a diffusing membrane is introduced. Examples include inner domes of approx. 5m Ø at CRES in Athens (2006), of 4.2m Ø at OSU, Oklahoma (2007), and of 3.1m Ø at Thessaly University (2008). However these appear to be only partially successful due to proximity of lamps to inadequate diffusers and lack of reflecting – and light integrating – outer domes (as was provided at the CUSA Skydome). Indeed, at least two earlier attempts to build such transilluminated skies failed: one at the Institute of Building Physics in Moscow, a 16.8m Ø dome of 1986, and the other at the Sekisui Building Institute in Nara, Japan, a 5m Ø dome of 1997.
Of these latter two skies it is reported that "their designed luminance patterns were overwhelmed by luminance unevenness caused by extreme luminance of sources (hot spots) and unwanted dim (stripes) of the sky's structural elements. In combination these gaffes created insurmountable problems and these sky simulators were never commissioned or calibrated." [R Kittler *et al.* 2011].



Left & below: the 5m Ø transilluminated domical artificial sky at the Centre for Renewable Energy Sources (CRES) in Athens designed in 1996 by the Martin Centre, Cambridge and completed in 2006.
Luminance design is on the Tregenza model and, though a fabric diffuser is introduced, significant polka-dot and halation effects persist, giving uneven luminance distribution. In consequence performance likely suffers.



"Many of the artificial skies designed recently ignore the first requirement of luminance evenness and smoothness of a fluent natural luminance distribution."
[S Darula & R Kittler 2014]
DC concurs. Such consideration was the starting point in the design of the CUSA Skydome after experience of the care taken over this aspect by BRS staff in their mirror-box sky designs.

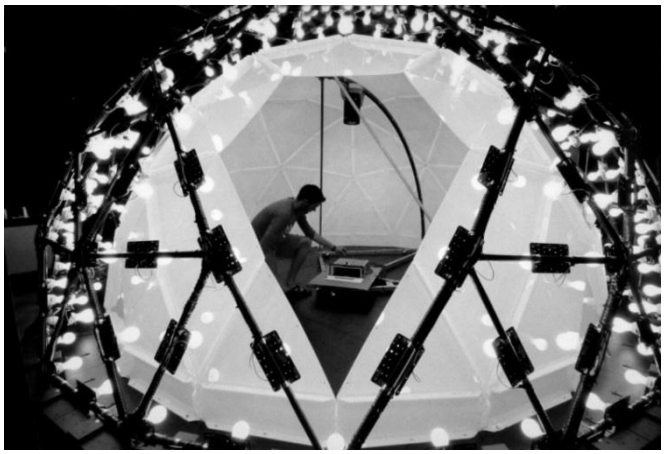


Left: section of the transilluminated domical artificial sky of 3.1m Ø at the Department of Architecture, University of Thessaly, Greece built in 2008.

DC has not seen report on the efficacy of this device but, as at CRES, likely it too will exhibit a 'polka-dot sky' lamp pattern on its fabric diffusing liner due to proximity of lamps.

It is the case that – much earlier in 1962 – an inter-dome space of 0.9m as adopted at the CUSA Skydome, with its reflecting inner surface of the outer dome and careful choice of diffusing plastics for the inner dome, ensured the elimination of lamp pattern and a smooth luminance gradation.

sectional drawing: K Vrontissi



Left: the transilluminated artificial sky built in 2007 at Oklahoma State University (OSU) comprising a geodesic lamp support frame and an inner 4.2m Ø geodesic dome of translucent diffusing 'Lexan' plastics in flanged self-supporting panels reminiscent of the 1962 CUSA Skydome.

Judging from the photo, lamp diffusion is effective. However, claim in designer K Mansy's CV to be "first to a new model design of artificial sky dome" seems over-optimistic.

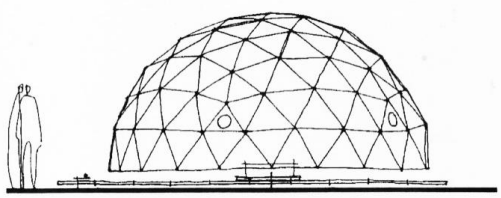


photo & drawing on right: OSU website 2015

....thus the transilluminated domical artificial sky was re-introduced nearly 45 years after its original appearance in Cambridge, but not always with the latter's efficacy....

Indeed, as above, examples of transilluminated skies in Russia and Japan completely failed and a whole generation of 'polka-dot' designs, with or without added diffusers, are distinctly suspect in terms of their suitability for photometric model studies or even visual evaluation.

(5) what of the other types of artificial sky: mirror-lined box & reflecting dome?

They both remain. Mirror-box skies of 'walk-in' dimension are popular and found in many universities, and indeed no school of architecture or architectural practice need be without, for these are available 'off the peg' in self-assembly form and are relatively inexpensive. However they cannot simulate conditions other than the CIE Standard Overcast Sky and in consequence their use is limited to basic undergraduate teaching. Reflecting dome skies are more flexible in application and versions of these also are commercially available, but of relatively small diameter with nothing known of their performance. Certainly the important 8m Ø dome of 1973 at Bratislava remains and after 40 years in use continues to be developed, latterly with an electronically-controlled LED lighting system [S Darula & R Kittler, 2014]. On completion it will be arguably the world's only fully effective, truly domical artificial sky.



photos: IDL website 2015



A large 'walk-in' mirror-lined box sky of 2012/13 at the Integrated Design Laboratory (IDL), University of Idaho that well-illustrates the inherent problem with inter-reflections in this type of sky: people and models are replicated to infinity, making simulation of external obstructions inexact.



photos: websites 2015

Left: The Hanyang University (S. Korea) 6.5m Ø skydome.

Standard artificial skies seem likely to become more common in view of the high cost of 'specials'. In addition to mirror-box skies, two reflecting domes are commercially available: the 4m Ø model AS-DO-201 from SVG-TECH of Selangor, Malaysia and (below) the 3.5m Ø model JT-1 from Beijing JT Science & Technology Co Ltd of China (costing $18,600).
However potential purchasers should be aware that such small diameter skies have limitations for serious work.

It is difficult to assess how seriously these are being marketed as their agents have failed to respond to requests for full details and good definition photos.



(6) a prediction for the future.....

Artificial skies for serious research that requires simulation of sky luminance conditions other than the CIE Standard (non-uniform) Overcast Sky are domical, and such a form immediately introduces structural considerations: this is not an easy shape to produce whatever the size. In the event also they must be large: ideally not less than about 7.5m Ø to limit errors arising from finite size, notably those of horizon, scale and parallax. Their artificial lighting should be colour-corrected and powerful to achieve high levels of illumination and it must be capable of accurate control to smoothly simulate required ISO/CIE luminance patterns (of which there are now 15). Inevitably such skies are space-consuming, complicated and expensive, and the temptation is for institutions desirous of acquiring such a facility to compromise. Usually it is size that first suffers reduction as building space is always at a premium. Where no successful domical sky has yet exceeded 9.2m Ø, it is here proposed that a size of the order of 12m Ø should be attempted to reduce inherent errors to inconsequential levels. Such a sky likely could be contemplated only on a national, even a supra-national level, as is the situation today with expensive equipment for astronomy, particle physics and space exploration. Though the costs involved in creating an ideal 'super sky' would be nothing like those arising in those other fields, the benefit of replication of advanced skies would be difficult to justify as the volume of top-flight research work or of high-value commercial consultancy is not great.

One of the problems – more a strength – of working with an effective artificial sky is the relative simplicity of the procedures involved. Given a properly designed and prepared model and a competent 'sky lab' technician, the required assessments of even a quite complex building model usually may be made in a few hours. The key becomes the model itself, with elements such as precise scale and representation of fenestration and surface reflectances being of prime importance. These can be fully resolved away from the lighting laboratory/artificial sky by means of training course and manual, and likely computer-controlled laser profile cutting and 3D printing will achieve wide application, particularly in the accurate representation of interior features and glazing frames. Given such preparation, the transfer of a model to what might well be a national artificial sky facility of heroic dimensions and technology for testing should be no great problem. A 'time slot' for processing would be booked in much the same way as today the use of a powerful main-frame computer is offered. Such procedure gains acceptance once it is appreciated that an artificial sky is an analogue computer.

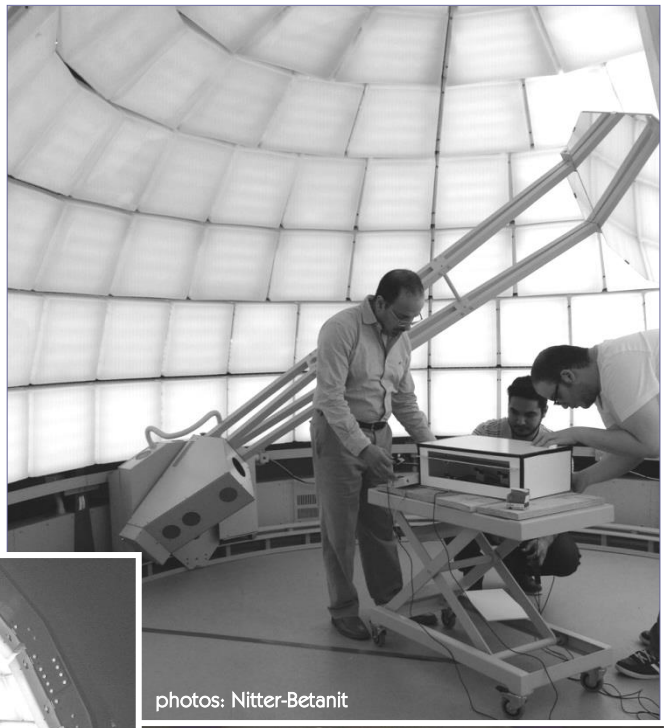
....a recent artificial sky that likely contains an essential germ for the future:

Right: skydome with heliodon at the University of the UAE at Abu Dhabi designed and manufactured by Nitter-Betanit of Piacenza, Italy in 2014.

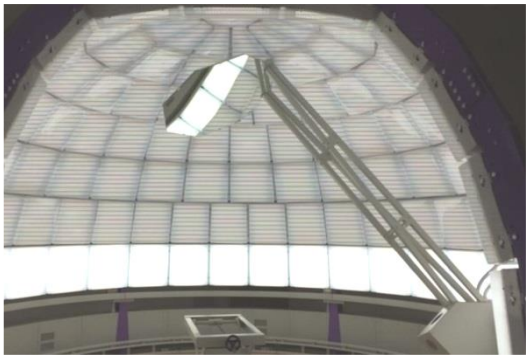
The hemi-dome is 4.2m Ø internally and raised 0.65m above floor level. There are 145 lighting modules of 8 sizes (each about 400x430x126mm) set on the Tregenza principle, each with 450 LEDs in a mix of cool and warm white giving a loading of 120W. Total electrical load is a relatively modest 18kW. Each module is microprocessor regulated with an integral 2mm thick white poly-carbonate diffusing 3D face panel thermo-formed to illuminate the inter-panel seam, reducing the pattern of joints.

The sky is controlled by PC to simulate a wide range of sky conditions.

Sole reliance on use of LEDs in the modular lighting elements is novel and important.







photos: Nitter-Betanit

The above example of a recent transilluminated artificial sky suggests that adoption of LED lighting – with its characteristics of multiple small sources, low power demand, low heat output and controllability that may be encapsulated in self-diffusing modular elements of modest thickness – has useful potential for such devices on much larger scale that offer good prospect of increased accuracy and flexibility. It is confirmed by designer GM Podesta of Nitter-Betanit that such modules may be formed in a variety of shapes and sizes without undue difficulty and installed as facets to follow a generally domical surface. Modules may electrically-linked, thermally-monitored and computer-controlled to enable the simulation of any sky condition for any place at any time of day with smooth and stable gradation of luminance distribution.

From such considerations, the outline description of a future LED 'super sky' might be:

The sky has an effective diameter of 12 metres based on a geodesic tubular framed octahedral hemisphere of 8v division frequency giving strut lengths in the range of 700 to 980mm. Triangular, pixelated LED lighting modules, with integral diffusers, are fitted to each of the 640 triangular spaces so formed. Depending on choice of actual luminaires, other support frame geometries may apply. This transilluminated lighting dome is raised 1.5 metres above working floor level.

As such a structure 7.5 metres high (with, in addition, all round access space) is difficult to house within a usual laboratory, it is proposed as an individual building. Accordingly there is a weatherproof and insulated outer domical enclosure of similar geodesic geometry but of frameless, self-supporting anodized aluminium panel construction. This is 14 metres in diameter and 8.5 metres high to provide an inter-dome void of not less than 900mm for luminaire ventilation and maintenance. Within this space is fitted a rotating rigid access ladder of curved profile tracking 100mm clear of the inner dome and its lighting modules.

The LED lighting modules – likely based on efficient Galium Nitride-on-silicon (GaN-on-Si) - are fully addressable wirelessly by computer and designed to produce colour-corrected sky simulations of evenly graded luminance for any hour of any day at any place (with characteristics adhering to the 15 standard ISO/CIE sky types). A computer-controlled heliodon is included.

In the centre of this sky is a workbench 1.5 metres square with adjustable height. The operative part of any building test model set at the dome's centre is limited to 1.0m x 1.0m x 0.5m high (8% of the dome radius) to largely obviate parallax error. Overall the installation provides a working horizon at approximately 10° and is air-conditioned to regulate lamp heat and eliminate dust. The structure is fire-resisting, fully alarmed and provided with an alternative escape route.

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Tregenza P. [1987].
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end of paper 1

paper 2

Daylighting by design:
some early examples of the use of an artificial sky

The interior daylighting of buildings may be studied at design stage in scale models by observation and by measurement of light levels, as daylighting is scale-less.
Such work may be attempted under the natural sky, but its luminance is continually varying and consistent results difficult to achieve. Accordingly 'artificial sky' simulators are preferred.

Architects in the UK first began to undertake such studies in the late 1950s using special photometers developed by the Building Research Station (BRS) at Garston, Watford. This government establishment had an artificial sky from 1954, but it was of small size: a top-lit, mirror-lined rectilinear box measuring 1.2m x 0.9m & 0.6m high. This was not available for general use and in any event was not suitable for testing other than simple side-lit rooms (though later, in 1963/64, a 'walk-in' version was built).

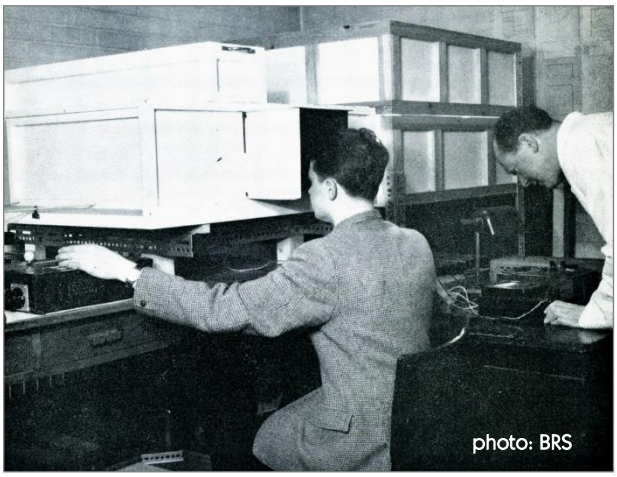
Elsewhere, notably in Russia and Texas USA, there were much larger artificial skies: respectively, a 9m diameter hemispherical dome (from 1943) and a 5.8m diameter hemi-ellipsoidal dome (from 1955). In these skies luminance was simulated by reflection from the whitened inner surface of the domes, with the source lamps set around the perimeter (invariably to the marked detriment of operational floor space).

Architects in the UK concerned with complex designs, such as unusually deep plans or roof-lit buildings had no such devices available at that time and were limited to working with models under the natural sky or relied on intuition or rule-of-thumb.

In 1959 the author (DC), having experienced the difficulty of outdoor measurement in models and also the limitations of the small BRS 'sky' (which he was loaned over 1958/59), designed an artificial sky at the Cambridge University School of Architecture (CUSA) as part of a PhD project. This was completed in mid-1962 and introduced the novel concept of the 'transilluminated domical sky' in which carefully located lamps were set outside and around a diffusing dome of translucent plastics, leaving the floor area entirely clear for operatives and student groups. The internal diameter was 7.6m, large enough usefully to limit inherent errors due to finite size. The whole was enclosed within a weatherproof outer dome of 9.5m diameter.

The examples of early model studies that follow include several made by DC prior to the availability of the CUSA 'Skydome' and others made by him or with his participation in the first few years following its commissioning. These range from design projects to buildings of national importance. Few, if any, of these designs could be satisfactorily resolved – then or now – by calculation techniques or digital computer simulation.
Also there are examples of 'daylight by design' that did not involve actual model studies under an artificial sky, but which depended on experience gained with this technique.

the only artificial sky in the UK in the late 1950s was at the BRS:



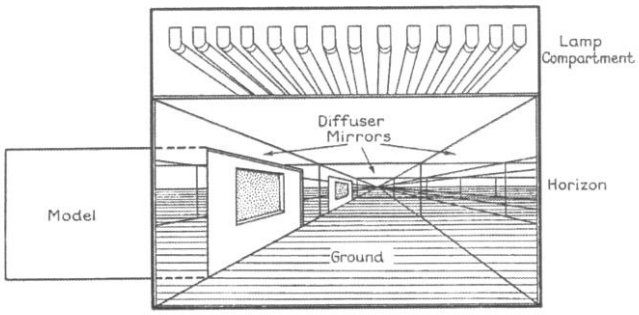
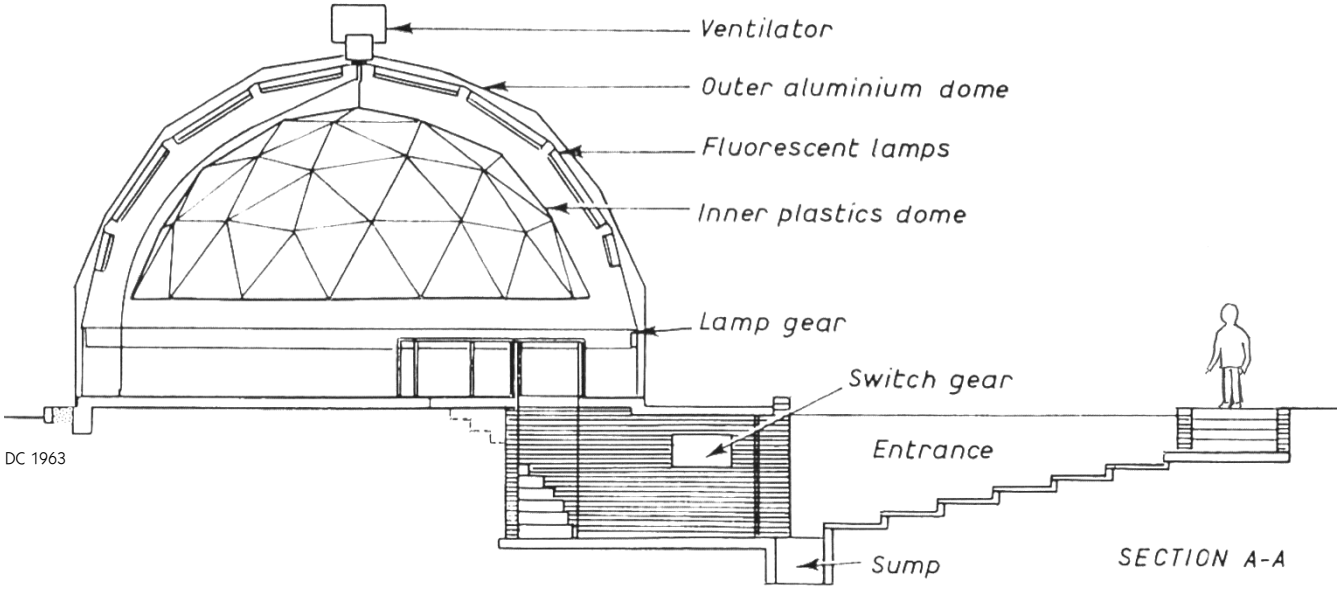


FIG. 15.4. The principal features of a small rectilinear mirrored artificial sky.

Above: schematic drawing of the BRS mirror box 'sky' of 1954
[from *'Daylighting'* by RG Hopkinson *et al.*, 1966]
Left: staff of the BRS Lighting Section at work with the BRS sky at Garston in 1958. The mirror-box sky was 1.2m x 0.9m x 0.6m.

DC's proposed research at Cambridge required a larger and more advanced device, so first he had to build one:



section of the CUSA 'Skydome' built in 1962: the first transilluminated artificial sky

The lamps are placed outside an inner diffusing dome of 7.6m Ø representing the sky vault and which displays luminance evenly graded 3:1 from zenith to horizon (an international standard). There are no disturbing reflecting mirrors and floor space is largely unobstructed. The underground access was planned to avoid disturbing the artificial sky's horizon.

For further details of the 7.6m Ø CUSA 'sky' see:

Croghan D. [1964a]
The design of an artificial sky,
The Architects' Journal, London 22/07/1964, pp.215-220.
Croghan D. [1964b]
Transilluminated domical artificial sky,
Light and Lighting, London 10/1964, pp.290-293.
Croghan D. [1964c]
Skydome at Cambridge,
The Builder, London 9/10/1964, pp.752-754.

The above papers each emphasize different aspects of particular interest to the target readership of the journals. An e-version of each of the papers is being made available.



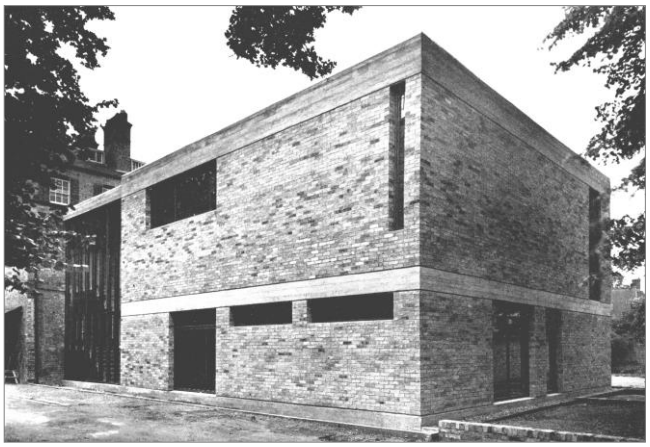
daylighting by design: example A

extension to the Cambridge University School of Architecture

Extension built in 1958/59 to the design of staff members Colin St.J Wilson and Alex Hardy. The latter was tutor in building science and at design stage in 1957 invited DC – then a 4th-year graduate student – to assist with the design of natural lighting by building a 1/6th scale model of the first floor and its roof-lighting system that was large enough to be used for the visual appraisal of the fall of daylight internally and also for photometric assessment.

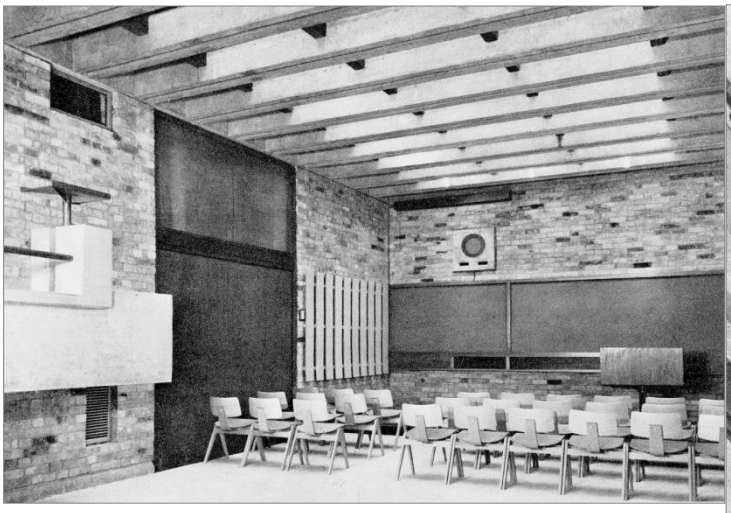
The standards required were even daylight factors horizontally at 900mm above floor level of 6% in the criticism room and 4.5% in the lecture room with, in both cases, not less than 2% DF vertically on the wall display panels.

The photometric study was carried out by DC at the Building Research Station (BRS) at Watford using an EEL/BRS Daylight Factor meter under the natural sky (as the BRS artificial sky was unsuitable for use with roof-lit buildings). BRS staff, notably J Longmore and P Petherbridge attended. (see footnote)



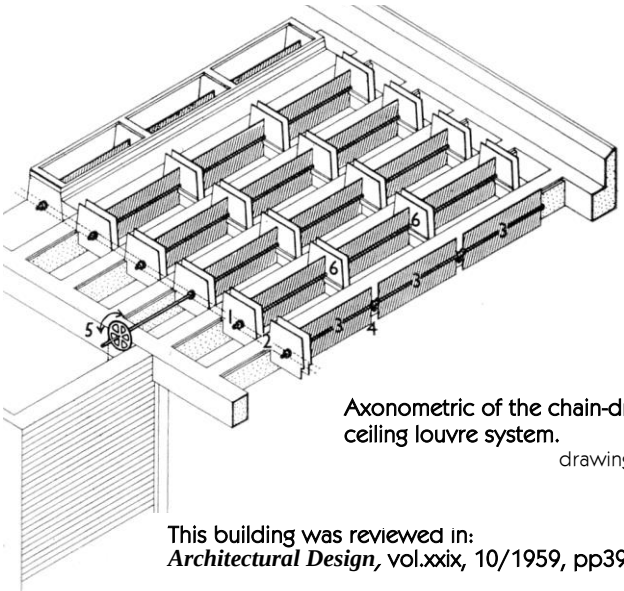
The 1959 extension at the rear of the School of Architecture at No.1 Scroope Terrace, Cambridge.

Below right: In the rooflights ply louvres on steel spindles are motorised to close & provide black-out conditions when required.





The lecture room. Here and in the criticism room the preferential daylighting of the slatted display panels was achieved by adjusting the width (on the model) of the solid margin of the ceiling structure.

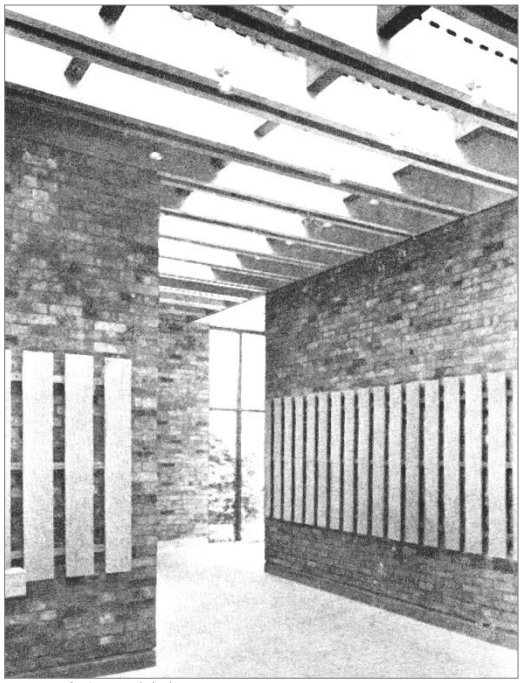


Axonometric of the chain-driven ceiling louvre system.

drawing: DC

This building was reviewed in:
Architectural Design, vol.xxix, 10/1959, pp395-399

Above: detail of roof lights. *Key:* **1** *two sprockets on one end of spindle* **2** *chain with adaptable linkage* **3** *three spindles spliced and pinned to receive ply louvre* **4** *patent connection: spindles need not be precisely centred on each other* **5** *drive sprocket to motor* **6** *brass bush*



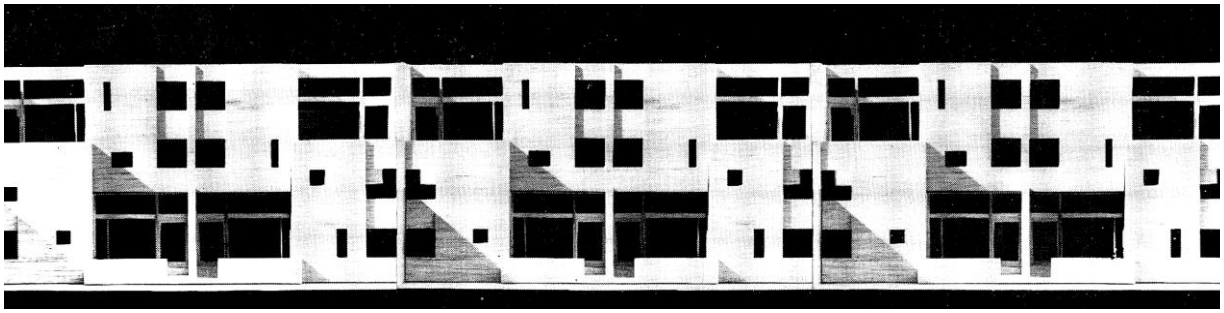
Part of the criticism room all photos: AD 10/1959

footnote: This is believed to have been the first photometric model study carried out in the UK by a designer outside the civil service.

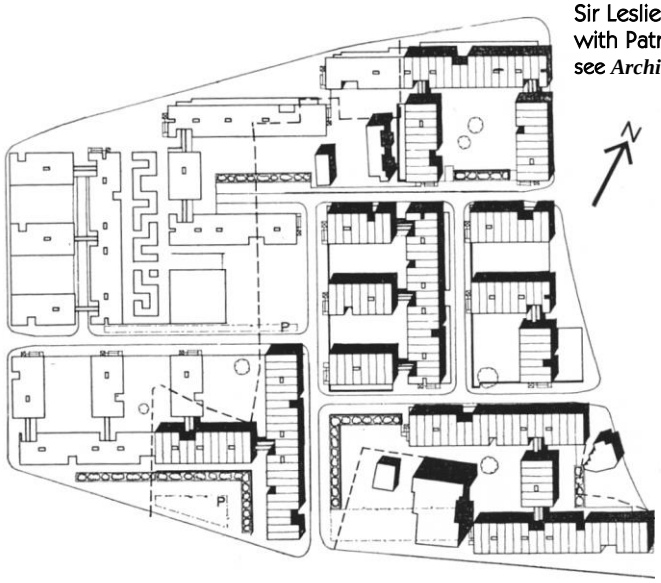
daylighting by design: example B

project for housing re-development in St. Pancras, London (1958)

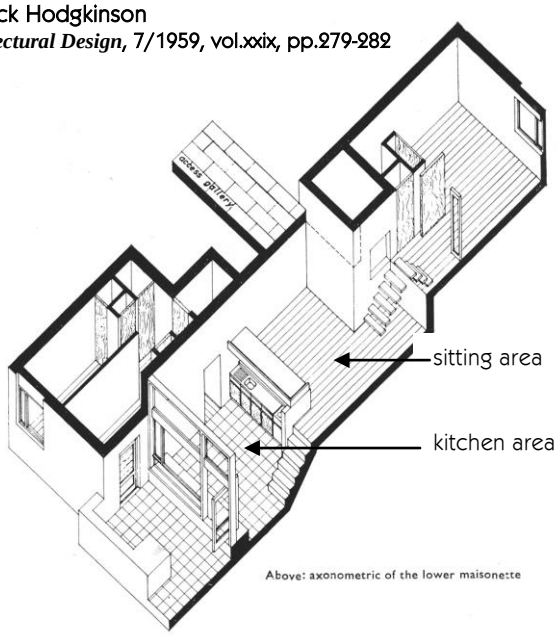
an innovative design for low-rise, high-density (136ppa/336ppha) terraced housing



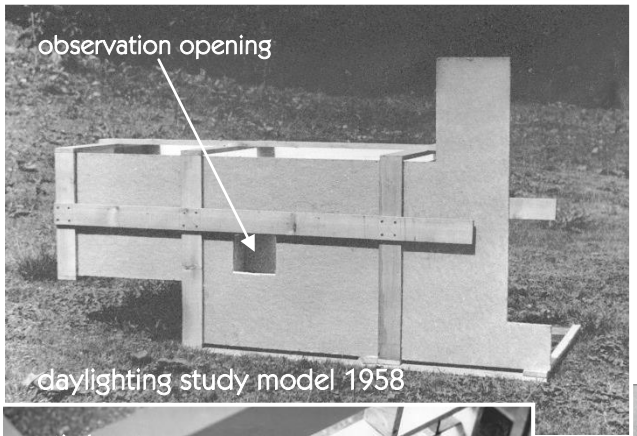
Sir Leslie Martin and Colin St.J Wilson, architects,
with Patrick Hodgkinson
see *Architectural Design*, 7/1959, vol.xxix, pp.279-282



Layout A: the 4.7ha (11.6 acre) site developed with 3½-storey dual aspect blocks of interlocking maisonettes set out in courtyards.

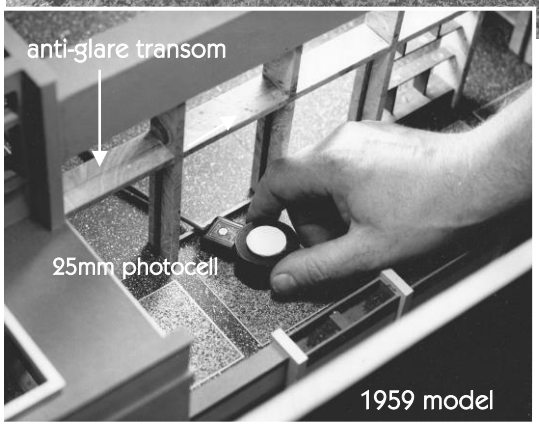


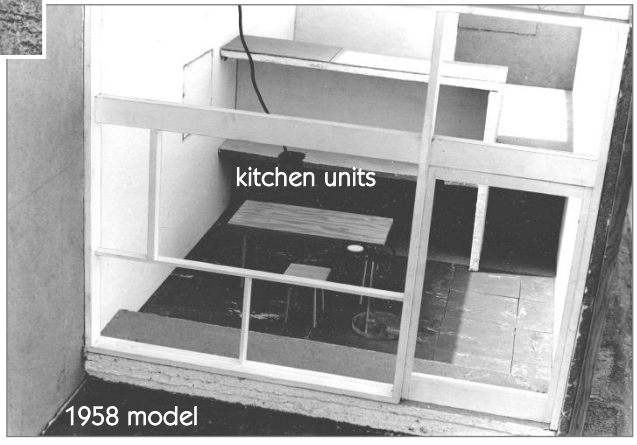
Above: axonometric of the lower maisonette



In the summer of 1958 DC was working as an architectural assistant in the practice office of Sir Leslie Martin when concern arose over adequacy of day-lighting in kitchen and also sitting areas of the lower of the two split-level maisonettes in the 15m deep block.

DC constructed a 1/6th scale model of these areas for subjective appraisal and photometric testing under the natural sky at the BRS (and again at Cambridge in 1959). Though conditions in the original design were satisfactory, improvements were made: an L-plan kitchen unit layout and a sky-glare limiting wide window transom.

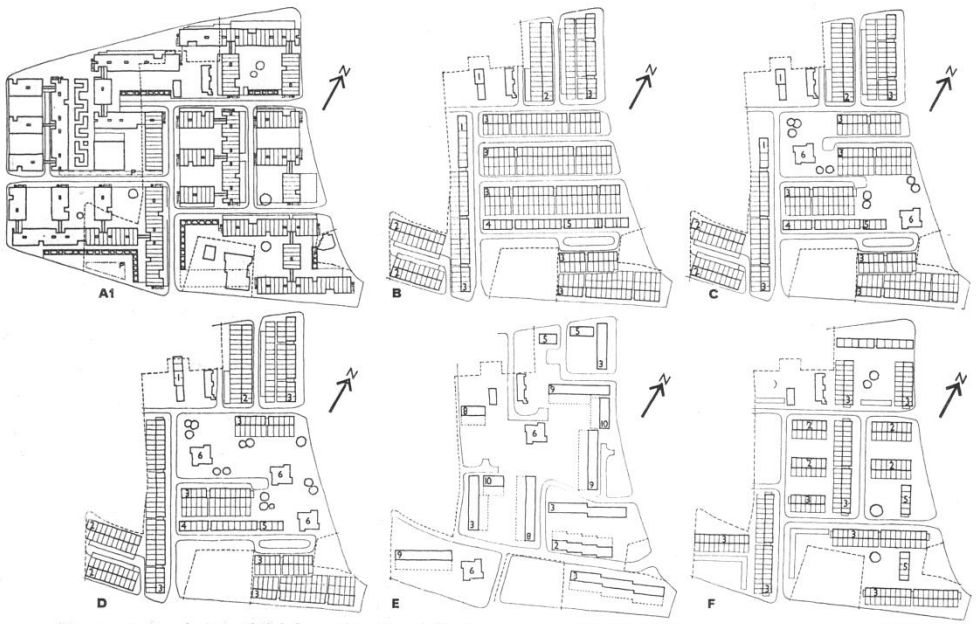




photos & drawings: DC

example B continued:

Comparative analysis (below) of different types of housing development on the NW London St Pancras site showing number of units, type of accommodation in terms of number of bedrooms, and amount of private and public open space provided for each dwelling. All layouts satisfied similar, then current, criteria for estate roads and block spacing (the latter based on ensuring natural lighting). This study developed by DC was well received by Sir Leslie Martin and, together with that in example J below concerning office development, may be among the strands later leading (in 1967) to the establishment of the Centre for Land Use and Built Forms Study (LUBFS) at the CUSA.



Above: alternative layouts for the same site in St. Pancras, using various standard housing types compared to the new 3 storey interlocking maisonette unit shown in **A & A1** *Key: 1 3 storey 1 bedroom flats 2 2 storey 4 bedroom houses 3 4 storey 2 and 3 bedroom maisonettes 4 2 storey bed-sitting room flats 5 3 storey bed sitting room flats 6 11 storey 1 and 2 bedroom flats 7 4 storey 1 bedroom flats 8 6 storey 2 and 3 bedroom maisonettes 9 8 storey 2 and 3 bedroom maisonettes 10 3 storey 4 bedroom houses*

		Accommodation provided				Total No. of dwellings	No. of units of private open space	Av. size of private open space where private open space is provided	Area of usable public open space per dwelling	Total area of open space per dwelling	No. of cars	Area of site	Net density
		BS	1B(d)	2B (2d) & 3B (2d.1s)	4B(2d. 2s)			ft. in. ft. in. sq.ft	sq.ft.	sq.ft.			
A	Development Illustrated	40	40	280	40	400	400	8 6×12 6 : 106	252	100% have 358	100	11·58	125
A1	As above, with additional block	44	44	305	44	437	437	8 6×12 6 : 106	234	100% have 340	100	11·58	136
B	Development to a max. density with 2-, 3-, and 4-storey terraces using standard plans	38	42	280	37	397	255	15 10×30 6 : 554	nil	64·5% have 554 35·5% have nil	115	11·58	123
C	Development with terrace types as in B, using in addition two point blocks	38	40	282	37	397	214	15 10×30 6 : 554	172	54% have 726 46% have 172	115	11·58	123
D	Development with terrace types as in B, using in addition three point blocks	44	44	305	44	437	200	15 10×30 6 : 554	158	46% have 712 54% have 158	115	11·58	136
E	Development using terraces, slab blocks, and point blocks	21	82	318	23	444	122	15 10×30 6 : 554	315	28% have 869 72% have 315		11·58	138
F	Development of site layout as in **A** using standard 2-, 3-, and 4-storey terraces	30	30	220	30	310	140	15 10×26 0 : 410	252	45% have 662 55% have 252	100	11·58	97

Notes

In **B** 142 dwellings have no private open space; 63 of these are family maisonettes. 78 upper maisonettes have no direct access to their garden plots.

In **C** 184 dwellings have no private open space; 106 of these are family maisonettes. 55 upper maisonettes have no direct access to their garden plots.

In **D** 237 dwellings have no private open space; 139 of these are family maisonettes. 50 upper maisonettes have no direct access to their garden plots.

In **E** 322 dwellings have no private open space; 219 of these are family maisonettes. Only ground floor dwellings have private open space.

In **F** 170 dwellings have no private open space; 110 of these are family maisonettes. Only ground floor dwellings have private open space.

In **B, C, & D** little account has been taken of phase II development, the requirements of which would almost certainly reduce densities attainable in phase I.

In all layouts recommended carriageway and pavement widths, curb radii, splays at road junctions, and block spacing are observed.

drawings & table: DC (as published in ***Architectural Design***, 7/1959, vol.xxix, p.280).

The context of this novel design is one in which the prevailing form of urban residential development at high density (i.e., over 100 ppa/250 ppha) was high-rise flats. It was generally assumed that high-density necessitated high-rise building, and government housing subsidy was based on this false assumption. In 1958 Alton Park West estate in Roehampton had only just been occupied and Alton Park East neared completion, both typical of the designs emanating from the Architect's Department of the LCC that had been headed by (the then) Dr JL Martin until 1956, when he was appointed to the Chair in Architecture at Cambridge. Though Sir Leslie Martin's views had advanced, subsidized high-rise flats were to remain the general fashion until the collapse of the 'Ronan Point' tower in 1968. It was lack of subsidy that sealed the fate of the St Pancras project.



Typical LCC high flats in 1958

Left: Alton Park West.

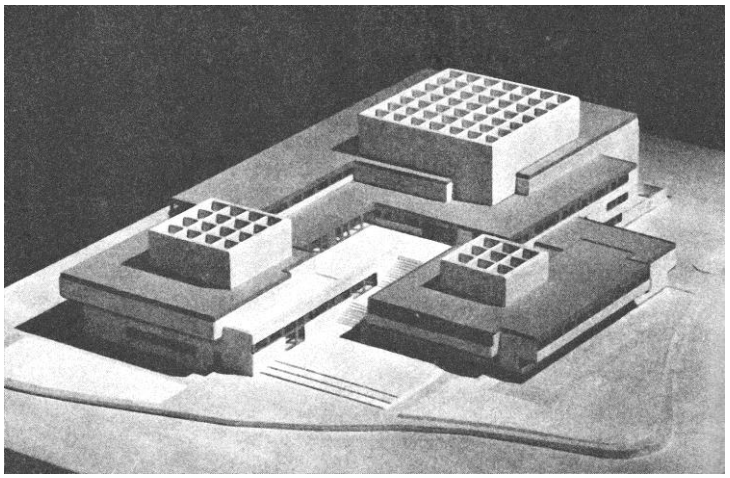
Right: Alton Park East



photos: www

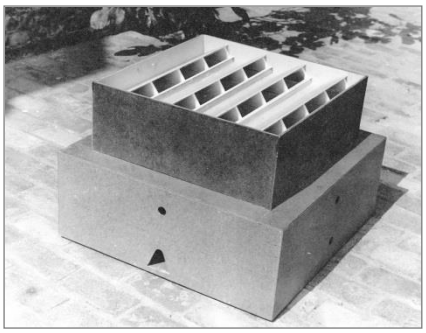
daylighting by design: example C

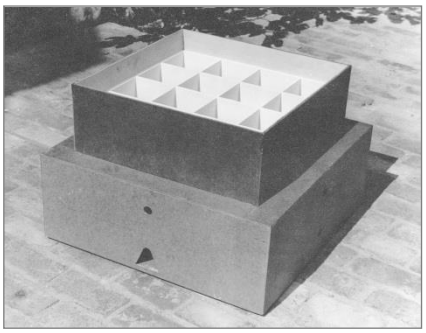
library complex for Oxford University

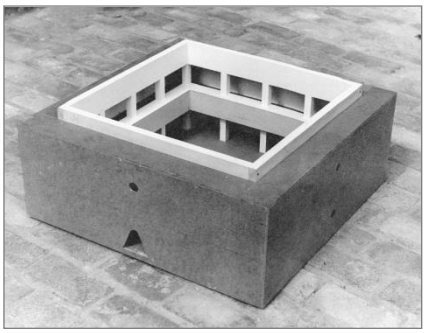


1960 design model of the proposed Law, English and Statistics library complex at Manor Road, St. Cross, Oxford
Sir Leslie Martin with Colin St.J Wilson and Douglas Lanham, architects.
complex completed in 1964.

DC was appointed consultant for natural lighting at detailed design stage in 1961.







Above: three photos of 1/24th scale model of the English Library reading room and adjacent bookstack areas made for visual appraisal of daylighting and photometry using an EEL/BRS Daylight Factor meter under the natural sky as no artificial sky of adequate size was yet available.



photo: AD 10/1960

Left: the finished building: English Library Reading Room

In an appraisal of the building in the *RIBA Journal* of 11/1966, pp.505-510, critic Geoffrey Robson observes of the Law Library Reading Room that its "even lighting is remarkable" and that the building overall is "uniformly well lit."

photos: DC



Above: the finished building:
view into rooflight of the Statistics Library Reading Room.

The relatively great depth of the ceiling beams arises as, acting as louvres, they prevent direct sunlight reaching the reading areas and bookshelving.

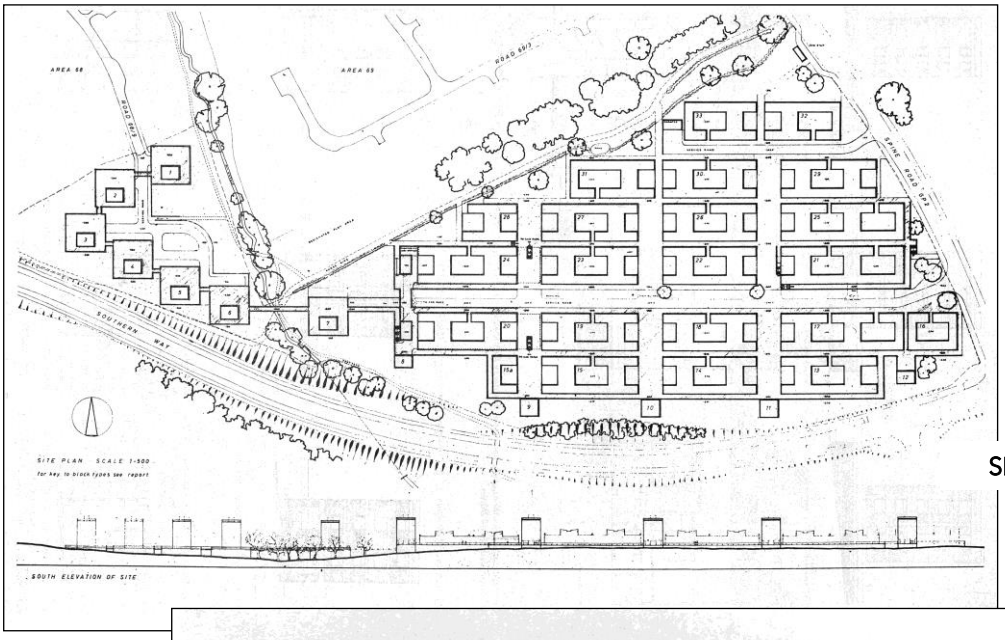
Below: the finished building: main entrance to complex



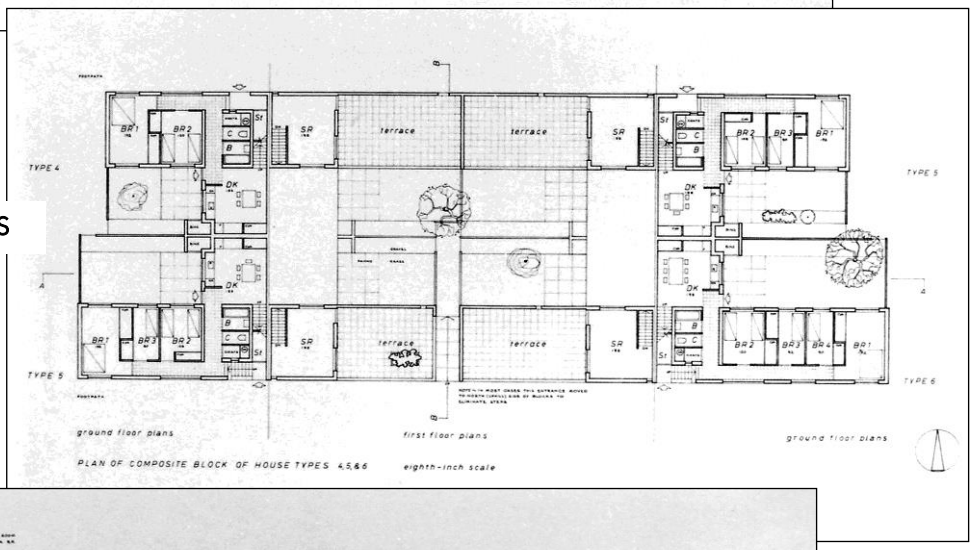
daylighting by design: example D

housing project for Area 71 at Great Parndon, Harlow, Essex (1961)

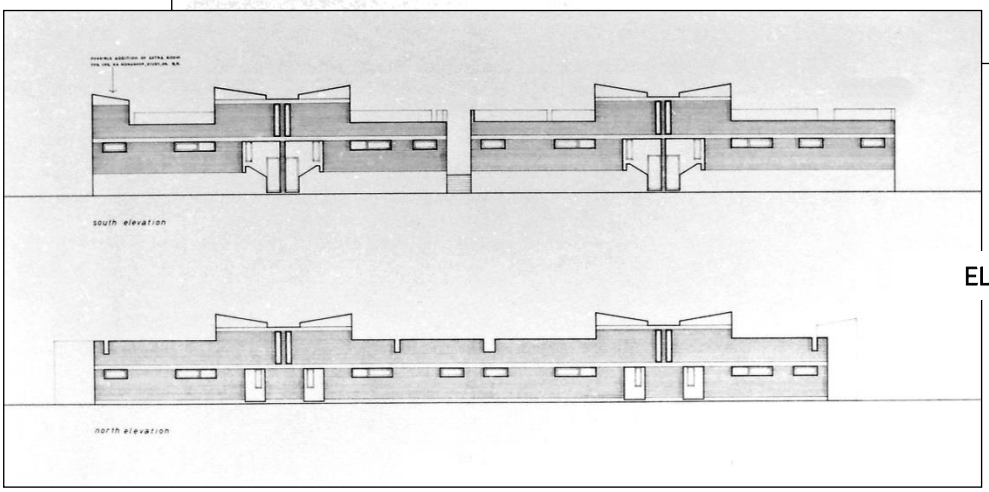
a medium density (65 ppa/160 ppha) layout in which good daylighting was integral to the design



SITE PLAN



FLOOR PLANS

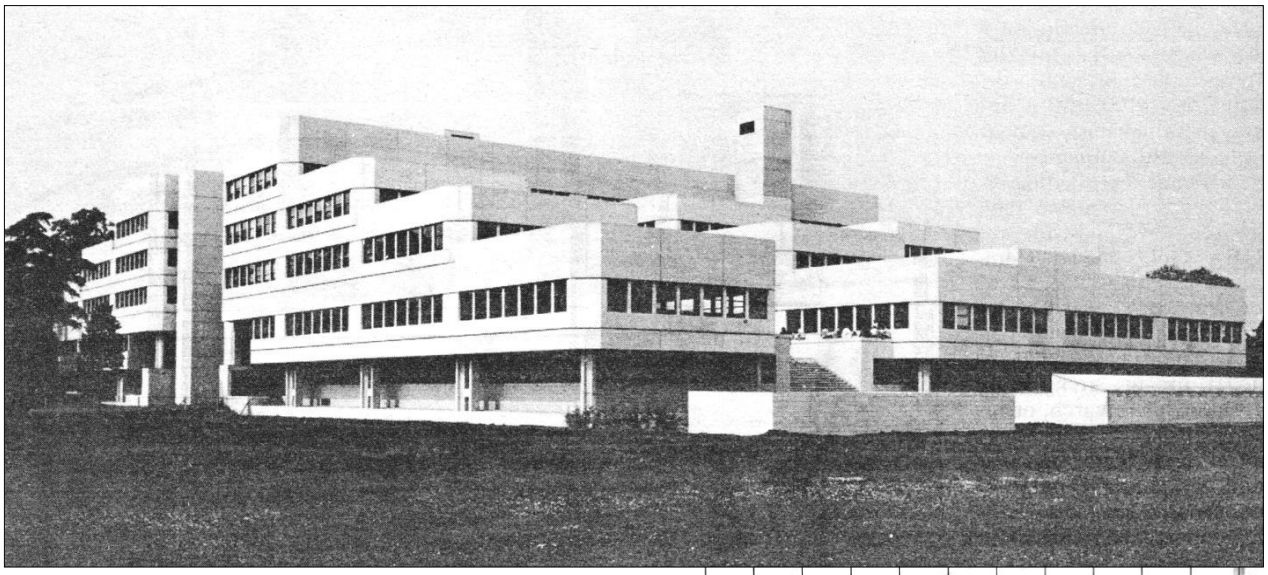


ELEVATIONS

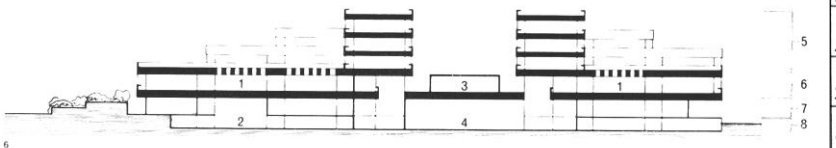
This design by DC for low-rise medium density cluster blocks of mainly 2, 3 & 4-bedroom courtyard houses was entered in a 1961 national architectural design competition and placed third. The basic element of a double H-block comprises 8 dwellings and demonstrates that design freedom can result in improved standards of daylighting. Where official standards would have permitted a 25° angle of daylight obstruction to any window of an habitable room, in this case the highest angle is 14°, and this is determined by the block form itself, not by surrounding buildings outside the designer's control, as often is the case. Any apparent austerity in layout geometry on plan would be mitigated in three-dimensional reality by a rise of about 12.5 metres diagonally SW to NE across the site.

daylighting by design: example E

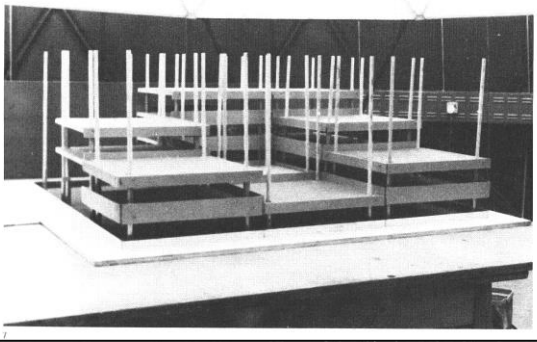
science buildings for Oxford University

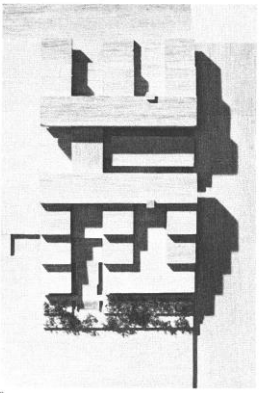


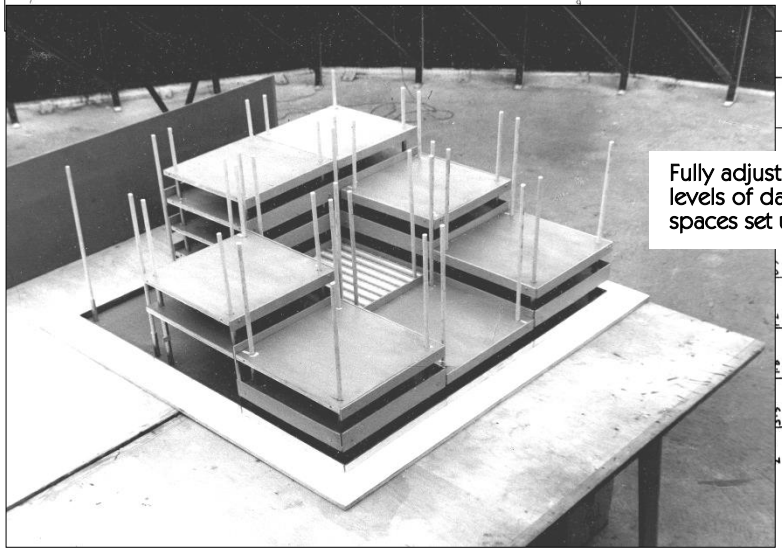
University Zoology and Psychology laboratory buildings
at South Parks Road, Oxford (the Tindbergen Building).
by Sir Leslie Martin and Douglas Lanham, architects.
DC was appointed consultant for natural lighting in 1963.
About 1/3rd of the proposed megastructure was completed in 1971.



Section, block model and daylighting test model as published
in ***Architectural Design***, 12/1964, vol.xxxiv pp.595-602







Fully adjustable model for measuring
levels of daylight in deep laboratory
spaces set up in the CUSA 'Skydome'.

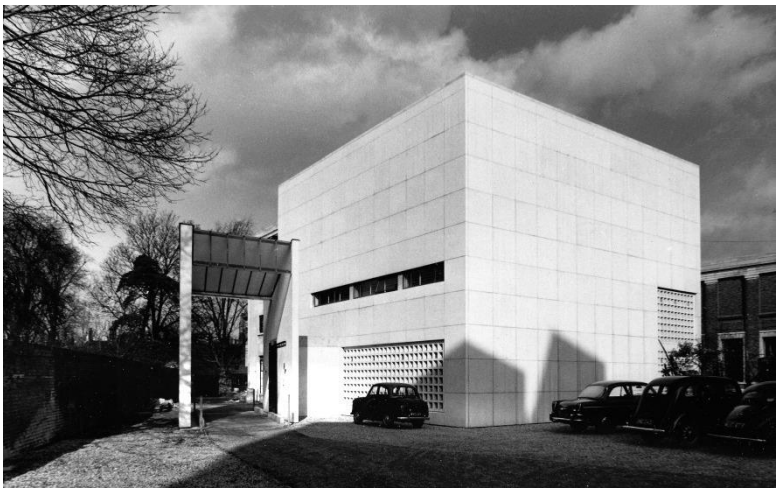
Part of the results chart showing measured
daylight factors plotted on floor plan grid.

lower two photos: DC

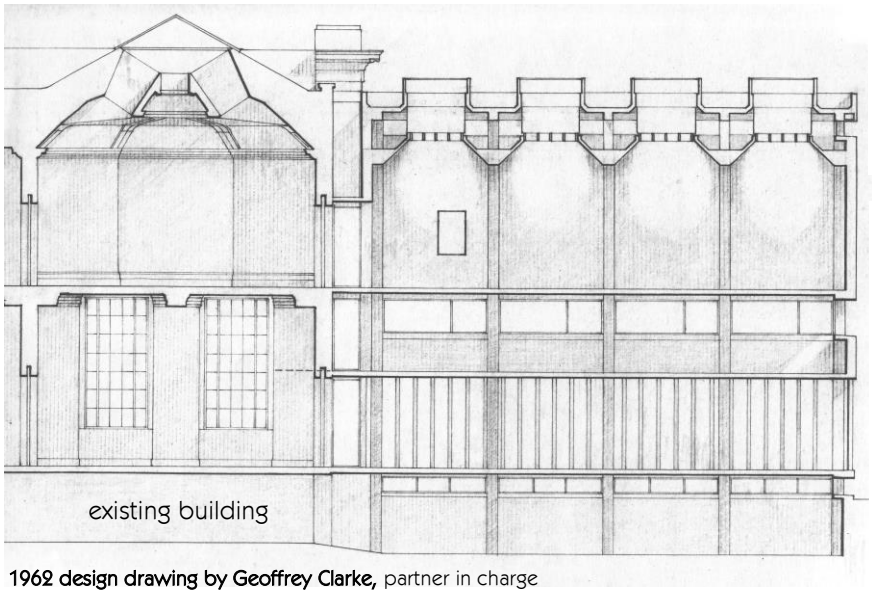
new gallery for the Fitzwilliam Museum, Cambridge

Extension to the Fitzwilliam Museum, Cambridge by architects David Roberts & Geoffrey Clarke. It was built between 1963 & 1965.

In 1962 DC was invited to consult on the design and natural lighting of the top-lit upper floor Loan Gallery (now the '20th Century Gallery'). Appraisal of a preliminary design by model study in the Cambridge 'Skydome' indicated that lighting distribution on the display walls would be uneven (see below). Working with job architect James Madge, DC developed a successful remedial design for the coffered ceiling in 1963.

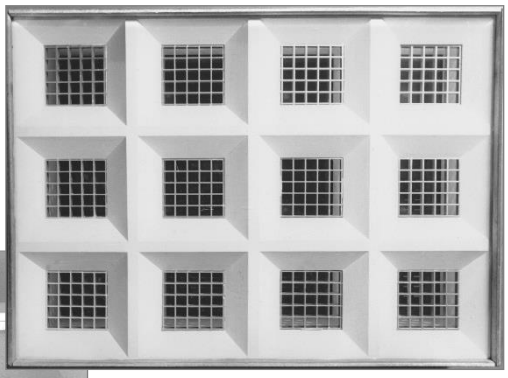


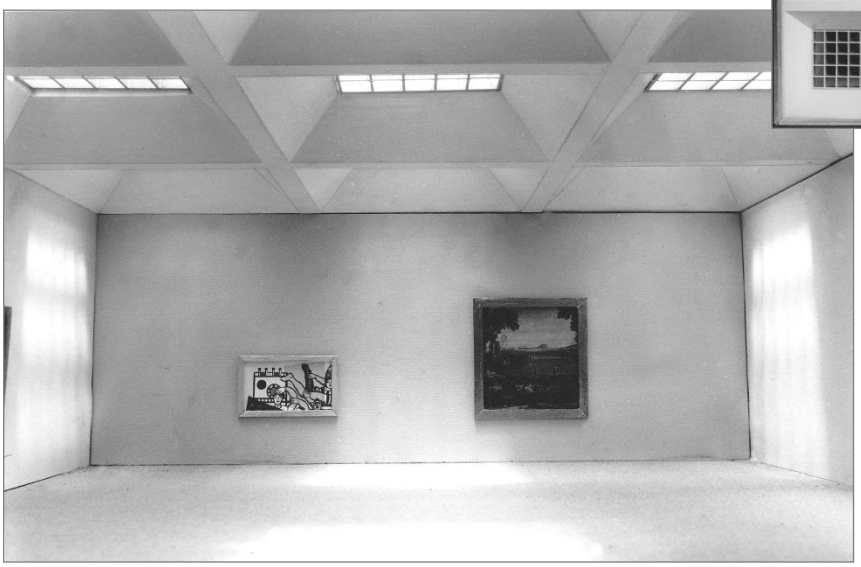
"...an immaculately white cube..."
N.Pevsner, *'The Buildings of England'*



1962 design drawing by Geoffrey Clarke, partner in charge

Below: 1/24th scale model of the first (1962) design for the proposed new gallery for the Fitzwilliam museum shows unsatisfactory distribution and excessive contrasts of daylight falling on walls and across the floor. As a direct result of this test, the coffered ceiling was re-designed in 1963.

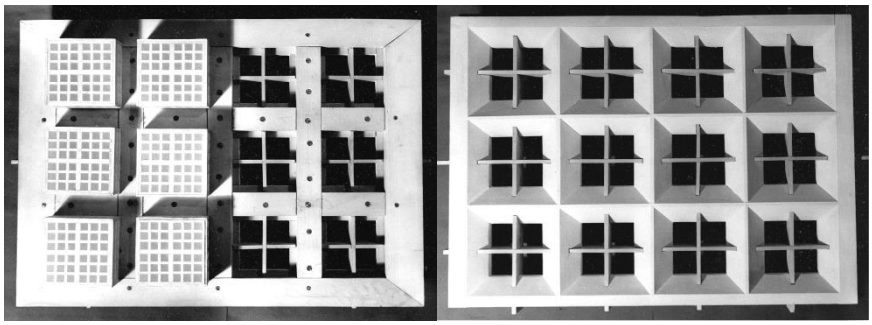




Above: model of coffered ceiling with louvres that produced the unsatisfactory daylight distribution evident in the view of the interior on left.

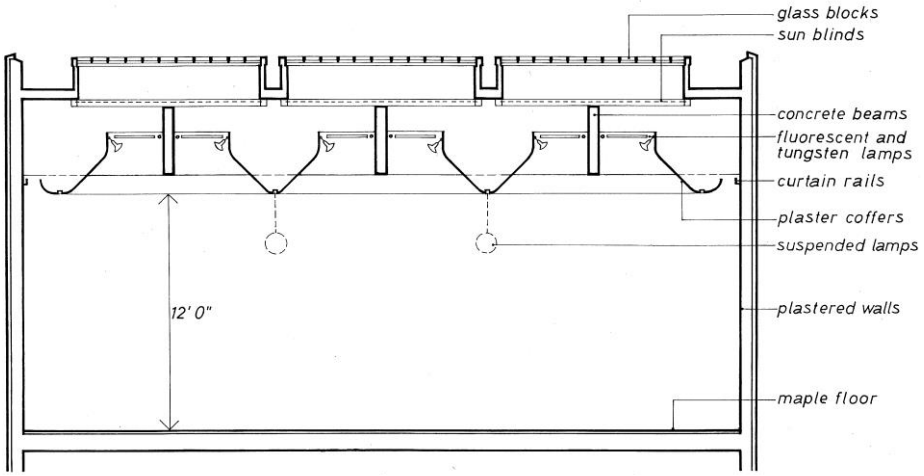
photos: DC

example F continued:



Left: exterior rooflights and underside of coffered ceiling of the test model of the revised (1963) design.

Specified as 'Glasscrete' glass blocks set in concrete frames, the rooflights offered good light diffusion and security. They were simulated in the model using tracing paper over a wood frame, the whole having similar light transmission to the full-scale materials.



Cross-section of the revised (1963) gallery design showing arrangements for natural and artificial lighting.



Above: view into the 1/24th scale test model of the revised gallery design.

Right: a trial exhibition mounted in the finished gallery shows good correlation with the model study. The day-lighting was considered satisfactory.

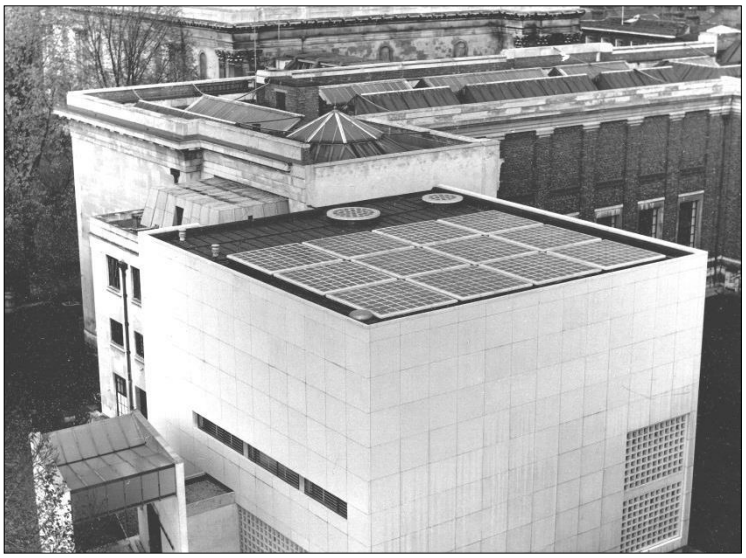
Measurements of daylight factor in both the design model and finished building were found to correlate closely, eg, model under artificial sky: 3.86%, finished building (overcast sky: 3.62% measured horizontally at 850mm over floor level.



photos & drawing: DC

Further photographs of the Fitzwilliam Museum extension of 1963-65.

The required high level of security provided by the 'Glasscrete' rooflights presented difficulty in the measurement of 'daylight factor' in the finished building, as no cables could be run from outside into the gallery. The problem was overcome using two sets of photometers and radio handsets (at a time well before the ready availability of mobile phones).



Above: the completed building showing the 'Glasscrete' rooflights that provide a high level of security for the often very valuable displays of pictures and sculptures.



Above: one of the twelve coffered apertures in the gallery's ceiling below the rooflights. The dark grey cruciform element is the intersection of two of the main structural roof beams in fair-faced concrete. The curved reveals of the ceiling coffers are fibrous plaster on expanded metal with light steel framing. Inset adjustable lighting tracks follow the ceiling grid and also are set around the top edges of each coffer. Between the coffering and the actual rooflight glazing there are fully closable Venetian blinds to cut out sunlight and limit natural light when required.

photos: DC (except that of gallery in 1975)



Above: the '20th Century Gallery' in 1975 with daylight illumination.

© The Fitzwilliam Museum.

Subjectively the finished ceiling shows good correlation with the design model.

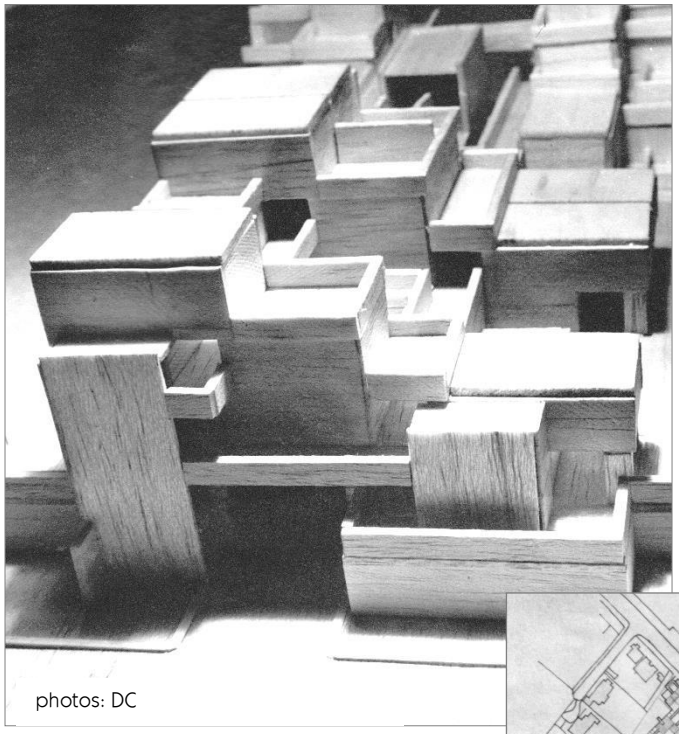


Left: the 20th Century Gallery in 2012. In recent years the concerns of museum conservators over the deleterious effect on artefacts of long-term exposure to ultra-violet (UV) radiation have determined that most exhibits now are lit by artificial rather than natural light. The fully adjustable 'track' lighting and sun blinds provided in the 1963 design have proved adequate for this task and are here shown in use.

END of example F

daylighting by design: example G

student design for high-density low-rise housing (1962)



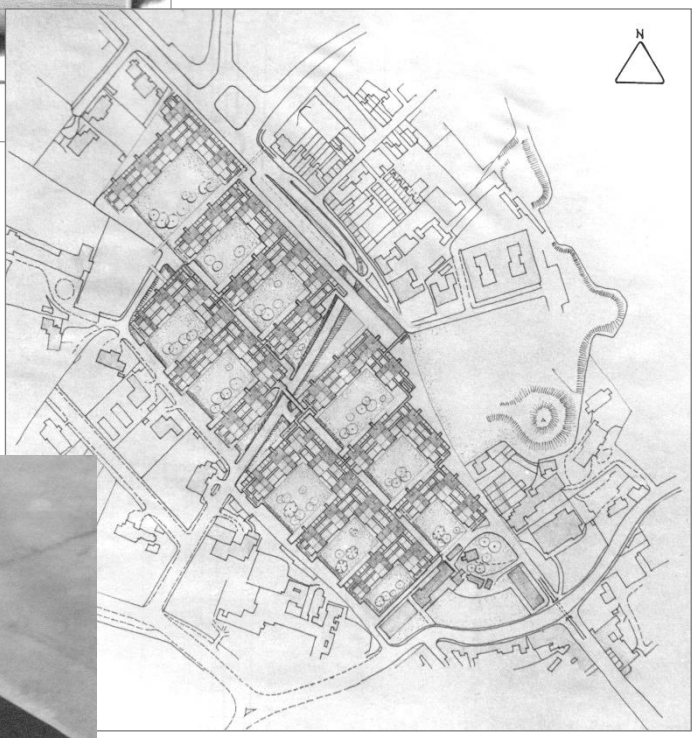
photos: DC

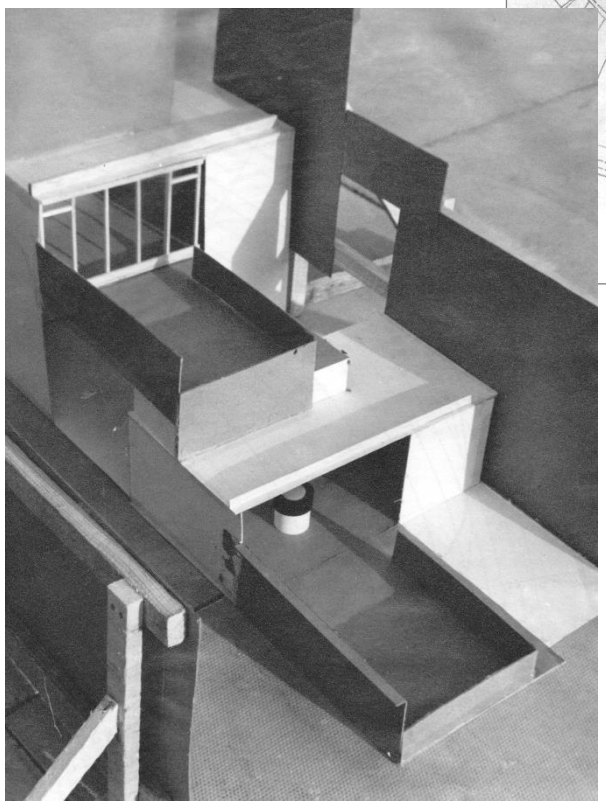
Left: balsa wood block model of the design for complex interlocking apartments, each having a useful amount of private open space in the form of a 'hanging garden'.

Such a sketch model is not directly suitable for the study of daylighting in an artificial sky.

This low-rise student design was made in 1962 at a time when high flats were still the norm. It demonstrated that comparable densities could be achieved while at the same time ensuring much better 'livability'.

Below: designer's site plan for the notional re-development of an area of Cambridge adjoining Castle Street.



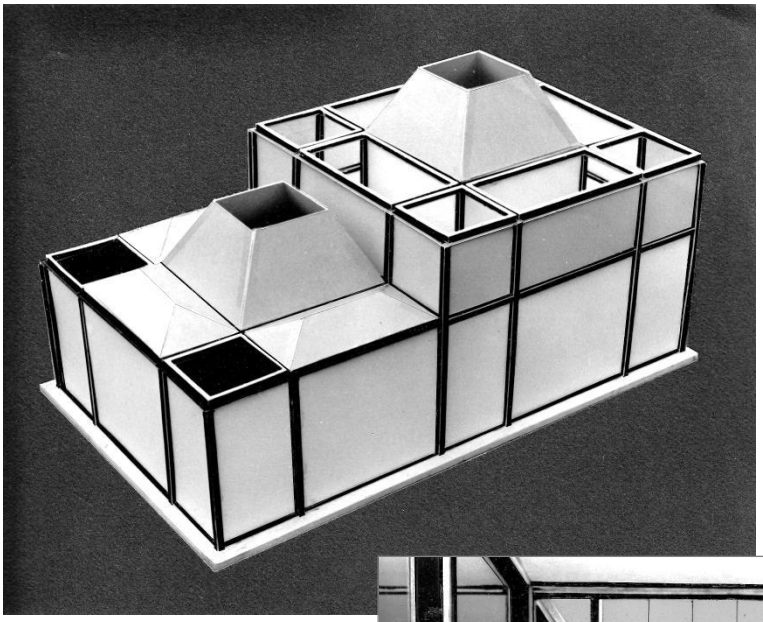


Left: scale model of an apartment prepared for a study of interior daylighting under a natural overcast sky.
A measuring photocell can be seen inside the lower apartment where the glazing has been removed.
{D Croghan PhD thesis 1963, part 5.2.4]

The block form, individual rooms, window openings with glazing and external obstructions require to be carefully represented to correct scale. Also it is important that all surfaces have light reflectance values equivalent to those of the finished building.

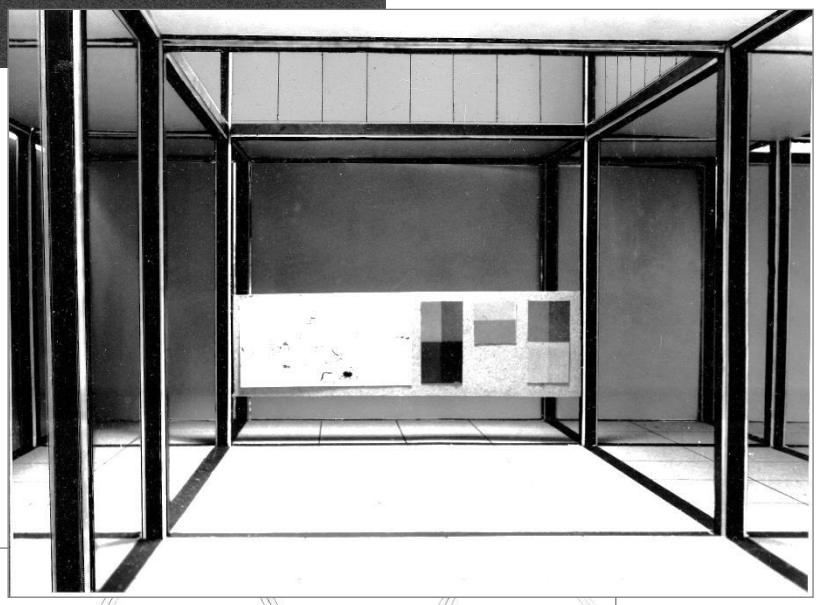
daylighting by design: example H

student design for an Art Gallery (1)



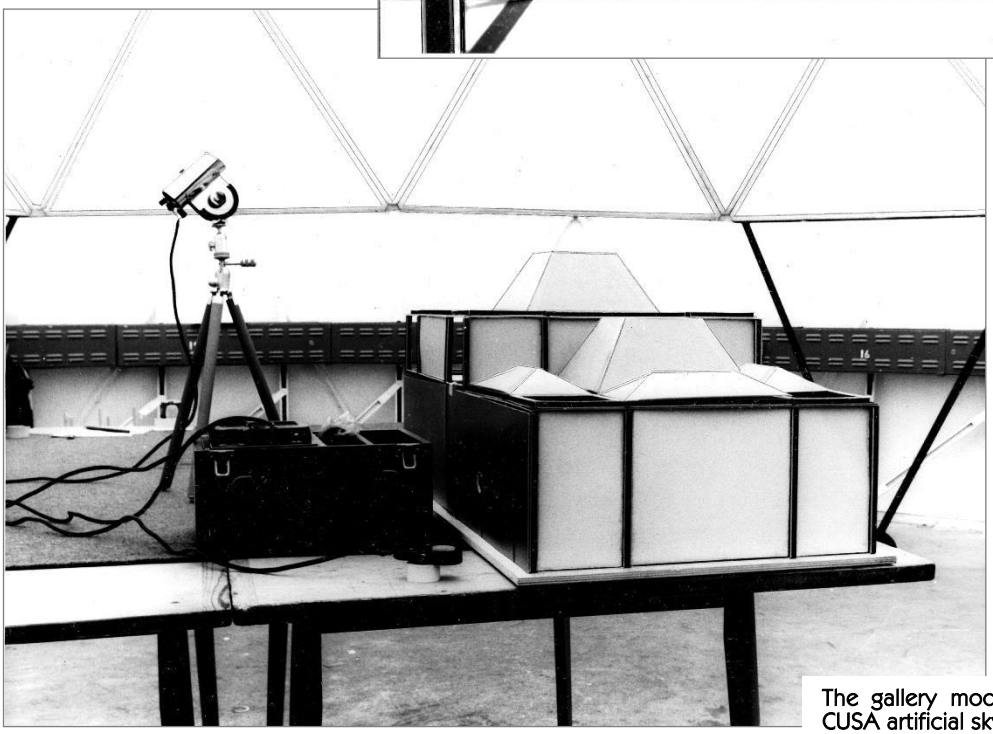
Model of a design for a roof-lit art gallery made in 1964 by a student at the C. U. School of Architecture under the supervision of DC.

Student projects involving daylighting studies were encouraged from 1964 when the 'Skydome' became fully operational.
At this time art galleries typically were day-lit whereas today there is concern over the long-term effect of ultra-violet light on pigments and canvases/backboards, and artificial lighting often is preferred.



Interior of the above model gallery showing preferential illumination of the vertical 'picture plane'. This can be more important than absolute light level, and it may be assessed on a model that, if necessary, can be modified.

photos: DC



The gallery model set up in the CUSA artificial sky for testing.

student design for an Art Gallery (2)

This further example of a photometric model study used in the design of an art gallery by a CUSA student under the supervision of DC shows something of the detail of natural lighting information that it was possible to gain using the Cambridge 'artificial sky' and its application in the design process.

Right: a 1/24th scale model set up in the centre of the 'Skydome'. The aim of the design was to achieve a distribution of natural light over the vertical 'picture plane' that was as even as possible and higher than that horizontally over the floor.
Assessment of the natural lighting potential of these relatively complex rooflights could not be carried out using any available calculation technique.

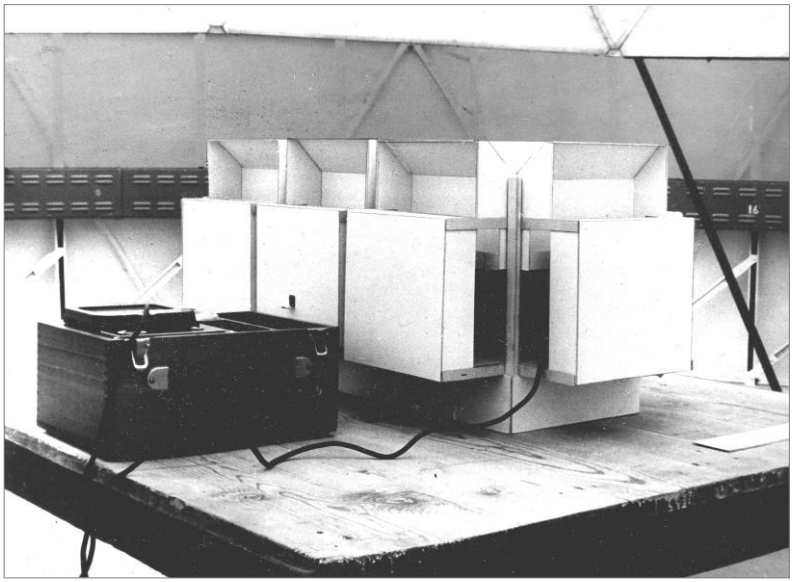
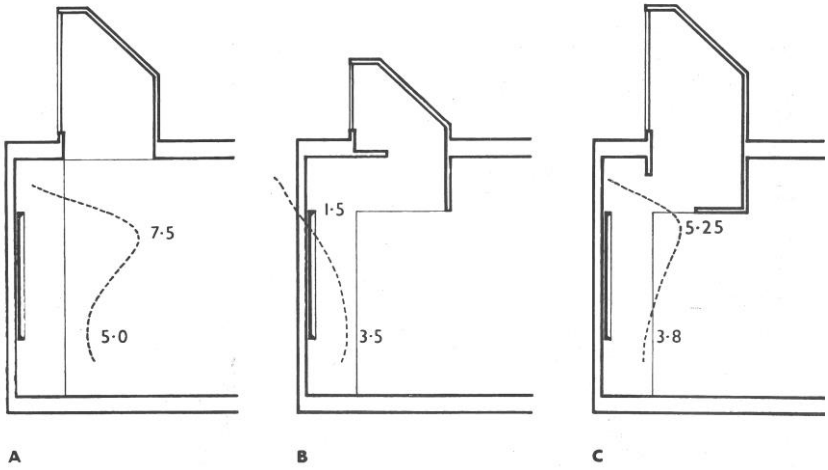


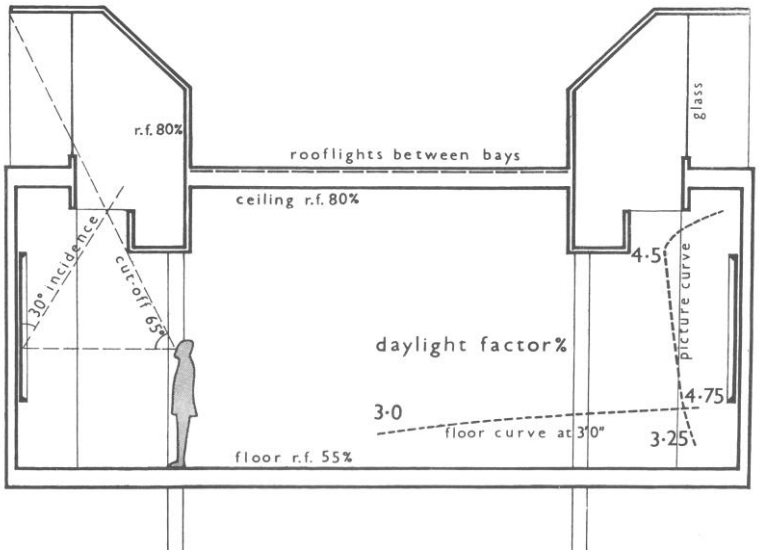
photo and drawings: DC



This study of 1964 was published in:
D Croghan, 'The use of an artificial sky in building design', *Polybuild,* issue 2, Singapore 1965.

Sections A, B and C above illustrate the development of the design of the rooflights consequent upon the results of 'daylight' measurement. The vertical 'daylight factor' contour in A shows a level too high overall and particularly high on the upper part of the 'picture plane'. In B the upper part of the picture plane is inadequately lit. In C the situation is better, but distribution could still be improved.

The section on right is of the final design. Further modification of the rooflights has achieved acceptable natural light distribution.



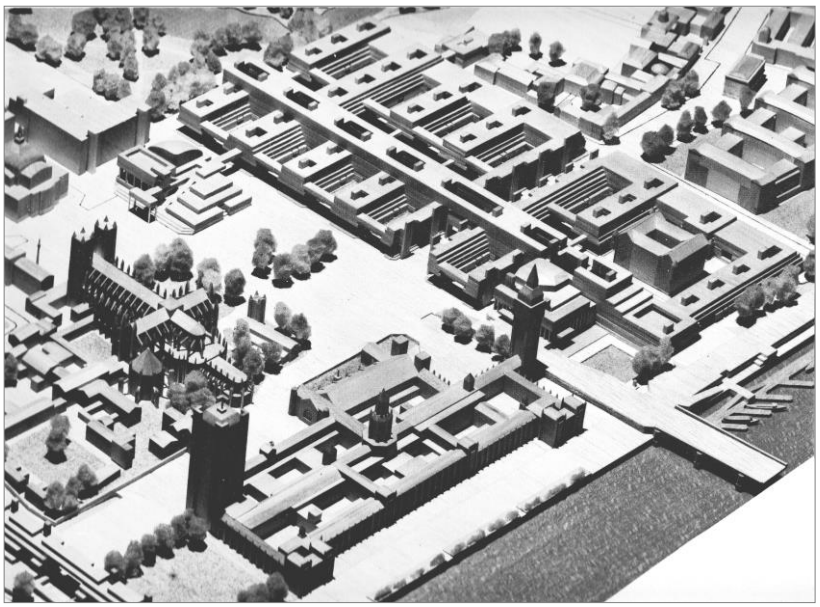
'Whitehall – a plan for the National and Government Centre'

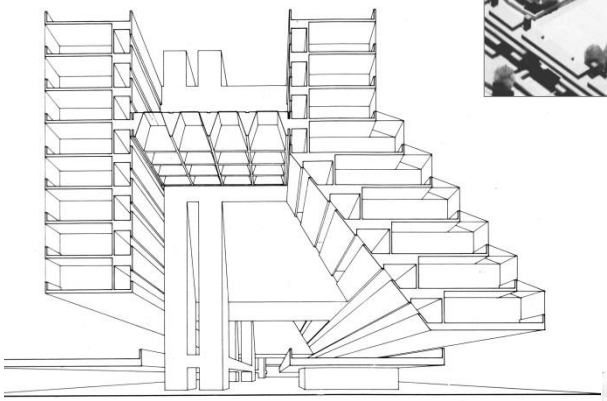
a report for HM Government
by Sir Leslie Martin

published by H.M. Stationery Office, London, 1965

In 1964 DC acted as consultant for a series of studies of alternative forms of development on the Whitehall site to measure the efficiency of planning layout in terms of plot ratio, office population and environmental factors such as natural lighting and provision and shadowing of exterior open space.

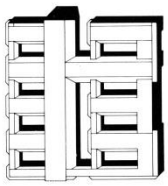
In this case no daylighting model studies were required, but background experience of the technique and its use in research that examined then current daylighting standards enabled DC to participate with the required authority.





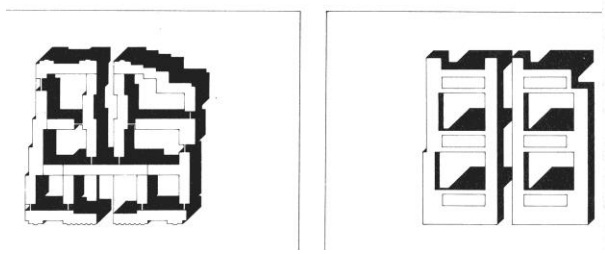
Though the Leslie Martin Whitehall plan was never implemented, it demonstrated that 'plot ratio' – a concept that had up to this time controlled much post-war urban development in the UK – could not regulate either the total effect or bulk or the scale of a building as it is too arbitrary and conceals too many unknowns. As a result, planning control in terms of 'plot ratio' largely was superseded. Also it became clear that the other main tool for the control of urban development, the 'Daylight Indicators' had little to offer on large sites.

Above: section of a gallery block along which groups of offices are arranged.
The stepping ensures good daylighting and limits ground shadowing (as plan on right).

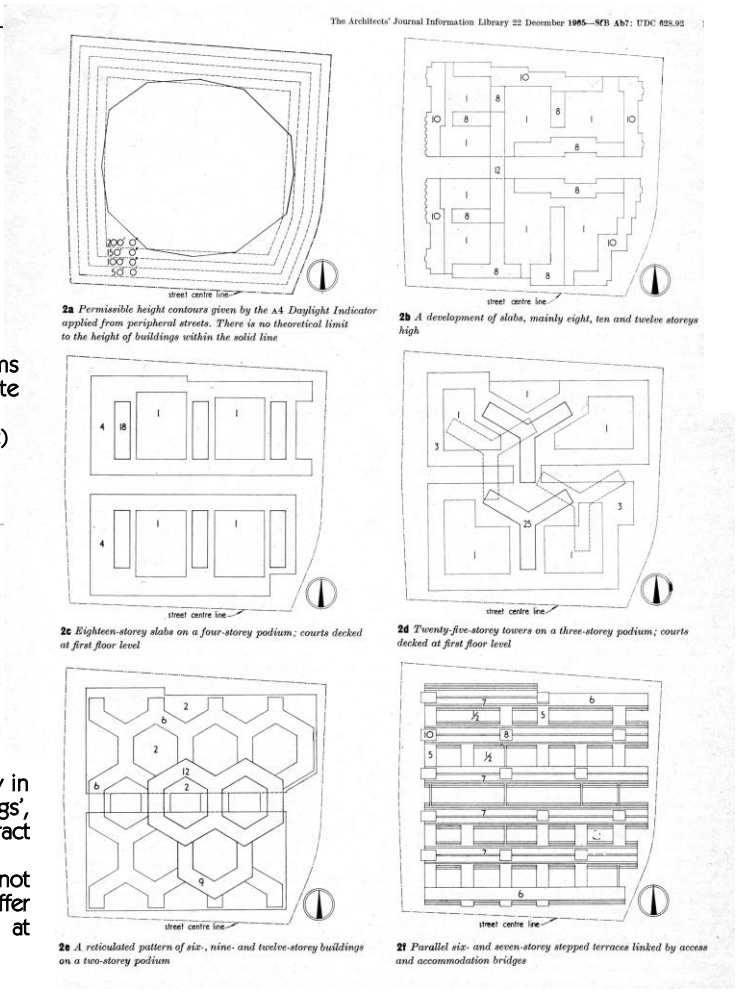




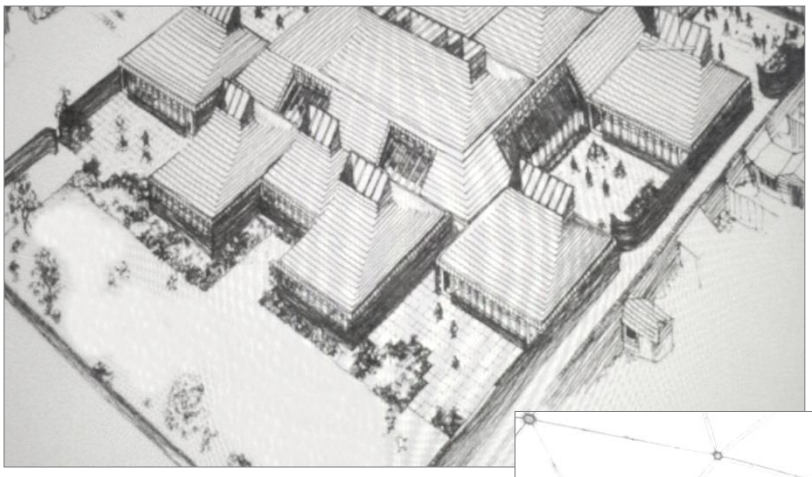
Studies of alternative forms of development on the site made by DC.
(p.52 of the published report)



DC's contribution to the study was published separately in expanded form as 'Daylight and the form of office buildings', *The Architects' Journal*, 22/12/1965, pp.1501-1507, as extract on right.
It was shown that in large developments high buildings do not necessarily provide the best possibilities for daylighting or offer any advantage in the amount of floor space obtainable at normal plot ratios.



Bromley Hall School, Tower Hamlets, London



This LCC/GLC special needs school was designed in 1965/66 by a team led by architect Bob Giles.
Built in 1967/68, it is fully described in *The Architects' Journal* of 27/08/1969, pp.505-522.
The school was closed in 08/2002 but listed Grade 2 on 09/01/2012.

Left: architect's axonometric drawing in the RIBA Drawings Collection.

Good natural lighting was an important design criterion, and this was 'proved' at design stage with a model in the CUSA 'Skydome'.
No calculation technique then or now (2015) could adequately model the daylighting of such a complex design.

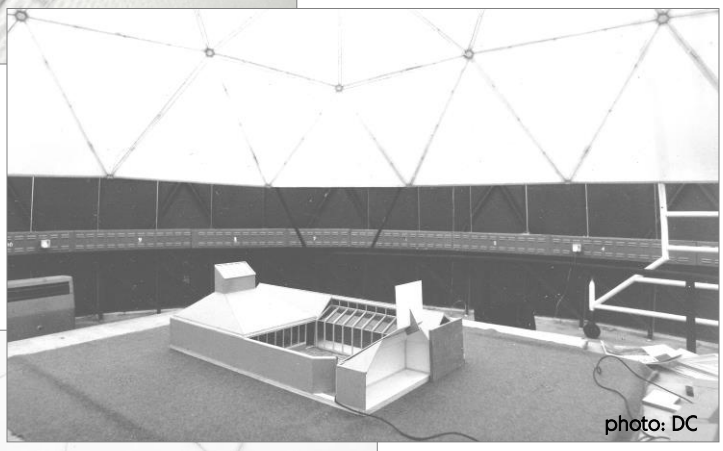


photo: DC



photo: DC

Left: a team of GLC architects assemble their model of part of the school for testing in the CUSA artificial sky in 1965.

In consultancy projects employing the 'Skydome' visiting architects were encouraged to make and test their own models so that the technique might diffuse more widely into the profession.

The building area is 8000m^2 on a site area of 0.63ha.

Right: the school library. This, like each classroom, opens onto a secure enclosed courtyard.

The daylighting in the finished building was considered good.



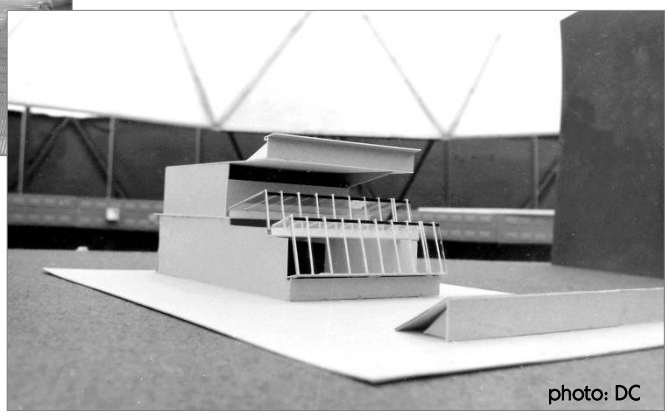
photo: City of London archive

daylighting by design: examples L & M

Pimlico School, Westminster, London (L)

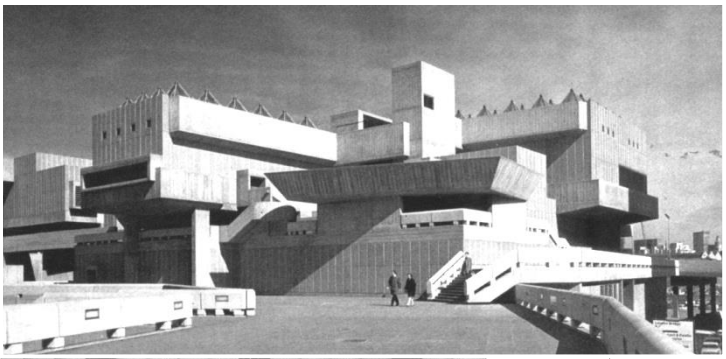


This celebrated 'New Brutalist' school was designed by a team of architects led by John Bancroft of the LCC/GLC Architect's Department in 1964/65 and built in 1967/70.
It received the 1972 RBA Architecture Award, but was narrowly denied Grade 2 listing and demolished amid much controversy in 2008/11.



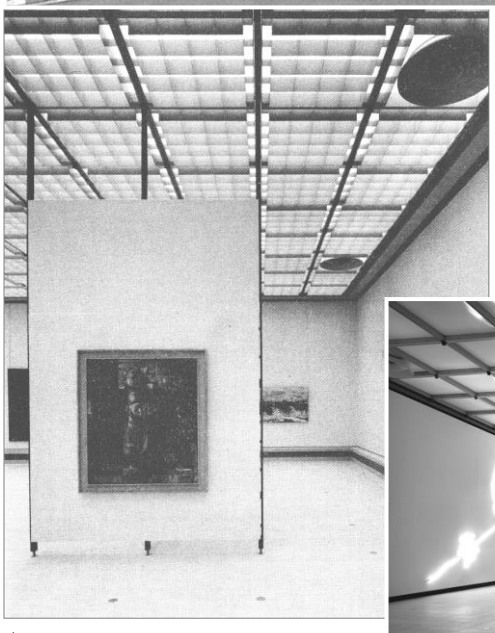
The natural lighting of extensive semi-basement areas was critical to the design and was 'proved' by model studies in the CUSA 'Skyome' in 1965.
The ultimate result in the completed building was considered entirely satisfactory.

The Hayward Gallery, South Bank, London (M)



Opened in 1968, this arts complex was designed in the Architect's Department of the LCC/GLC in 1961/67 largely by Alan Waterhouse and Denis Crompton.
Though controversially denied Grade 2 listing, it was placed on the Protected List of the World Monuments Fund in 2011.

Daylighting of the top-lit galleries on the upper floors by the distinctive pyramidal north-lights was 'proved' at design stage in 1966 in the CUSA 'Skydome'.







This exhibition by Tracy Emin preferred artificial light, but at least it demonstrates that roof-lights can be effectively blacked-out.

photos: www

proposed extension of the National Gallery, London



Covell, Matthews Wheatley with London & Edinburgh Investment Trust Co Ltd

Gallery: 3215 m² nett
Non-gallery space including offices: 7095 m² gross

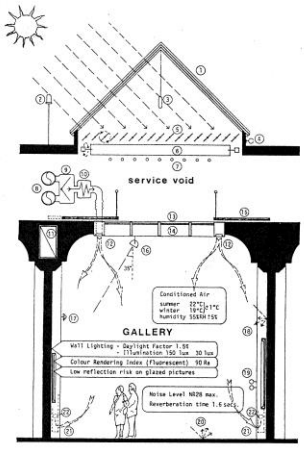
Second-stage report states: 'One major element which is fundamental to the design and bears on both the building and its immediate environment is the courtyard or *cortile*. Not only does this element deliver light and ventilation to the central zones of the building, ensuring that commercial accommodation at lower levels is of the highest quality and value, but it lends the building much of its individual character by providing a sanctuary in the heart of the site in the form of a "secret garden" to which all parts of the building relate. Furthermore its location adjacent to the concourse allows pedestrians en route to Leicester or Trafalgar Squares to pass by the garden and appreciate its particular serenity after the surrounding bustle and activity. It is our opinion that this *cortile* will become a vital and much-loved complement to the city.'

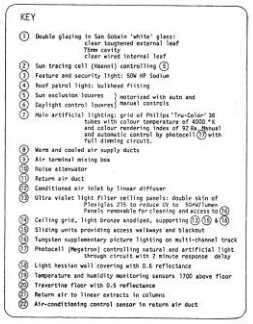




1 *Section through new building proposed by Covell Matthews Wheatley showing position of cortile.*
2 *Model showing Covell Matthews Wheatley's proposals in relation to National Gallery.*
3 *Main entrance to new gallery.*

from The Architects' Journal 25 Aug 1982





THE NATIONAL GALLERY - HAMPTON SITE EXTENSION

SECTION OF TYPICAL GALLERY WITH ENVIRONMENTAL SYSTEMS

Dr David Croghan: consultant for gallery lighting and the coordination of mechanical & electrical services, acoustic control and energy conservation

In 1982 an open architect/developer design competition was held for a west extension to the National Gallery, London. This was to contain new galleries and, on lower floors, a large amount of commercial floor space.
DC was invited by the architectural firm of Covell, Matthews Wheatley working with the London & Edinburgh Investment Trust Co. Ltd. to act as lighting consultant and also to coordinate mechanical and electrical services, acoustic control and measures for energy conservation.

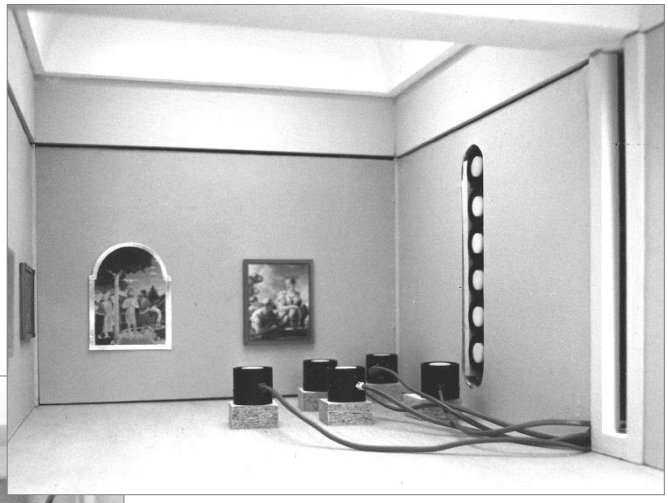
The CMW submission was short-listed from a total entry of 79.
Much controversy arose with the modernist 'winner' famously described by the Prince of Wales as a "monstrous carbuncle". A second, limited competition was held in 1986 with an idiosyncratic, post-modernist design by Venturi, Scott Brown then accepted and built in 1991. With project funding now provided by the Sainsbury family, these architects were released from many of the commercial constraints to which others earlier had worked. The CMW design would not have required any capital or running subsidy.

Below: photo of a 1/12th scale model of one of the display galleries. This shows arrays of photocells set to measure levels of natural light vertically on walls and horizontally on the 'working plane' (at 900mm above floor level). The testing was carried out using the large rectilinear artificial sky at the Bartlett School of Architecture, University College London (UCL), as the CUSA 'Skydome' was by then out of use.

Above top: Illustration of the CMW National Gallery extension competition entry as published in ***The Architects' Journal*** of 23 Aug 1982. The gallery spaces were to be on the top floor over 3 floors of commercial offices and basement car parking that would fund the scheme.

Above lower left: a presentation sectional diagram of the gallery design produced to demonstrate compliance with all the required environmental standards. A particular feature was a continuous, fully accessible service void in the ceiling.

Below: photo of the same model as that on the right prepared for subjective visual appraisal. On the basis of this, a panel of experienced observers agreed that the distribution of daylight in the gallery likely would be successful.





sectional diagram and photos: DC

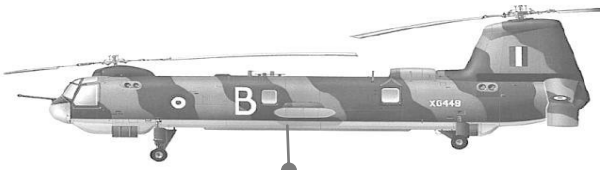
This was DC's last daylighting consultancy apart from many 'rights to light' cases. Though always interesting and sometimes important, there had never been a great number of commissions, and over the years it had become increasingly difficult to maintain the facilities necessary for such work. DC had finally left the CUSA in 1970 and a few years later the 'Skydome' suffered an electrical fire and was closed-down, being considered too expensive to repair.

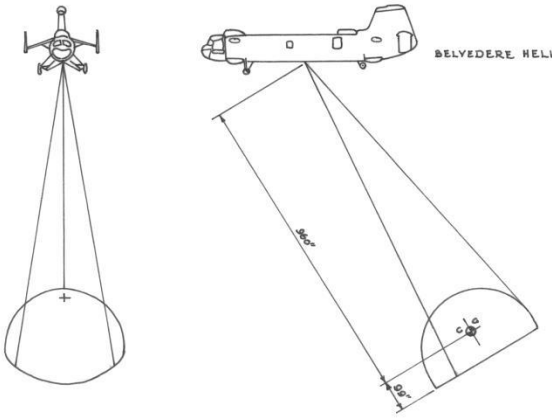
end of paper 2

potential Cambridge high-flyer grounded.....

Initial doubt that the thin (12g) aluminium panels of the 9.45m diameter outer shell of the CUSA 'Skydome' could survive disassembly after necessary trial assembly at its manufacturer's factory in Essex, gave rise to suggestion for airlifting the completed structure to Cambridge. Fresh from success in April 1962 lifting the flêche on to the roof the new Coventry cathedral, Westland Aircraft and 72 Sqn RAF were keen to assist and carried out detailed appraisal. However, when site reconnaissance was carried out, the noise and presumed danger of the huge Belvedere helicopter hovering at roof parapet level between the School of Architecture and the Department of Engineering resulted in complaint to the Vice-Chancellor who expressed displeasure, effectively ending the airlift project.....

from the feasibility study by Westland Aircraft Ltd.





OPERATIONAL TABLE

STATIC WEIGHT (INCLUDING SLINGS AND ATTACHMENTS)	3,400 LB.
AERODYNAMIC EFFECT AT HOVER (ESTIMATED)	400 LB. TOTAL WEIGHT 3,800 LB.
DRAG AT 35-40 KNOTS AIRSPEED (ESTIMATED)	2,000 LB. TOTAL WEIGHT 5,400 LB.
MAX. ALLOWABLE A/U WEIGHT	18,000 LB.
A/U WEIGHT OF AIRCRAFT (3 CREW, NO FUEL)	12,000 LB.
PLUS TOTAL LOAD (INCLUDING DRAG)	5,400 LB.
FUEL ALLOWANCE	600 – 700 LB.
RANGE WITH LOAD (APPROX.) AT 40 KTS.	30 – 35 MILES

SCHEMATIC LAYOUT FOR PROPOSED AIRLIFT OF DOME

"Behaviour of the load was studied by means of a model towed (by car) at scale speed and it was found to be remarkably stable..."


photo: DC

Belvedere pilot Sqn Ldr John Dowling observed:
"Due to high drag, the flight plan for this lift allowed only 15 minutes in hover over the 'target'. If placement not then achieved, the load would be jettisoned on Coe Fen to enable safe landing and re-fuelling....."


photo: DC

In the event, the dome was safely disassembled and its 105 panels despatched from Braintree to Cambridge by road, where reassembly took place next day in 10 hours without incident. It remained for 40 years in full view of the Depart-ment of Engineering, none of whose structural experts had wished to be involved in its design....