THE IMPORTANCE OF THE SPHEROIDAL FORM IN ARCHITECTURAL MORPHOLOGY; FOCUS ON THE GREATER LONDON AUTHORITY BUILDING (CITY HALL)

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ABSTRACT: This research paper sets out to explore the following research question: "what importance does the elliptical shape and spheroidal form offer when utilised in the design and construction of the tall office building in order to achieve energy efficiency?" This involves the exploratory case study of a spheroidal building, the Greater London Authority (GLA) building. The Greater London Authority building has been acclaimed as being energy efficient, with claims of 75 % reduction in its annual energy consumption compared to a high specification office building. This claim is explored to better understand the nature of the spheroidal form in construction. The Greater London Authority building appears to have achieved a high level of energy efficiency but a number of problems have been reported. However, it is not clear how many of these problems are associated with its morphology.

Keywords – Energy efficiency, Greater London Authority building, Spheroid

1. INTRODUCTION

1.1 Reason for focus on the Spheroid Form

The focus on the spheroid form is predicated on important factors that have been identified from literature reviewed:

"… a sphere is already efficient: it encloses the most volume with the least surface." (Baldwin, 2004 p. 1) "…as the most economical shape for containing matter, the sphere's perfect form has fascinated the minds of men for millennia. From planets to raindrops, nature adores the sphere." (Sautoy, 2004 p. 2) "…the sphere is a special case of the spheroid in which the generating ellipse is a circle." (Wikipedia, 2004)

"…another problem with sphere shaped building is thermal expansion and contraction. The sphere is the worst possible shape for that. Not only is it a single surface, but it also has constant curvature in all directions. A prolate spheroid or oblate spheroid would do better than a sphere, having different curvature in different directions." (Ambrose, 2002 p. 53) (refer to fig. 5 and fig. 6 for prolate and oblate spheroid illustration and section 2.2 for their definition)

The following deductions are derived from these factors: the first and second factors suggest the sphere as being the most efficient way of enclosing volume and this provides the opportunity to accommodate as much gross floor area as possible with the least surface area available. This minimises surface area exposure to external climatic conditions and permits minimal use of energy to control internal climatic conditions. The third factor identifies the relationship between the sphere and the spheroid; however the fourth factor identifies two types of spheroids (refer to fig. 5 and fig. 6) and suggests that they perform more satisfactorily in thermal expansion and contraction than the sphere. The reason for focus on the spheroid form pertains to its quality of volume enclosure efficiency, which hypothetically suggests its potential in tackling the research problem.

2. LITERATURE REVIEW

2.1 Statement of the Research Problem

"The question of what shape a building should be is one of the most fundamental issues that confront an architect." (Hawkes, 1996 p. 36) The importance of this statement is predicated on two factors, which are related, one is the factor of energy efficiency and the other is the factor of cost efficiency, with the latter being a derivative of the former. Factors one and two are identified as issues in two questions; "What shape should a building be to reduce heat losses?" (Martin and March 1972 p. 57) and "What shape should a building be to reduce its cost?" (Martin and March 1972 p. 67) Further, from literature reviewed five important factors have been identified:

"The Energy Review (PIU, 2002) highlights the need to improve energy efficiency in buildings and recommends action to deliver a phased transition to low energy commercial buildings through the development of the Building Regulations." (Wade et al, 2003 p. 1)

"Within the commercial sector, offices, together with warehouses and retail premises, are a significant contributor to energy use and carbon emissions. From these three sub-sectors, offices seem to offer the greatest potential for action to achieve significant savings: the range of technical solutions is not too large as the nature of energy service demands in offices is relatively homogenous…." (Wade et al, 2003 p. 4) (refer to table 2) The pie chart in figure 3 (refer to fig. 3), "shows that space heating makes the largest contribution, of about 58%, to the total annual consumption of delivered energy of these office premises. A further 15% results from lighting, followed by 7% from computers and computer accessories, and 5% from water heating. The remaining 15% comes from a variety of energy uses including cooling, catering, fans, and small power equipment." (Mortimer et al, 2000 p. 715)

"The rapid growth in energy consumption in offices over the last three decades reflects expansion in floor space, and increased heating, lighting, IT and air conditioning (A/C) loads in individual buildings." (Wade et al, 2003 p. 5) Mortimer et al, (2000) collaborate this statement by summarising results for the sample of eighty-four office premises in which a relatively good correlation between total annual consumption of delivered energy and gross external floor area is suggested (refer to fig. 1 and refer to fig. 4). "Hence it can be concluded that energy use in offices is related, quite clearly, to floor area. [In fig. 1 and fig. 2] The gradient represents part of this relationship which in this case indicates that total annual consumption of delivered energy increases by about 500 GJ yr^{-1} for every additional 1000 m^2 of external floor area." (Mortimer et al, 2000 p. 715)

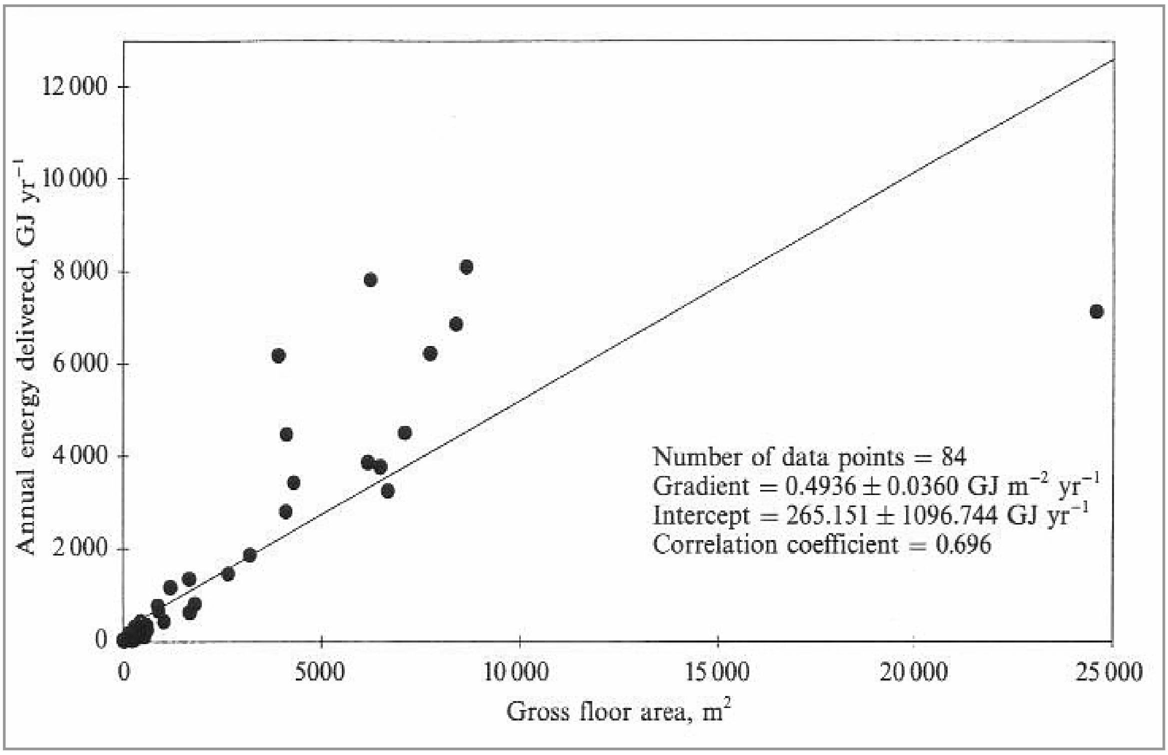

Fig. 1 Variation of total annual consumption of delivered energy with gross floor area for office premises (Figure source: Mortimer et al, 2000 p. 714), where the gradient indicates that total annual consumption of delivered energy increases by about 500 GJ yr $^{-1}$ for every additional 1000m^2 of external floor area thus suggesting a relatively good correlation between delivered energy and external floor area

"One commonly cited reason for the lack of investment in energy efficiency in buildings is that energy represents a small percentage of total occupancy costs, and therefore it is given little attention. However, in offices, particularly air conditioned ones, energy and the maintenance of heating and cooling equipment comprises a significant proportion of service charges." (Wade et al, 2003 p. 13)

"In 2000, A/C office buildings had an average annual service charge of £53.82 per m^2, compared to £37.24 for non-A/C buildings (Jones Lang LaSalle, 2001) (refer to table 1 and fig. 2). Thus, in A/C offices energy itself represents 16% of total service charges; by including maintenance of heating and A/C systems this brings the proportion up to 35%. These are significant proportions, and therefore one might expect that tenants would be interested in lowering energy consumptions in their premises." (Wade et al, 2003 p. 14)

Table 1. Service charges in UK offices by component percentages in 2000

	A/C	**Non A/C**
Energy	16 %	11 %
Heating and A/C maintenance	19 %	9 %
Other	65 %	80 %

Based on Jones Lang Lasalle (2001) (Table source: Wade et al, 2003 p. 14), where in 2000, A/C office buildings had an average annual service charge equalling £53.82 per m^2, which is higher than the £37.24 for non-A/C buildings

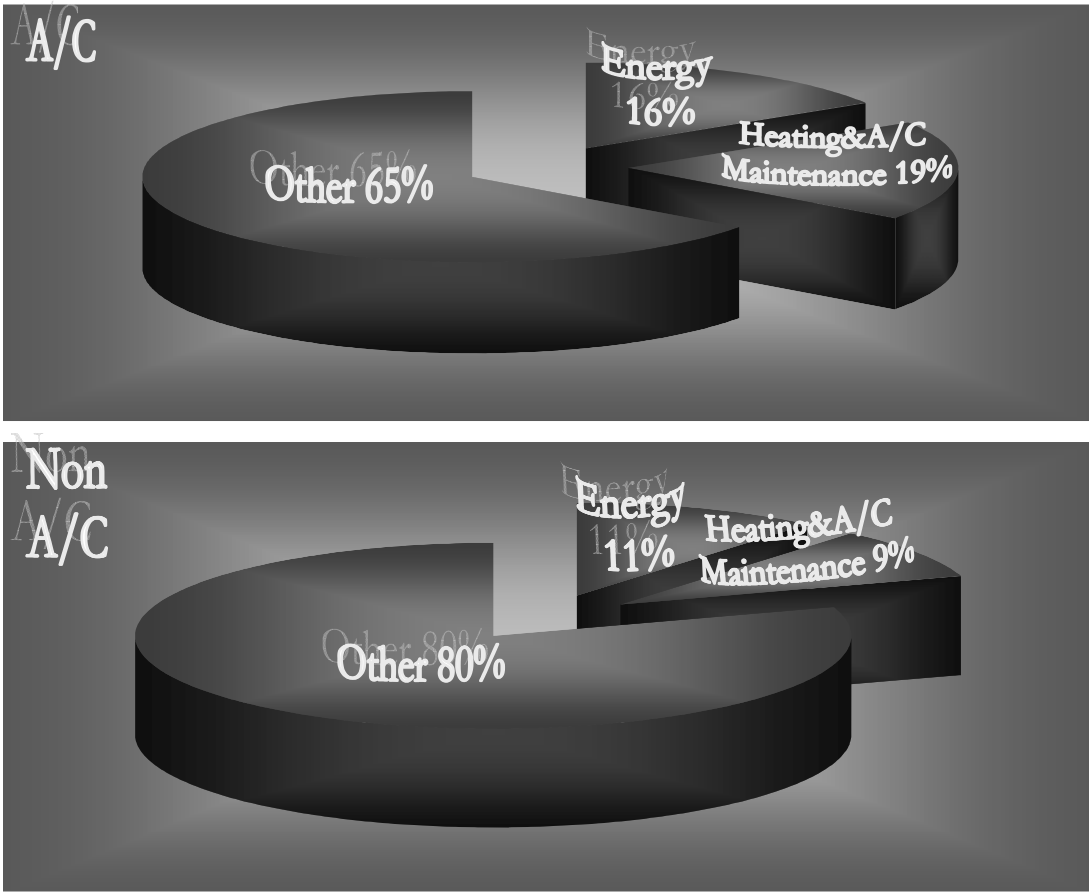

Fig. 2 Service charges in UK offices by component percentages in 2000
Based on Jones Lang Lasalle (2001), where in 2000, A/C office buildings had an average annual service charge equalling £53.82 per m^2, which is higher than the £37.24 for non-A/C buildings

Table 2. Energy consumption and CO_2 emissions in UK commercial offices

	Heating	**Hot water**	**Catering**	**Light**	**Cooling**	**Small Power**	**IT**	**Other**	**Process**	**Unknown**	**Total**
Fossil fuels (PJ)	46	5	3	-	-	-	-	-	-	-	**54**
Electricity (PJ)	5	0	3	16	11	2	12	2	3	0.3	**56**
CO_2 (kT)	3680	469	370	2238	1319	250	1031	184	7	121	**9669**

(Table source: Wade et al, 2003 p. 4) where table depicts the homogenous nature of energy service demands in offices, despite consumption and emission levels, thus indicating potential for significant savings

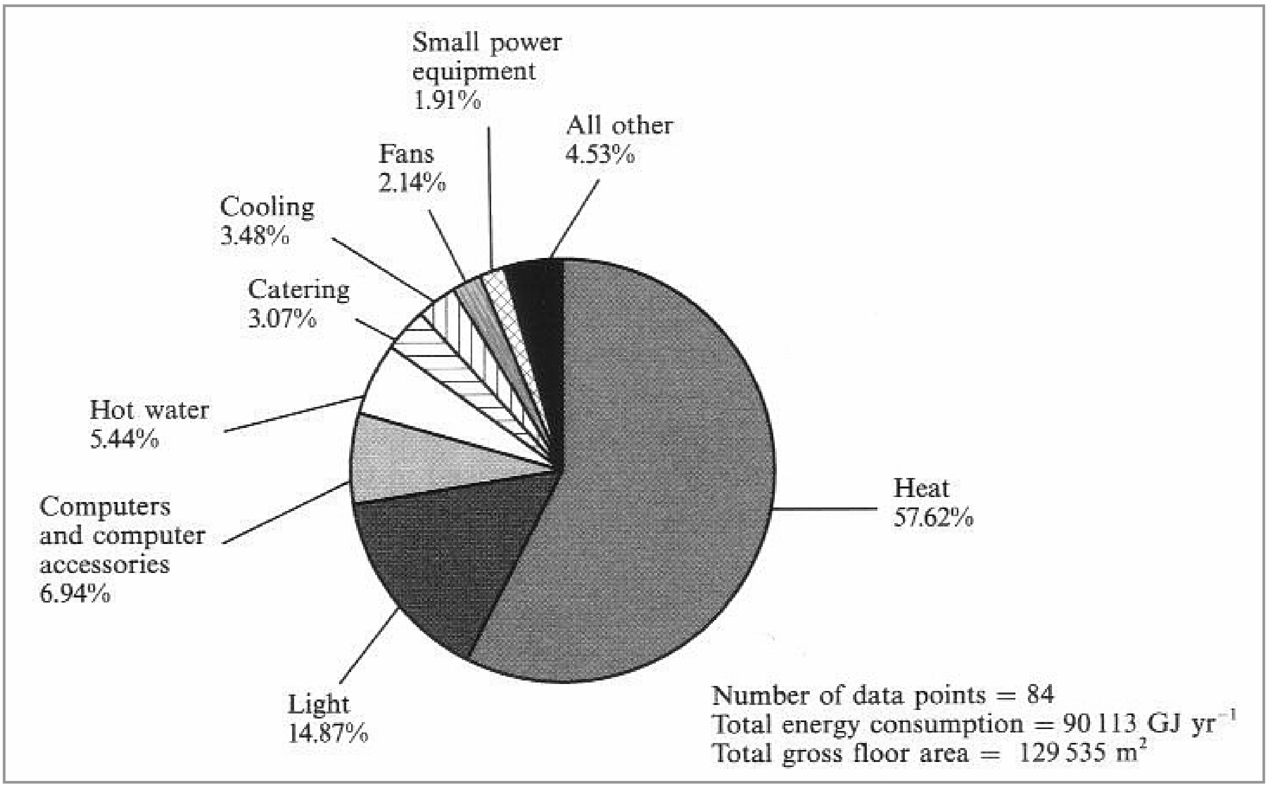

Fig. 3 Aggregated annual energy consumption by application for office premises (Figure source: Mortimer et al, 2000 p. 715), where space heating makes the largest contribution, at ≈ 58%, to the total annual consumption of delivered energy of these office premises

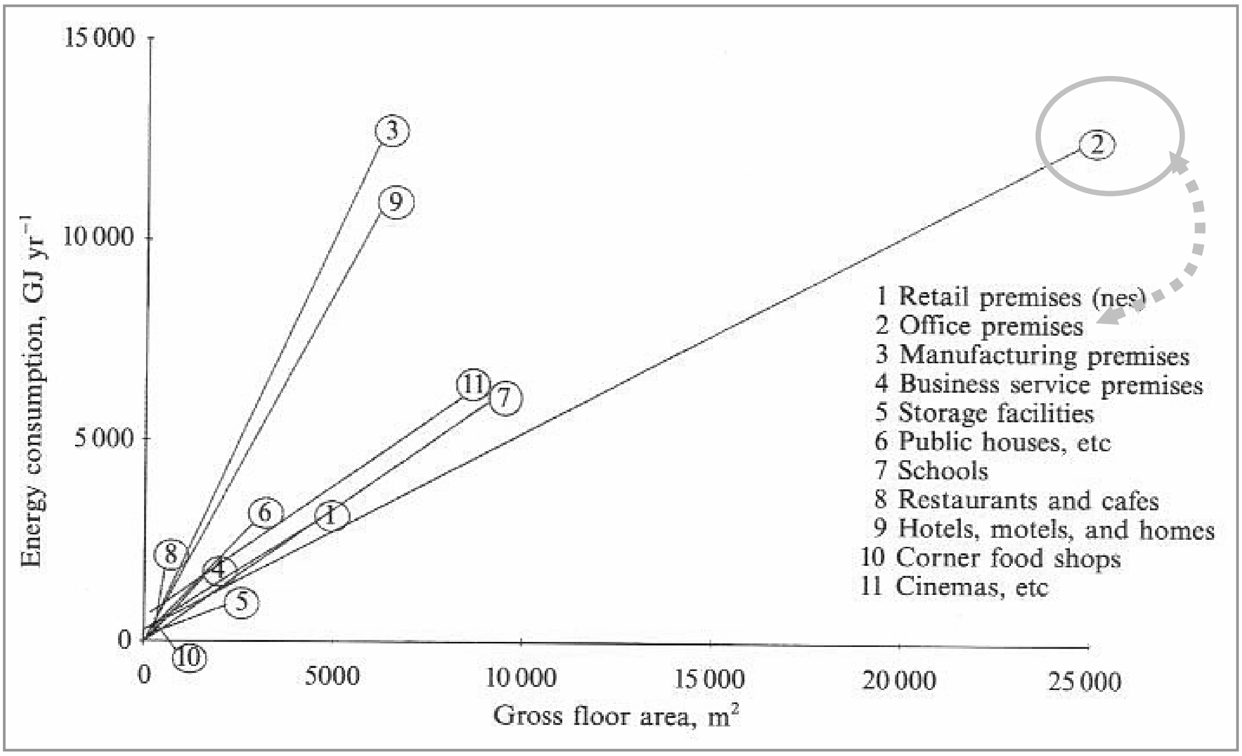

Fig. 4 Variations of total annual consumption of delivered energy with gross floor area for activity categories (Figure source: Mortimer et al, 2000 p. 718), where the gradient indicates a relatively good correlation between delivered energy and external floor area

In researching the problem of energy efficiency in tall office buildings, this paper focuses on the spheroid form, and its nature, as well as potential will better be understood through knowledge of its concept.

2.2 The Spheroid Form Concept

Wikipedia (2004) defines a spheroid as a quadric surface in three dimensions obtained by rotating an ellipse about one of its principle axes. Further, Ambrose (2002) identifies two types of spheroids; one is stated as a prolate spheroid (refer to fig. 5) and the other as an oblate spheroid (refer to fig. 6). A prolate spheroid is obtained by rotating an ellipse about its major axis (refer to fig. 5) and has morphology similar to that of the Greater London Authority Building (refer to fig. 7). An oblate spheroid is obtained by rotating an ellipse about its minor axis (refer to fig. 6) and has morphology similar to that of a geodesic dome, such as the US Pavilion at Expo '67 (refer to fig. 8). The volume and surface area of a prolate and oblate spheroid are influenced by eccentricity of the ellipse (e), as well as by major axis length (a) and minor axis length (b) (refer to table 3). Wikipedia (2004) further describes a sphere as a special case of the spheroid in which the generating ellipse is a circle, while a spheroid is a special case of an ellipsoid, where two of the three major axes are equal.

Table 3. Volume and Surface Area data for a Prolate and an Oblate Spheroid

Spheroid Type	**Volume**	**Surface Area**
Prolate Spheroid	$4/3\ \pi\ ab^2$	$\pi\ (2a^2 + b^2/e\ 1n\ (1 + e/1 - e))$
Oblate Spheroid	$4/3\ \pi\ a^2b$	$2\pi b(b + a\cdot\arcsin(e)/e)$

Where e is eccentricity of the ellipse = $(1 - (b^2/a^2))^{1/2}$, a is the major axis length
b is the minor axis length

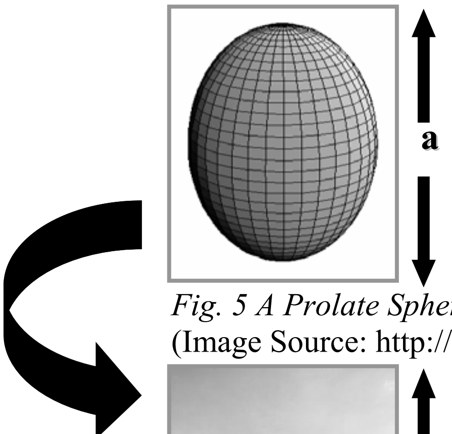

Fig. 5 A Prolate Spheroid

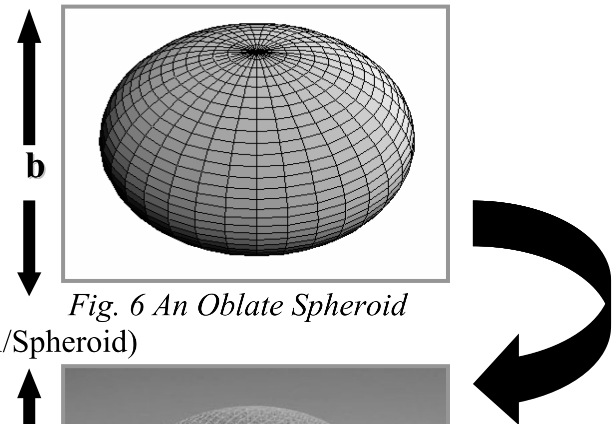

Fig. 6 An Oblate Spheroid

(Image Source: http://en.wikipedia.org/wiki/Spheroid)

Fig. 7 Greater London Authority Building

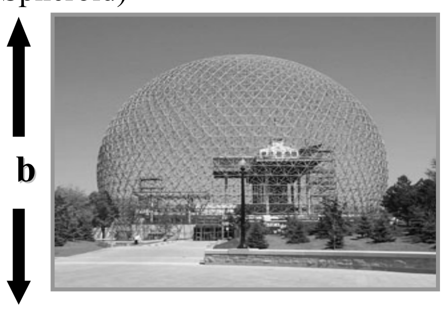

Fig. 8 US Pavilion at Expo '67

(Image sources: GLA and Image Gallery Biosphere Expo 67 US Pavilion)

The theoretical focus on the spheroid form has necessitated the first author's investigation of this form in practice as represented by the exploratory case study of the Greater London Authority building (City Hall London).

3. CASE STUDY

3.1 Greater London Authority building (City Hall London)

On the 23rd of July 2002, the New City Hall, known as the Greater London Authority (GLA) building was officially opened by Her Majesty, the Queen, and was heralded as a solution to the issue of environmental efficiency in tall office buildings. However, concerns have arisen regarding its claims of energy efficiency.

The design and construction of the Greater London Authority building led to the emergence of arguments relating to the actual and perceived problems, as well as benefits associated with the use of the spheroid form in attempting to achieve environmental efficiency in tall office buildings.

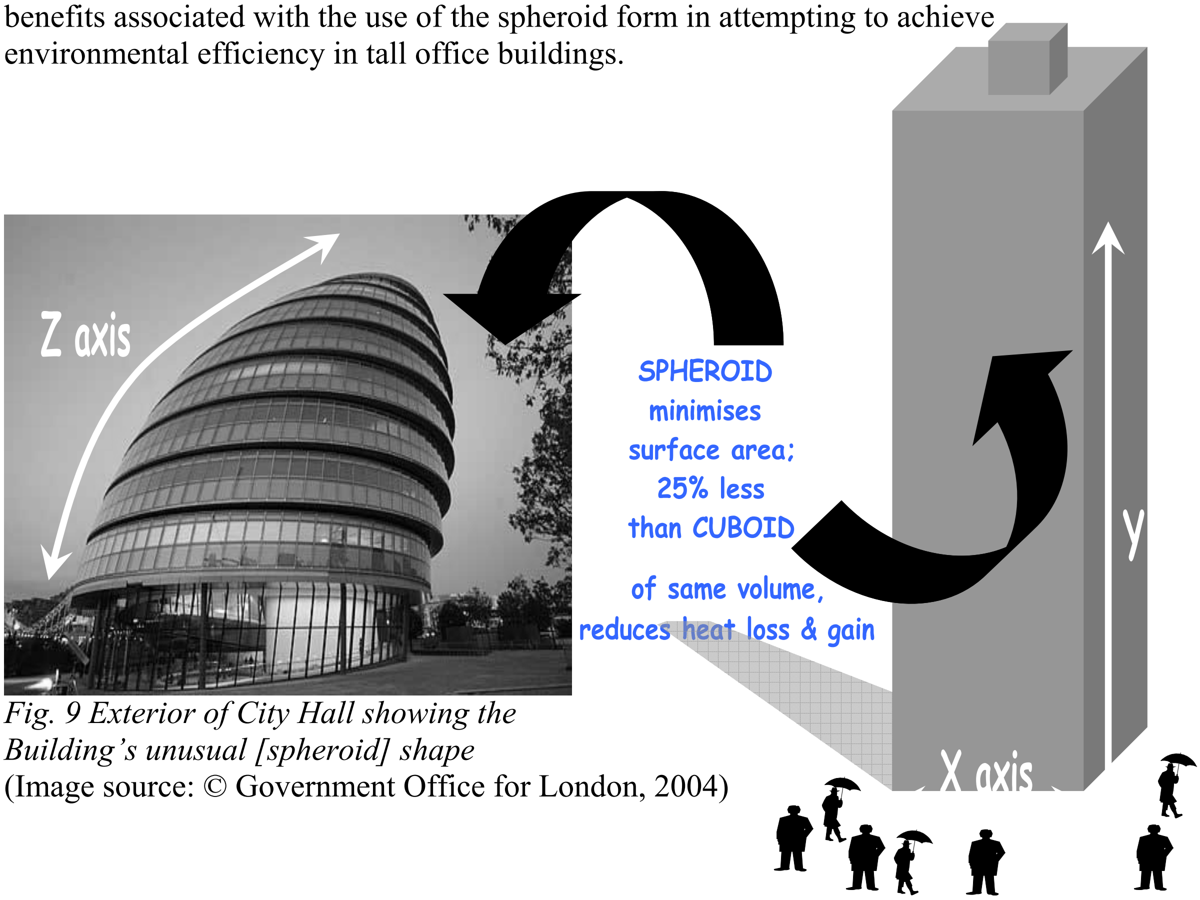

Fig. 9 Exterior of City Hall showing the Building's unusual [spheroid] shape
(Image source: © Government Office for London, 2004)

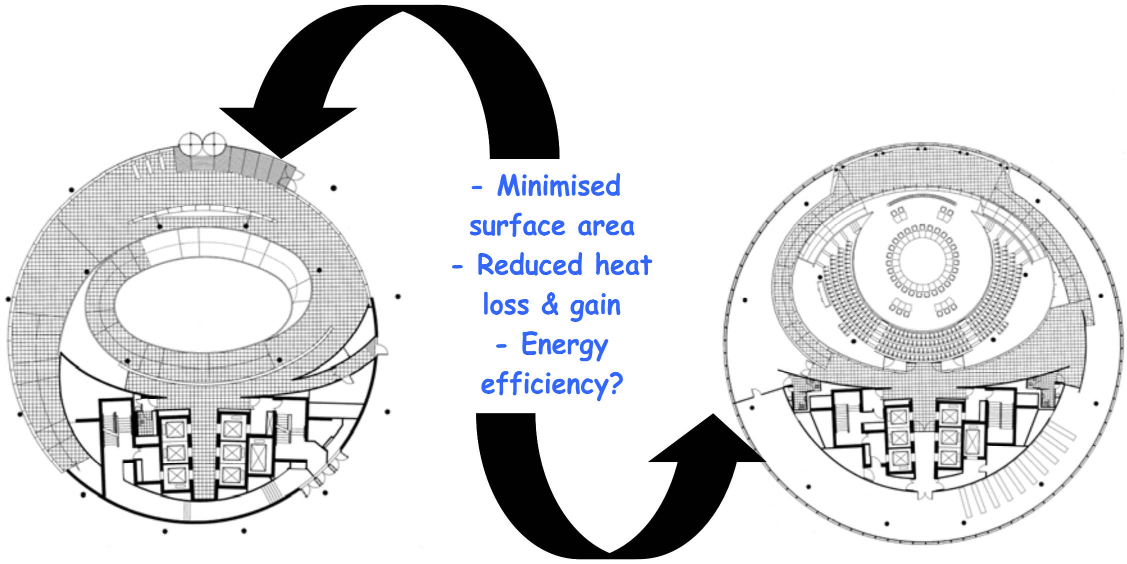

Fig. 10 GLA Building's Ground floor plan
(Image source: © Foster and Partners)

Fig. 11 GLA Building's 2nd floor plan
(Image source: © Foster and Partners)

According to (Powell, 2002, p. 1), "for Ken Shuttleworth of Foster and Partners, 'the starting point of the project was to reduce the energy load of the building by 75 percent.' The headquarters of the Greater London Authority, to be known as City Hall, is nothing if not environmentally responsible, a practical demonstration, the architect claims, of the potential of sustainable design in a world city where, so far, that concept has made a negligible impact."

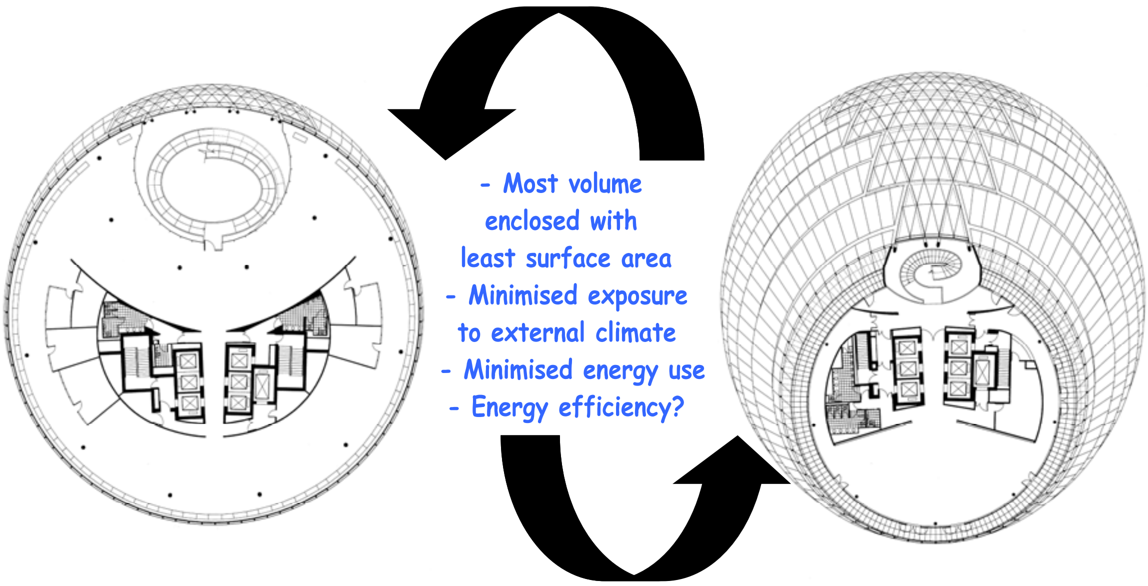

Fig. 12 GLA Building's 3rd floor plan
(Image source: © Foster and Partners)

Fig. 13 GLA Building's 9th floor plan
(Image source: © Foster and Partners)

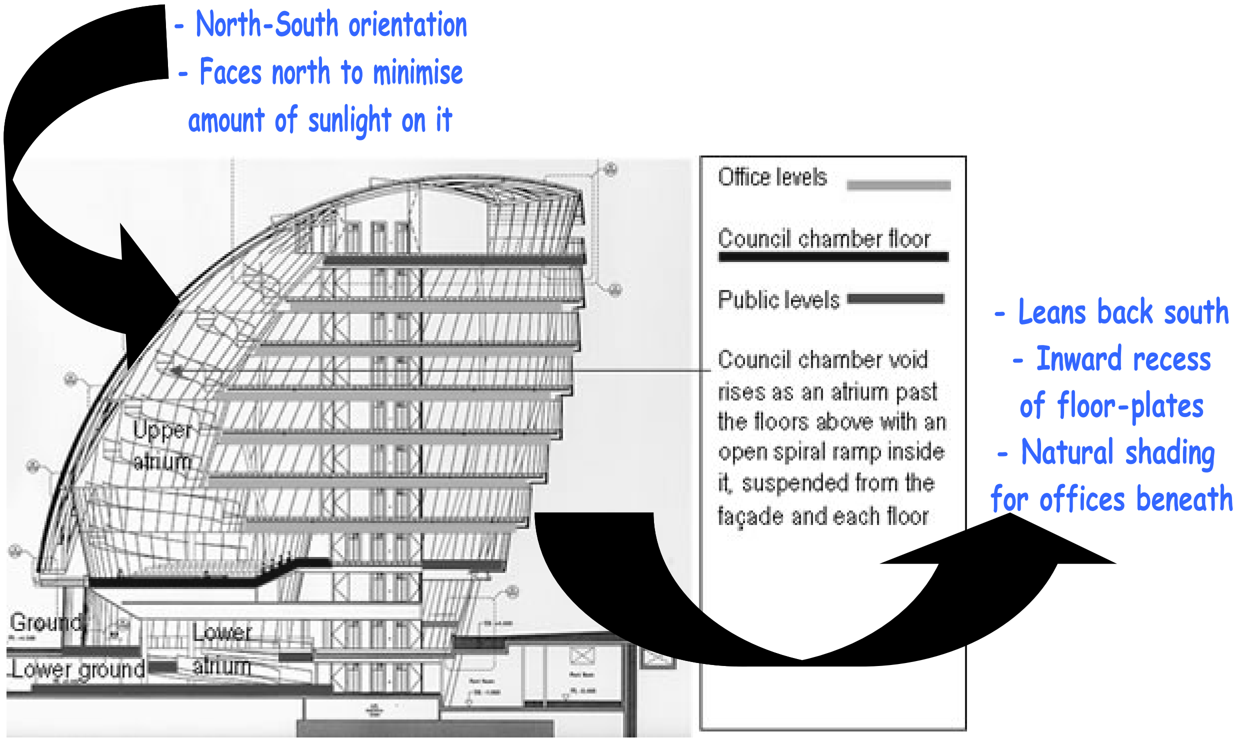

Fig. 14 GLA Building's section showing the main components of the accommodation
(Image source: © ARUP 2005)

3.2 Energy efficiency exploration of the Greater London Authority Building

"Energy consumptions for [the Greater London Authority Building's] environmental systems are less than half levels in DETR good practice office guide. (refer to table 4) The radical shape of the building minimises the surface area (approximately 25 percent less than equivalent rectangular building), is self shading and the high performance façade ensures excellent energy efficiency." (Greater London Authority 2005 p. 1)

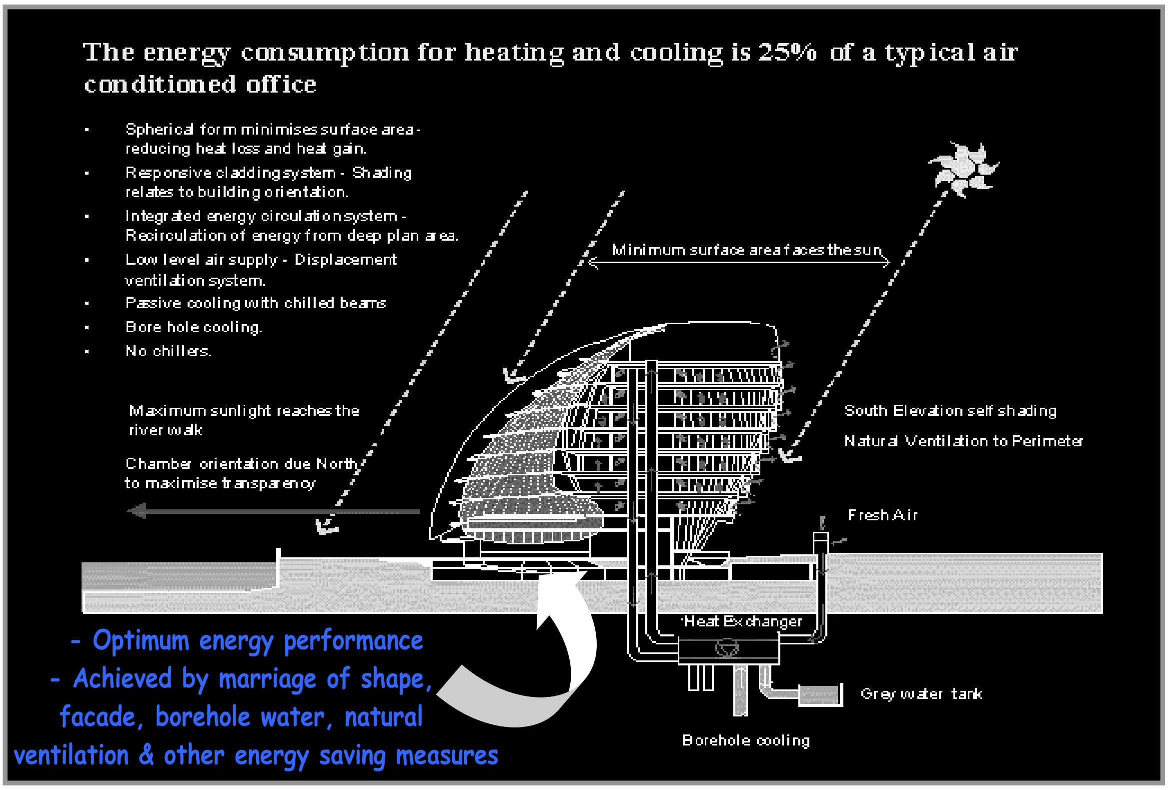

Fig. 15 Greater London Authority Building's Environmental Details
(Image source: Foster and Partners 2005)

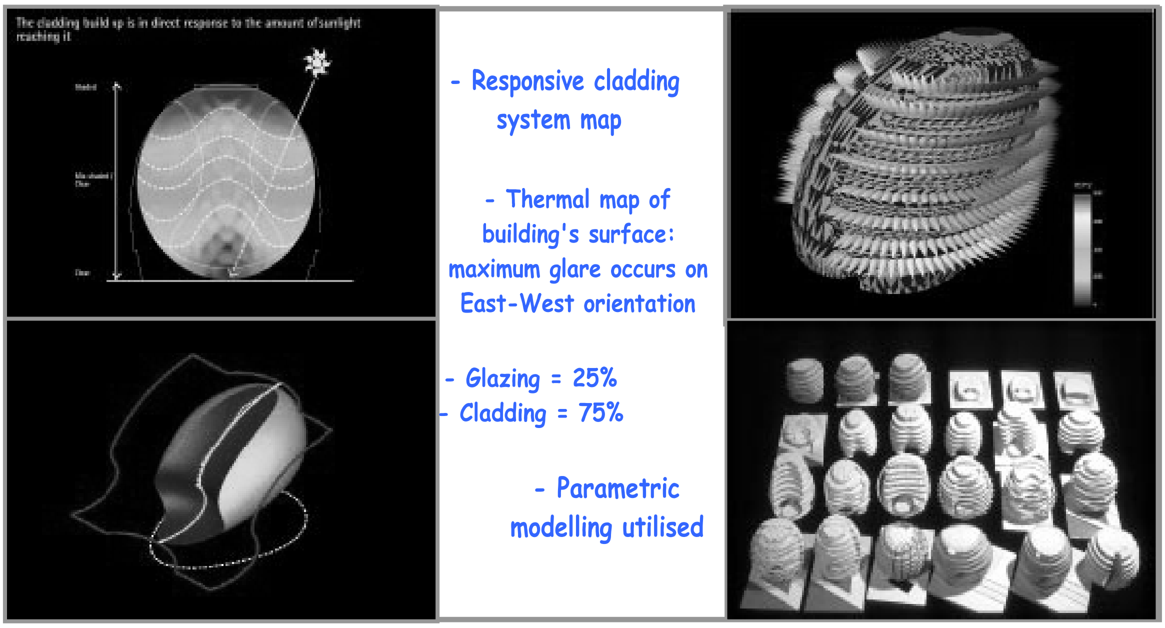

Fig. 16 Cladding system map, Thermal map, Parametric modelling, Glazing/Cladding
(Image(s) source: Foster and Partners 2005)

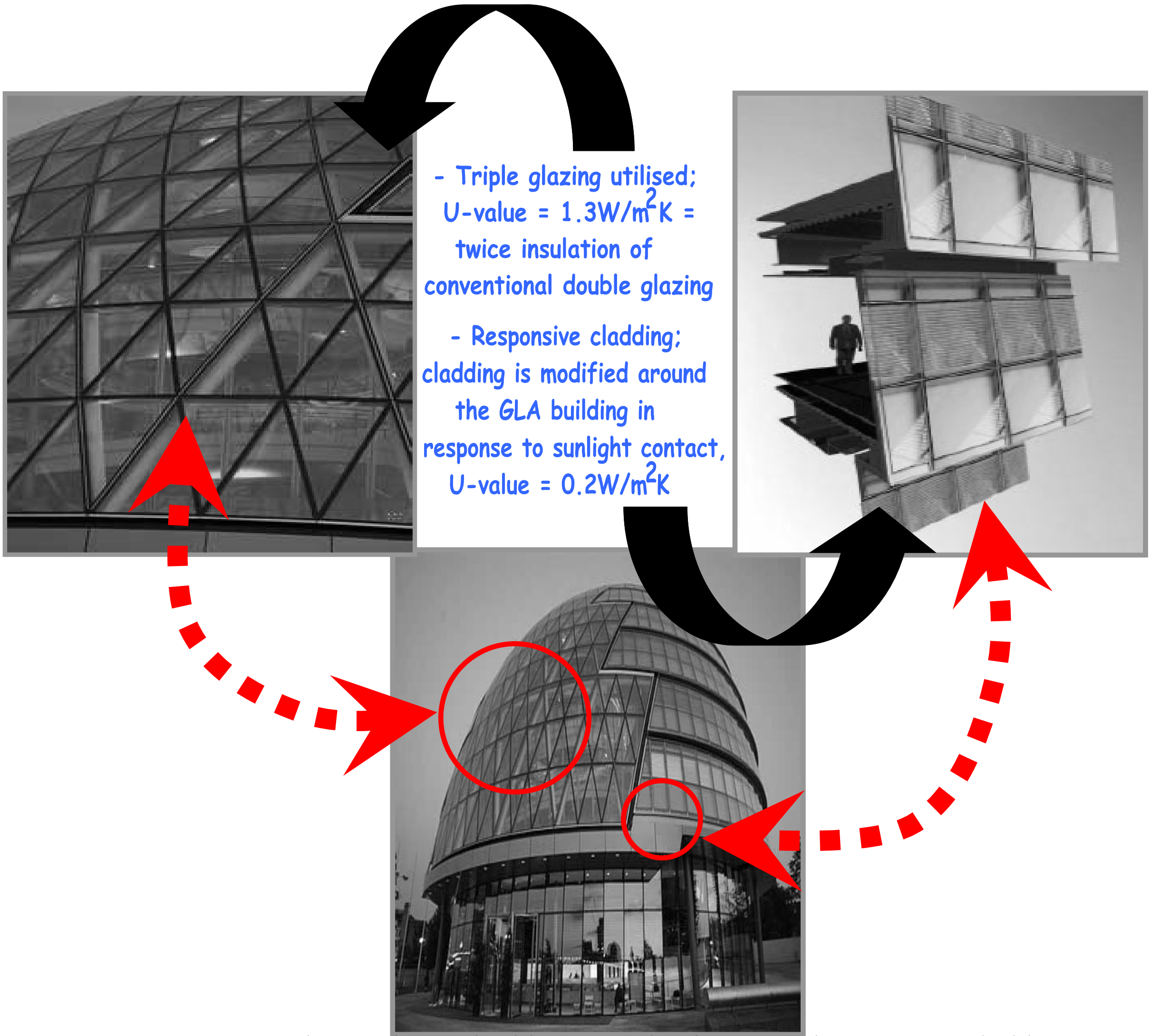

Fig. 17 Greater London Authority building's triple glazing and responsive cladding
(Image(s) source: Foster and Partners 2005)

Table 4. Typical and Good Practice Energy Consumption in Offices in the UK

	kWh/m² of treated floor area							
	Type 1		**Type 2**		**Type 3**		**Type 4**	
	Good practice	**Typical**	**Good practice**	**Typical**	**Good practice**	**Typical**	**Good practice**	**Typical**
Heating & hot water	79	151	79	151	97	178	107	201
Cooling	0	0	1	2	14	31	21	41
Fans, pumps & controls	2	6	4	8	30	60	36	67
Humidification	0	0	0	0	8	18	12	23
Lighting	14	23	22	38	27	54	29	60
Office equipment	12	18	20	27	23	31	23	32
Catering	2	3	3	5	5	6	20	24
Other electricity	3	4	4	5	7	8	13	15
Computer room	0	0	0	0	14	18	87	105
TOTAL	**112**	**205**	**133**	**236**	**225**	**404**	**348**	**568**

Based on DETR (2000b) (Table source: Wade et al, 2003 p. 7)
(Where **Office Type 1**: Naturally ventilated cellular; **Office Type 2**: Naturally ventilated open-plan; **Office Type 3**: A/C, standard; **Office Type 4**: A/C, prestige)

Mean of good practice levels = (Type 1 + Type 2 + Type 3 + Type 4) ÷ 4…equation 1
Mean of good practice levels = (112 + 133 + 225 + 348) kWh/m^2 ÷ 4 ….equation 2
Mean of good practice levels = 818 kWh/m^2 ÷ 4 …equation 3
Mean of good practice levels = 204.5 kWh/m^2 …equation 4

If the Greater London Authority (GLA) building's pre-occupancy environmental systems energy consumption is, as claimed, less than half levels in DETR (Department of the Environment, Transport and the Regions) good practice office guide, then from equations 1, 2, 3 and 4 we derive:

GLA building's energy consumption level = ½ (Mean of good practice levels) …..... 5
GLA building's energy consumption level = ½ (204.5 kWh/m^2) ...equation 6
GLA building's energy consumption level = 102.25 kWh/m^2 ...equation 7
GLA building's energy consumption level = < 102.25 kWh/m^2 …equation 8

It can be deduced from the results of equations 1 to 8 that the pre-occupancy energy consumption level claims of the Greater London Authority building is less than half mean levels in DETR good practice office guide, is less than individual DETR good practice office guide total levels for Type 1 (Naturally ventilated cellular) and Type 2 (Naturally ventilated open- plan), and is less than half levels in DETR good practice office guide for Type 3 (A/C, standard) and Type 4 (A/C, prestige) (refer to table 4 and refer to fig. 18).The Greater London Authority building's pre-occupancy low energy consumption claim can be attributed not only to its spheroid form but also to other innovative solutions, such as:

– "For cooling the building, naturally chilled borehole water is brought up 125m from the aquifer below the London clay. The boreholes use less energy than conventional chillers and cooling towers and are an economical alternative to install and maintain." (Arup 2002 p. 1)
– "The diagrid structure supports the north façade of the GLA building and is in fact the largest radiator in London. The majority of the horizontal steel elements, measuring a staggering 300mm in diameter each, have hot water coursing through them to act as a discreet heater for the atrium space that doesn't require extra fittings or pipe work installation." (Arup 2002 p. 1)
– "Detailed analysis by Arup resulted in the design of a very efficient façade. It is made up of insulated panels that reduce the solar gain, as well as heat loss to half that of a normal office building." (Arup 2002 p. 1)
– "The façade also incorporates flexible, locally controlled natural ventilation. When the natural air vents are opened, 'smart' air conditioning and heating systems deactivate themselves in the adjacent area to prevent energy waste." (Arup 2002 p. 1)

In the comparison of energy consumption levels (in kWh/m^2), based on data from table 4, in relation to the result from equations 1 to 8, we have in figure 18, **Type 1** (Good Practice) = 112 kWh/m^2, **Type 2** (Good Practice) = 133 kWh/m^2, **½** (**Type 3** [Good Practice]) = 112.5 kWh/m^2, **½** (**Type 4** [Good Practice]) = 174 kWh/m^2, **½ Mean** (Type 1+Type 2+Type 3+Type 4) = ½ Mean (2231 kWh/m^2) = ½ (278.87 kWh/m^2) = 139.43 kWh/m^2, **GLA building** pre-occupancy energy consumption claims (Greater London Authority building pre-occupancy energy consumption claims) < 102.25 kWh/m^2, where the GLA building pre-occupancy energy consumption claim is graphically represented as lower than the other energy consumption levels for the office types.

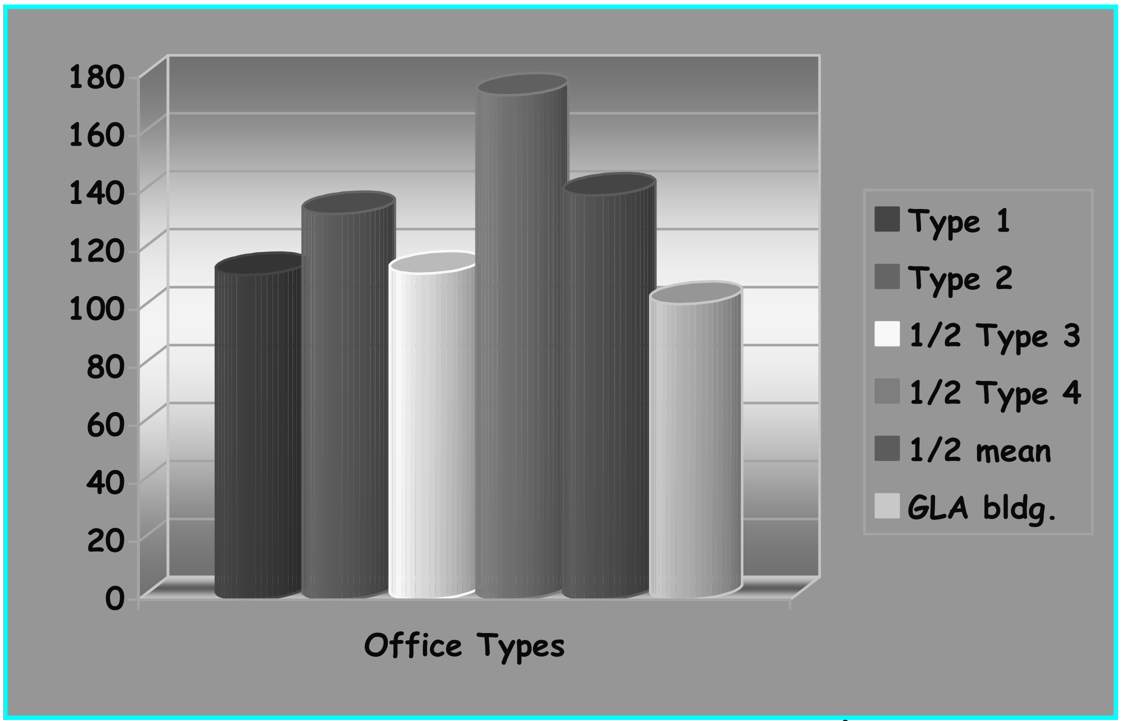

Fig. 18 Comparison of ***Energy consumption levels in kWh/m²*** *for Office Types*

The apparent energy efficiency of the Greater London Authority building, based on its pre-occupancy energy performance claims, has necessitated the first author's exploration of its post-occupancy energy performance prior to the conduction of a post-occupancy analysis at a later date in his PhD research. Some concerns have been raised relating to the energy performance of the Greater London Authority building.

3.3 Greater London Authority building's energy performance concerns

Greater London Authority building's (City Hall London's) pre-occupancy energy efficiency claims heralded it as a solution to the issue of environmental efficiency in tall office buildings. However, concerns have arisen regarding its claims of energy efficiency.

One of such concerns occurred during a question and answer session between Liberal Democrat Assembly Member, Mike Tuffrey, and Mayor of London, Ken Livingston, on the 14th September 2005. According to Ken Livingstone (2005 p.1), "recent research has shown that the energy use of City Hall is approximately 50% greater than envisaged at the design stage…"

Based on the relationship between City Hall London's Pre-Occupancy energy efficiency claims, the present DETR energy benchmark, and City Hall London's post-occupancy energy performance concerns (as confirmed by the Mayor of London), the first author will conduct a Post-Occupancy Analysis Building Use Study (BUS) at a later date in his PhD research in order to evaluate the post-occupancy energy performance of City Hall London as it relates to its spheroid form.

4. SUMMARY

This paper explored the spheroid morphology when utilised in the design and construction of the tall office building in order to achieve energy efficiency. An exploratory case study was carried out on a spheroid building, the Greater London Authority (GLA) building, focussing on its energy performance. The Greater London Authority building was acclaimed as being energy efficient, with claims of 75 % reduction in its annual energy consumption compared to a high specification office building. Its energy efficiency claims were explored in comparison to that of other office types, utilising the DETR (Department of the Environment, Transport and the Regions) energy benchmark. There appears to be disparity between the Greater London Authority building's pre-occupancy energy performance claims/aspirations, its post-occupancy energy performance, and the DETR energy benchmark for good practice energy consumption in United Kingdom offices. The Greater London Authority building's energy performance was explored to better understand the importance of the spheroid form in the architectural morphology of twenty-first century office buildings.

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