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# ENERGY SIMULATION METHODOLOGY FOR THE GREATER LONDON AUTHORITY (GLA) AND SWISS RE SPHEROID BUILDINGS

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**ABSTRACT:**This research paper explores the following research question: "what level of energy performance does the spheroid form offer in the design and construction of the tall office building?" Preliminary studies involving the initial exploratory case study of two spheroid buildings, the Greater London Authority (GLA) building and the Swiss Re building, revealed encouraging results when measured against performance indicators from the Department of the Environment, Transport and the Regions (DETR) energy benchmark. These two buildings have theoretically been acclaimed as being energy efficient. However, a number of concerns have arisen relating to these pre-occupancy claims of optimum energy performance. Particularly, these claims have neither been scientifically authenticated nor their various levels of morphological and technological attributes ascertained. This research paper will look at the methodology of Comparative Case Study Energy Simulation Analysis which the first author has adopted for the energy performance analysis of his two selected spheroid building case studies. The first author's research aims to develop a Hybrid Spheroid Form Shading Method for the achievement of significant HVAC energy efficiency in both spheroid and cuboid tall office buildings.

**Keywords** - Energy simulation, GLA building; Spheroid, Swiss Re building, Tall office.

## 1. INTRODUCTION

### 1.1 The Importance of the Spheroid Form

The first author's interest in 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 an oblate spheroid would do better than a sphere, having different curvature in different directions." (Ambrose, 2002 p. 53) (refer to Fig. 1 and Fig. 2 for prolate and oblate spheroid illustration and Section 1.2 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. 1 and fig. 2) 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 of energy efficiency.

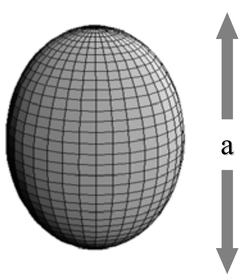
### 1.2 The Characteristics of the Spheroid Form

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. 1) and the other as an oblate spheroid (refer to Fig. 2). A prolate spheroid is obtained by rotating an ellipse about its major axis (refer to Fig. 1) and has morphology similar to that of the Greater London Authority (GLA) building (refer to Fig. 3) and Swiss Re building. An oblate spheroid is obtained by rotating an ellipse about its minor axis (refer to Fig. 2) and has morphology similar to that of a geodesic dome, such as the US Pavilion at Expo ’67 (refer to Fig. 4). 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 1). 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 1. 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



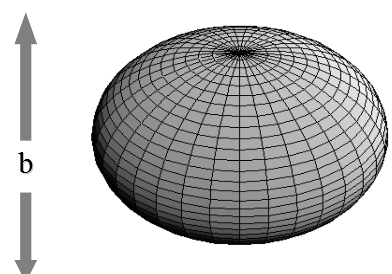




*Fig. 1. A Prolate Spheroid* *Fig. 2. An Oblate Spheroid*
*(Image source: http://en.wikipedia.org/wiki/Spheroid)*



*Fig. 3. Greater London Authority Building* *Fig. 4. 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) and also the Swiss Re building which presents a greater vertical configuration.

## 2. THE ENERGY SIMULATION ANALYSIS RESEARCH METHOD

Sustainable architecture can be defined as a deliberate attempt at designing a built environment that is energy and ecologically considerate both internally and externally. Hui (2002) identifies *green features* for sustainable architecture, and the first author's research explores the green feature of Building Operations (BO) and more specifically Energy Efficiency (EE). *The Energy Performance of the Spheroid Form in Tall Office Buildings* PhD research aims to develop a Hybrid Spheroid Form Shading Technique for tall office buildings in order to achieve significant HVAC energy efficiency in both spheroid and generic cuboid tall office buildings.

One Research Method that will be adopted by the first author and utilised in his PhD research is Energy Simulation Analysis and this is a method identified in (Crawley et al 2005). The GLA and Swiss Re buildings have theoretically been acclaimed as being energy efficient. However, a number of concerns have arisen relating to these pre-occupancy claims of optimum energy performance. Particularly, these claims have neither been scientifically authenticated nor their various levels of morphological and technological attributes ascertained. The Energy Simulation Analysis Research Method will be used to evaluate the Greater London Authority (GLA) and Swiss Re buildings' exact levels of energy use attributable to HVAC Systems, as well as to other sources, such as lighting, computers/computer accessories, and small power equipment in order to determine the exact impact of Architectural Technology and Architectural Design and Morphology on these buildings energy use. This research paper looks at the methodology of Comparative Case Study Energy Simulation Analysis which the first author has adopted for the energy performance analysis of his two selected spheroid building case studies.

The energy simulation software that was initially considered for use by the first author is the 4D energy simulation software, identified in (IES 2007), and developed by Integrated Environmental Solutions (IES) Limited. This energy simulation software is known as the *Integrated Environmental Solutions 4D Applications Software Suite*. It offers a variety of available performance assessments that can be undertaken on the GLA and Swiss Re buildings' design utilising just one computer model of each of these buildings. This 4D Applications Software Suite includes:

1. *RADIANCE* that permits Photo-realistic lighting simulation
2. *SUNCAST* that permits Solar mapping and insulation studies
3. *MACROFLO* that permits Simulation of infiltration and inter-zone bulk air flow
4. *MICROFLO* that permits Computational Fluid Dynamics Simulation of air flow
5. *ESP* that permits Simulation of building energy and occupant comfort

This 4D Applications Software Suite could also assist in the evaluation of the interrelationship of the sun and the GLA, as well as Swiss Re buildings' forms and orientation in order to evolve a Hybrid Spheroid Form Shading Technique, which lends itself to achieving significant HVAC energy efficiency in both spheroid and high specification tall office buildings. The Hybrid Spheroid Form Shading Technique's performance can also be assessed utilising the 4D Applications Software Suite, especially utilising the *ESP* software component of this 4D Applications Software Suite.

Although the IES 4D Applications Software Suite was initially considered for the first author's energy simulation research method other energy performance simulation programs do exist with varying aspects of building performance assessments and some of these energy simulation programs were explored by the first author in other to identify the appropriate one to adopt for his energy performance simulation research method.

### 2.1 Energy Simulation Research Method Tools: The Features and Capabilities of Building Energy Performance Simulation Programs

Crawley et al (2005) identify twenty major building energy simulation programs and these include: BLAST, Bsim, DeST, DOE-2.1E, ECOTECT, Ener-Win, Energy Express, Energy-10, EnergyPlus, eQUEST, ESP-r, IDA ICE, IES <VE>, HAP, HEED, PowerDomus, SUNREL, Tas, TRACE and TRNSYS. Out of the twenty major building energy simulation programs, the author has been acquainted with ECOTECT, EnergyPlus, IES <VE> and HEED but awaits further training in ECOTECT as this is going to be his adopted energy simulation program for use in his Energy Performance Simulation Research Method. An overview of the ECOTECT building energy simulation program is described in the next section (refer to Section 2.2).

### 2.2 Adopted Research Method Tool: ECOTECT building energy simulation program

Crawley et al (2005, p. 4) and Marsh (1996) describe ECOTECT as "a highly visual and interactive complete building design and analysis tool that links a comprehensive 3D modeller with a wide range of performance analysis functions covering thermal, energy, lighting, shading, acoustics, resource use and cost aspects." What interests the first author about ECOTECT is that it has the capability to handle various geometries and in the case of the first author's present research these would be limited to tall spheroid and cuboid forms. ECOTECT's role and involvement in low energy building design commences right from the conceptual stage and this creates an opportunity for truly innovative approaches, such as through morphologic design, in an attempt to create a truly low energy consumption building.

Further, Crawley et al (2005, p. 4) and Marsh (1996) identify that "ECOTECT aims to provide designers with useful performance feedback both interactively and visually (refer to Fig. 6)." Crawley et al (2005, p. 4) and Marsh (1996) also note that "…in addition to standard graph and table-based reports (refer to Fig. 7 and Fig. 8), analysis results can be mapped over buildings surfaces or displayed directly within the spaces that generated them (refer to Fig. 5), giving the designer the best chance of understanding exactly how their building is performing and from that basis make real design improvements."

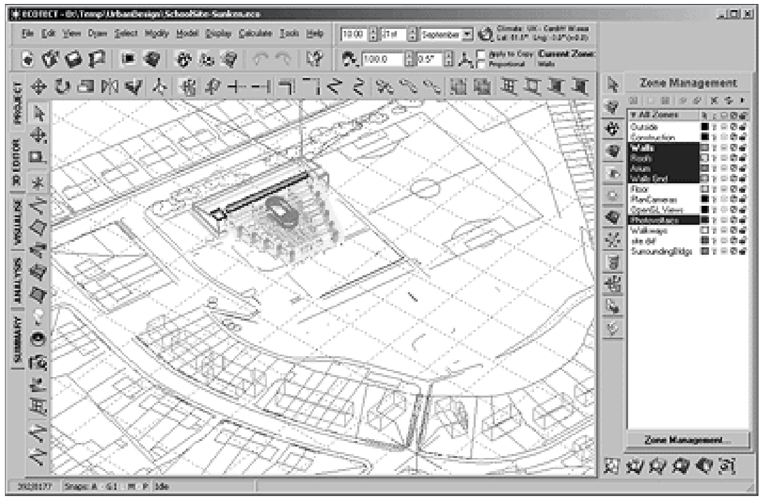


*Fig. 5. 3D Editor and Modelling Page (Image source: http://www.squ1.co.uk/ecotect/screenshots)*

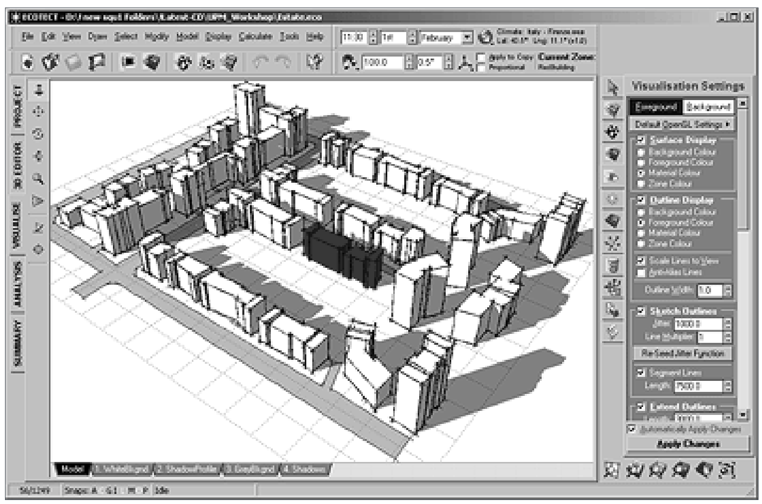


*Fig. 6. 3D Visualisation Page(Image source: http://www.squ1.co.uk/ecotect/screenshots)*

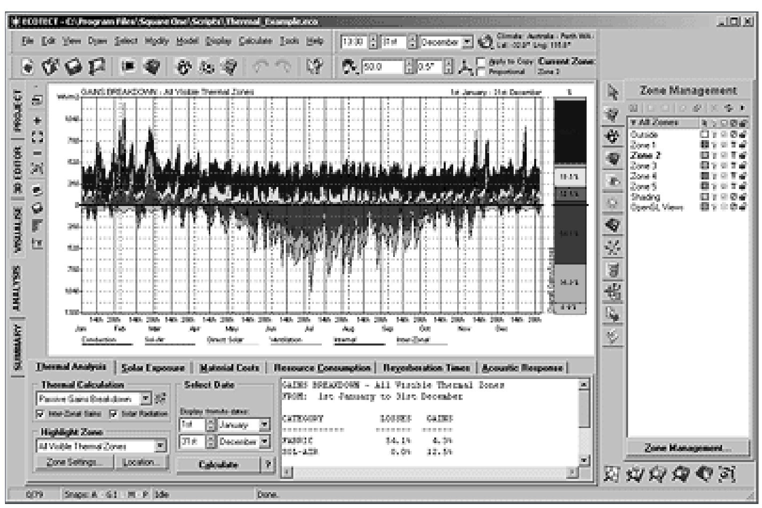


*Fig. 7. Graphical Analysis Page(Image source: http://www.squ1.co.uk/ecotect/screenshots)*

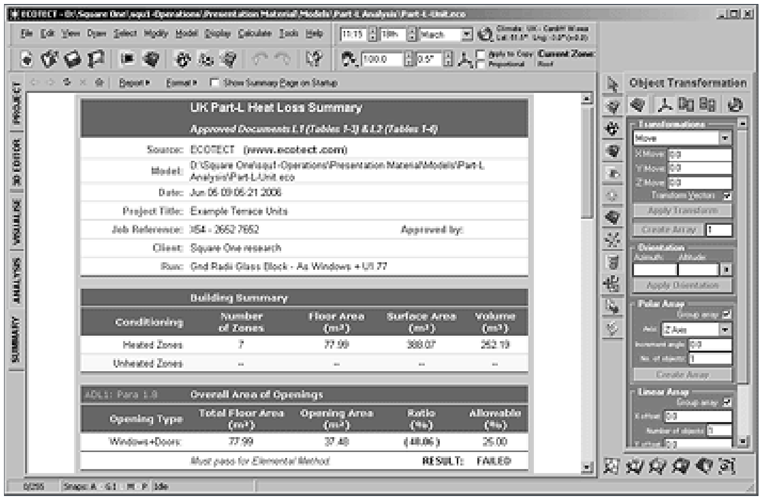



*Fig. 8. Summary Page Showing Analysis Results(Image source: http://www.squ1.co.uk/ecotect/screenshots)*

In further assessing the features and capabilities of ECOTECT, Crawley et al (2005, pp. 4 – 5) and Marsh (1996) state that "as well as the broad range of internal calculations that ECOTECT can execute (refer to Fig. 9), it also imports/exports to a range of more technical and focussed analysis engines, such as Radiance, EnergyPlus [which the first author has utilised], ESP-r, NIST FDS and others…"

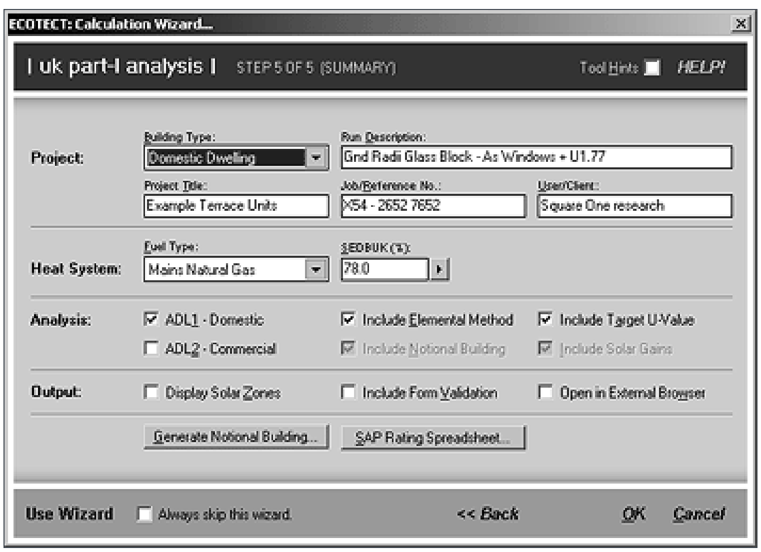



*Fig. 9. Calculation Wizard: UK Part-L Summary Page (Image source: http://www.squ1.co.uk/ecotect/screenshots)*

One such beneficial import/export compatibility feature of ECOTECT is with ArchiCAD. According to Marsh (2006), "with ArchiCAD's unique ability to generate and export spatial/thermal zones, it is now possible to extract exactly the information required by ECOTECT for detailed thermal, lighting and acoustic analysis, as well as compliance with the latest Part L of the UK building regulations. This integration is achieved through the full support of gbXML by both programs. This marks a significant breakthrough that allows designers to effortlessly incorporate performance analysis in their typical design/CAD work flow…"

ECOTECT also now incorporates the added feature of a scripting engine that provides the opportunity for direct access to various model geometry and calculation results and this once again enhances the opportunity to impact optimally on the design right from the conceptual stage through to the finalised design. Scripting permits the interactivity and self-generative quality of models, allowing for flexibility in the control and manipulation of a number of parameters, materials, zone settings and geometry. An interesting aspect of ECOTECT that has influenced the first author's adoption of it as his Research Method Tool is the excellence of its scripting functions which permit the automating of "…more mundane tasks involved in calculation runs, results comparison [a very important aspect of the first author's Research Method] and report creation." (Crawley et al, 2005 p. 5)

The suitability of ECOTECT for researchers with an architecture background is confirmed by Crawley et al (2005 p. 5) in which it states that "ECOTECT is unique within the field of building analysis in that it is entirely designed and written by architects and intended mainly for use by architects…"

### 2.3 Comparative Case Study Energy Simulation Analysis Research Method: Simulating the Energy Performance of the GLA and Swiss Re Spheroid buildings

An overview of the ECOTECT building energy simulation program has revealed that it possesses scripting functions which are "…excellent for automating the more mundane tasks involved in calculation runs, results comparison [a very important aspect of the first author's Research Method] and report creation [also a very important aspect of the first author's research dissemination, and knowledge contribution]." (Crawley et al, 2005 p. 5) ECOTECT will not only permit the individual energy performance simulation analysis of both the GLA and Swiss Re buildings but also a comparative energy simulation analysis between these two case study buildings, recommended Department of the Environment, Transport and the Regions (DETR) energy consumption levels, and a Hybrid Spheroid Form with ideal energy consumption levels (refer to Fig. 10 for example illustration of results).

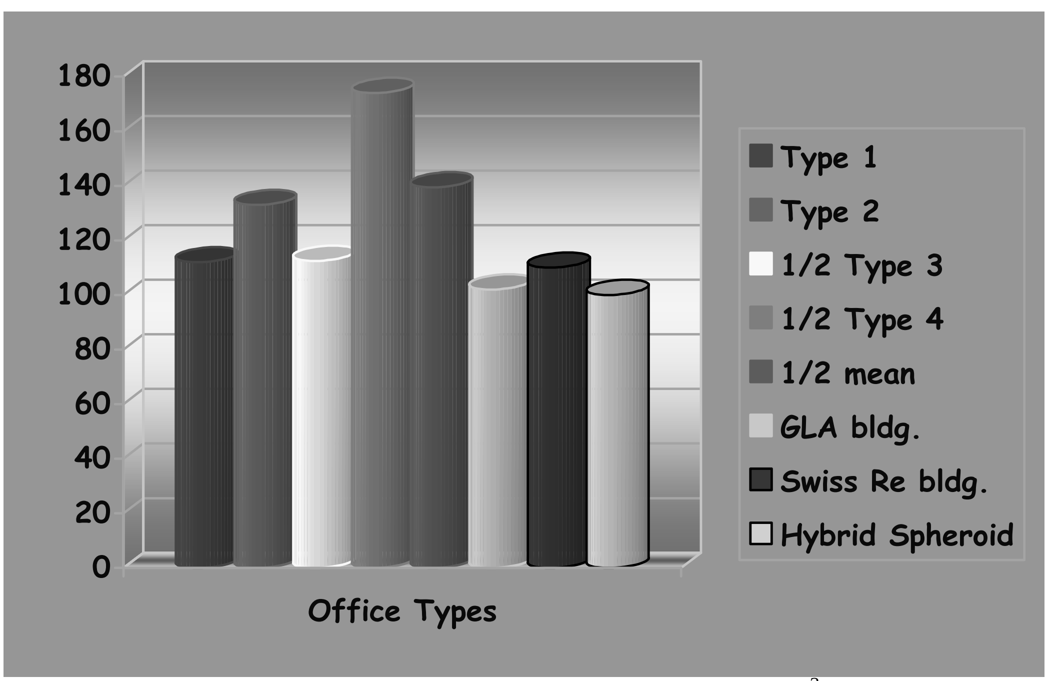



*Fig. 10. Comparison of Energy consumption levels in kWh/m$^2$ for Office Types*

The Comparative Case Study Energy Simulation Analysis Research Method will be used to evaluate the Greater London Authority (GLA) and Swiss Re buildings' exact levels of energy use attributable to HVAC Systems, as well as to other sources, such as lighting, computers/computer accessories, and small power equipment in order to determine the exact impact of Architectural Technology and Architectural Design and Morphology, more specifically the spheroid form, on these buildings energy use.

## 3. CONCLUSIONS

This paper explored the following research question: "what level of energy performance does the spheroid form offer in the design and construction of the tall office building?" It was revealed from previous preliminary studies, involving the initial exploratory case study of two spheroid buildings, the GLA and Swiss Re buildings, that encouraging results were proclaimed. These initial unauthenticated results also appear encouraging when measured against performance indicators from the Department of the Environment, Transport and the Regions (DETR) energy benchmark. However, it has been highlighted that a number of concerns have arisen relating to these pre-occupancy claims of optimum energy performance. Since these claims has neither been scientifically authenticated nor their various levels of morphological and technological attributes ascertained, the first author presented an overview of his adopted Comparative Case Study Energy Simulation Analysis Research Method. This Research Method would be used to evaluate the GLA and Swiss Re buildings' exact levels of energy use attributable to HVAC Systems, as well as to other sources, such as lighting, computers/computer accessories, and small power equipment in order to determine the exact impact of Architectural Technology and Architectural Design and Morphology, more specifically the spheroid form, on their energy performance.

This paper also presented an overview of the ECOTECT building energy simulation program that has been adopted by the first author as his Research Method Tool and it was revealed that apart from other beneficial features and capabilities, it possesses scripting functions which are "…excellent for automating the more mundane tasks involved in calculation runs, results comparison [a very important aspect of the first author's Research Method] and report creation [also a very important aspect of the first author's research dissemination, and knowledge contribution]." (Crawley et al, 2005 p. 5) ECOTECT will not only permit the individual energy performance simulation analysis of both the GLA and Swiss Re buildings but also a comparative energy simulation analysis between these two case study buildings, recommended Department of the Environment, Transport and the Regions (DETR) energy consumption levels, and a Hybrid Spheroid Form with ideal energy consumption levels.

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