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# 191: The Building of the Great Exhibition of 1851, an Environmental Design Experiment

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## Abstract:

The building of the Great Exhibition of 1851 (1850-51) represents the earliest large scale experiment in the use of the horticultural glasshouse for exclusively human, non-horticultural purposes. It illustrates the process by which Joseph Paxton applied the environmental design methods and criteria, previously developed in the context of horticulture, to a building intended for human habitation. Paxton proposed a sophisticated environmental design strategy by which he intended to achieve optimal lighting conditions for the display of 10,000 exhibits and to maintain adequate indoor temperatures and sufficient levels of ventilation inside a building occupied by up to 90,000 visitors at any one time. In order to assess the buildings environmental performance the temperature inside the building was systematically monitored during the period of the Exhibition. This was one of the earliest post-occupancy studies ever conducted inside a building for exclusively human, non-horticultural use. The collected data was used in a final post-occupancy report published by the Commissioners of the Great Exhibition in 1852 which comprised a critical and scientific evaluation of the building's environmental performance and provided insights which informed the design of Paxton's second prototype, the Crystal Palace at Sydenham (1852-54).

Keywords: Environmental Design History, 1851 Great Exhibition Building, Crystal Palace

## 1. Introduction

At a lecture held at the Society of Arts in November 1850, Joseph Paxton, head gardener at the Duke of Devonshire's Chatsworth estate, explained that the Victoria Regia House at Chatsworth acted as a prototype for his design for the 1851 Great Exhibition building.[19] While the Victoria Regia House was originally designed to provide an indoor habitat for a specimen of the *Victoria Amazonia*, a giant tropical water lily recently introduced to Britain[12], Paxton's objective was to adopt the structural and environmental design principles underlying its design as a means to fulfil the specific spatial, environmental and structural requirements of a large scale exhibition building. It demonstrated in principle a way of enclosing and providing good natural lighting throughout a very deep and totally open plan space by means of a highly rationalized and economic construction system. [6] According to *The Palace of Industry*, published anonymously in 1851, the proposal for adopting the glasshouse as a model for the Great Exhibition building was primarily a response to historical circumstances. Paxton, collaborating with saw mills, the iron-contractor Henderson and Fox and the Chance Brothers glass manufacturer, appropriated glasshouse technology for an industrial approach to building construction

to guarantee its completion within a very tight timeframe. [6]

However, contemporary sources also illustrate that the design of the Great Exhibition was deeply rooted in the horticultural design tradition, and that Paxton's long term aspiration was to adopt glasshouses as means to create large scale public spaces with ideal environments for human beings. A number of hypothetical projects by Paxton, which were published in pamphlets and contemporary British newspapers and journals between 1850-52, [9, 10] illustrate that Paxton's aspiration was to appropriate the horticultural glasshouse prototype for human habitation. He believed that large scale glasshouses, could be used to create bright interior public spaces with autonomous artificial climates, and that the indoor climate, analogous to the climates inside horticultural glasshouses, could be designed specifically for its human occupants, providing thermal comfort and benefits in terms of mental and physical health. [10] Paxton's proposals resonated with contemporary concerns about atmospheric pollution, insufficient ventilation daylight in urban dwellings and its detrimental effect on public health. Medical doctors such as Seymour Haden, who promoted Paxton's idea of a public winter garden, argued that buildings that provided large covered spaces for recreation and

exercise with unrestricted access to natural light and clean air at all seasons, would improve public health. [11]

While there are a large number of detailed studies on the history of the Great Exhibition Building of 1851[1-4], the environmental design aspirations underlying the design of the building appear to have received no attention. Research pursued by the author reveals that the design of the Great Exhibition building represents Paxton's first experiment with appropriating glasshouses for exclusively human habitation. It shows that Paxton adopted a sophisticated passive environmental design strategy to provide controlled natural lighting for the display of artefacts, to protect exhibits from excessive humidity and to regulate the internal temperature for human comfort. During the opening hours of the Exhibition the internal temperature was systematically monitored, revealing the difficulties of making fully glazed structures climatically suitable for human purposes. However, the environmental history of the Great Exhibition building, which hitherto has not been addressed by historians illustrates that environmental design ideas acted as a major driving force behind its design. It also shows that the Hyde Park building and the Crystal Palace at Sydenham represented two generations of a prototype that transformed the original horticultural glasshouse into an environmental design model for architecture.

## 2. Environmental Design Strategy and Objectives

An overarching environmental design strategy, as contemporary sources illustrate, had been an integral part of the design from the very beginning. The aim was to provide good lighting conditions for the display of artefacts through diffuse top lighting, to provide adequate levels of ventilation and to maintain a comfortable indoor temperature during the period of the exhibition. The objective was to keep the indoor temperature lower than the external temperature during periods of extreme heat. [13] A very brief summary of Paxton's environmental design strategy and objective is given in the following two sections. [5]

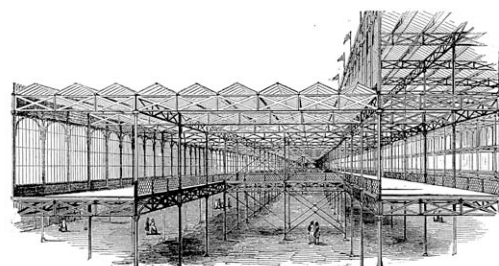
### 2.1 Lighting

One of the major environmental objectives behind the design of the Crystal Palace was the creation of a uniformly lit interior space,

using daylight as the only source of light. [19] To maintain the transparency of the iron and timber space frame, used to create a flexible open plan interior space, the roof and vertical elevations were almost completely glazed, using two glazing systems. For example, the ridge and furrow glazing used to glaze the horizontal part of the roof, made it possible to enclose, drain and adequately daylight an extremely deep floor plan on the ground floor of 408 by 1,848 feet. [8]

In order to subdue the intense sunlight, the entire horizontal part of the ridge and furrow roof was covered with translucent calico screens, that means the interior was illuminated by a relatively uniform diffused top light. [12] The lighting strategy also governed the internal layout. While the central aisle, the transept and first floor gallery had direct access to top light from the roof, the deck was punctured by a sequence of courts to bring top light down to the ground floor spaces below. As a consequence, the galleries were reduced to a network of shallow bridges twenty four feet in depth. Since the daylight regime limited the extent to which multiple storeys could be inserted inside the volume of an extremely deep plan building it was practically a single storey building with a secondary level of shallow bridges. Its volume was divided into three tiers of diminishing width, forming the shape of a stepped pyramid in cross section.

Fig. 1: Sectional perspective of first floor gallery surrounding the courts in the side aisles. [Illustrated London News, February 1<sup>st</sup>, 1851, p.72]



### 2.2 Thermal Environment

In order to control the thermal environment, Paxton adopted a combined shading and ventilation strategy. Calico screens were used to cover the entire surface of the ridge and furrow roof externally to exclude excessive solar gains. [16] The purpose of the ventilation system was to prevent the stratification of hot air and sustain an adequate supply of fresh air in a building occupied by up to 90.000 visitors at any one

time. The ventilation apparatus constituted of continuous rows of ventilators in the upper wall section of each of the three tiers. Rows of low level ventilators were installed at ground floor level.[7] Three hundred feet of ventilators could be operated simultaneously. The S-shape cross section of the louvre blades prevented rain entering the building when the ventilators were open, and thereby permitted continuous ventilation.[6] The ventilators were regulated by the Royal Sappers and Miners, who kept a two hourly register and systematically monitored the internal temperature in the whole building by means of fourteen thermometers installed in different parts of the building. [7]

However, the environmental design strategy that was implemented in the final design, excluded a number of features of Paxton's original proposal. It included additional canvas shades in front of the glazing in the south elevation [15] to further reduce solar gains and internal *punkha fans*, [18] large sheets of canvas sheets that were made to move up and down to expose visitors to an artificial breeze. Aware that ventilation and shading was not capable of effectively lowering the indoor temperature below the potentially high outdoor air temperature during the summer, Paxton proposed to employ a passive evaporative cooling system which was composed of canvas sheets installed in front of the ventilators which were periodically moisturized to cool down the incoming air stream by evaporation. [16]

### **3. The Great Exhibition Building as a Large Scale Environmental Design Experiment**

Contemporary sources reveal that an extensive post-occupancy analysis was conducted inside the Exhibition building on behalf of the Commission's executive committee during the period of the Exhibition, demonstrating that the interior temperature was systematically monitored and recorded. Various contemporary British newspapers reported the detailed temperature measurements inside the building during opening hours and a summary of this post-occupancy study was included in the *First Report of the Commissioners of the Great Exhibition*. [7] This appears to be one of the first systematic post-occupancy studies ever

conducted inside a building for non-horticultural use. In horticulture glasshouses were monitored, in some cases sporadically, in others systematically [13] to ensure that vulnerable foreign plants were kept in an adequate artificial climate. In the Great Exhibition building, the first full scale environmental design experiment with glasshouses intended for exclusively human purposes, the monitoring process facilitated an objective evaluation of the interior environmental conditions with respect to human comfort. The monitoring data provided objective feedback for the regulation of the ventilation apparatus during the opening hours and was used for a critical analysis of the building's overall environmental performance after the exhibition.

#### **3.1 Post-Occupancy Study**

Following the Executive committee's decision in March 1851 to monitor the performance of the ventilation system during the period of the exhibition [25] forty thermometers were installed throughout the interior on two levels of the building by a thermometer maker named Mr. Bennet of Cheapside, although no information was given on their exact position. [24] The Royal Sappers and Miners, who were responsible for regulating the ventilation, monitored and kept register of the interior temperature. [7] Between May 19<sup>th</sup> and October 14<sup>th</sup> readings were taken daily from each of fourteen thermometers at two hourly intervals between 9 am and 6pm except from the period after the 9<sup>th</sup> September when the last reading was taken at 5pm. Three additional thermometers were installed outside the building to monitor the corresponding external temperature. [7]

#### **3.2 Historical Data**

While the evidence from original temperature log sheets had been lost, large parts of the data collected during the Exhibition were documented in various contemporary British newspapers and in the *First Report for the Commissioners of the Great Exhibition*, [7] forming the basis of a reconstruction of the actual environmental conditions that occurred inside the building. The *First Report* included a summary and a brief analysis of the post-occupancy study, listing the daily maximum, minimum and average indoor temperature (based on 56 readings) and daily average external temperature (based on 12 readings) recorded between May 19<sup>th</sup> and October 11<sup>th</sup>

1851. In addition a large quantity of the original monitoring data was printed in various contemporary British newspapers such as the *Times*, *Daily News* and *Morning Chronicle*, which frequently reported on the temperature conditions inside the building between 18<sup>th</sup> June and October 14<sup>th</sup> 1851. These articles included more detailed records of the original temperature recordings than the *First Report* including reports of the temperature change measured across the period of a day at two hourly intervals. In order to illustrate the relationship between the indoor and outdoor temperatures, minimum and peak temperatures, outdoor temperature data of the Horticultural Gardens Chiswick, published in the *Gardener's Chronicle* during the same period, was added by the author. [14] The following section is a reconstruction and analysis of the building's environmental performance based on the temperature records discussed above.

### 3.3 The Environmental History of the Great Exhibition Building and its Analysis

On the 27<sup>th</sup> June 1851, for the first time since the opening of the exhibition in May, the *Times* gave an account of the climate inside the Crystal Palace, reporting the unprecedented, high temperatures inside the building. The intense direct solar heat of 104°F, at an outside air temperature of 83°F in the shade. It caused even greater extremes of heat in the interior the Crystal Palace, with a maximum air temperature of 97°F in the afternoon and a daily average of 78.7°F. [24] This extreme heat, which continued to occur inside the building on the following days, was perceived as extremely uncomfortable by both visitors and the staff and the *Times* gave several accounts of people's desperate attempts to find ways of adapting themselves to these conditions. [21,22] The management, having consulted visitors and exhibitors about the extreme heat in the building, removed the glazing units of the East and West elevation on July 2<sup>nd</sup>, [24] with the intention to reduce the indoor temperature and "to secure a refreshing thorough draught from end to end of the interior." [20] It reported that it lowered the indoor temperature at ground level,[22] but hot and stuffy air continued to accumulate at the upper part of the building. [17] To improve the climate at gallery level parts of the glazing in the north and south galleries were removed on the 7<sup>th</sup> July. It resulted in a more uniform temperature across both levels. Around the 19<sup>th</sup> July when the minimum indoor temperature had

fallen to 59°F, the glazing was restored and the ventilators were used to regulate the indoor temperature in response to varying degrees of solar gains. [17]

The problematic temperatures reported between the late June and early July were part of the first of two periods with distinctly higher indoor temperatures. In the first period temperatures ranged between 80°F and 90°F on nine days, which followed by a period with notably lower indoor temperatures, ranging between 70-80°F. The second period, occurring between August 1<sup>st</sup> and 22<sup>nd</sup> the peak indoor temperature exceeded 80°F on fourteen days.

In the whole the measurement demonstrated that the temperature inside the Crystal Palace was very variable both across the day and between individual days. On June 2<sup>nd</sup> the indoor temperature ranged between 47°F and 78°F and on the August 1<sup>st</sup> the average indoor temperature rose from 68°F at 10 am, to 72°F at noon and arrived at peak temperatures of 77°F at 2 pm, which prevailed until 6 pm. [23] Strong temperature variations between daily average temperatures were recorded, among others, in the period between 22<sup>nd</sup> August and 3<sup>rd</sup> September. The average indoor temperature dropped from 73°F on August 22<sup>nd</sup> to 58°F on August 30<sup>th</sup> but rose to 69°F on September 3<sup>rd</sup>.

The peak indoor temperature consistently exceeded the peak outdoor temperature by a minimum of 2°F and a maximum of 15°F, demonstrating that the shading and ventilation strategy employed was not sufficient to prevent the indoor temperature from exceeding the outdoor temperature, the aim of Paxton original strategy. While the highest indoor temperature was recorded on July 27<sup>th</sup> the most extensive heat period and the highest excess temperatures was recorded between August 1<sup>st</sup> and October 11<sup>th</sup>. Also the daily minimum indoor temperature, ranging between 45°F [September 25<sup>th</sup>] and 69°F [August 13<sup>th</sup>], constantly exceeded the daily minimum outdoor by between 3°F to 20°F.

### 3.4 First Report of the Commissioners

The *First Report of the Commissioners*, published in April 1852, illustrated that the collected temperature data was used for a scientific analysis of the building's overall environmental performance after the

Exhibition. It included data tables with the maximum, minimum and average indoor temperature and the average outdoor temperature for each day between May 19<sup>th</sup> and October 11<sup>th</sup>. It showed that out of a total of 126 days on which the temperature was recorded, the average indoor temperature exceeded the outdoor temperature by between 1° F to 9°F on 70 days while only on 26 days the average internal temperature was recorded to be between 1-4°F lower than the corresponding external temperature. [7]

The report also included a chart comparing, among others, the daily number of visitors with the daily mean indoor temperature. It concluded that statistically variations in the number of visitors inside the building had only had a marginal effect on the indoor temperature. It wrote "*On 79 days on which the Visitors were more than 40,000, the mean excess of the interior over the exterior was 1.11 degrees; on 40 days that the Visitors were less than 40,000, it was .85 degrees.*" [7]

The main cause of the extreme interior temperature, it concluded, was insufficient ventilation. However, the proper operation of the original ventilation strategy was inhibited by the large quantities of exhibits and portions on the ground floor along the north elevation, obstructing the air flow in the building. In order to compensate for the restricted air-flow it became necessary "*to remove about 90 sashes, each about 20 feet high by 8 feet wide, in different parts of the building, the openings being closed when necessary by canvas blinds.*" [7]

#### **4. Conclusion**

This paper has shown that aspirations to maintain ideal lighting conditions for the display of artefacts and to provide fresh air and thermal comfort inside a large scale building with thousands of visitors, had been an integral part of the design of the Great Exhibition building. It also reveals that it represented an experiment on adopting a large scale 'glasshouse' for exclusively human purposes. To achieve these objectives a completely passive environmental design strategy was proposed and a post-occupancy study was conducted by the building management during the opening hours of the Exhibition, to objectively evaluate its thermal

performance. The post-occupancy study indicated that the ventilation and shading strategy employed in the Great Exhibition was not effective in preventing extremely high indoor temperatures during the hottest period of the summer in 1851. Even after removing a large portion of the vertical glazing, the peak indoor temperature could only be lowered at best to the level of the peak external air temperature. It also demonstrated that the climate inside the building was subject to daily and hourly temperature fluctuations, contrasting with the controlled artificial climates that Paxton aspired to create inside his visionary glasshouse projects.

Further Research conducted by the author reveals that Great Exhibition Building in Hyde Park was a prototype to the Crystal Palace at Sydenham. The Sydenham building was redesigned in response to the post-occupancy analysis. It represented a second step towards appropriating the horticultural glasshouse prototype for human habitation. While the Great Exhibition building was designed for summer use only, the aim of the second prototype was to appropriate a large scale fully glazed structure for permanent use.

Retrospectively the Sydenham Crystal Palace and the Great Exhibition building can be interpreted as two independent environmental design experiments, with the first experiment being about 'cooling, the adoption of a fully glazed structure to severe summer conditions and the second experiment being about 'heating' the adoption of a fully glazed structure to severe winter conditions. While Paxton evidently contemplated the idea of creating highly controlled environments he did not take the final step to combine the strategies employed at Hyde Park and Sydenham into one integrated environmental management system.

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